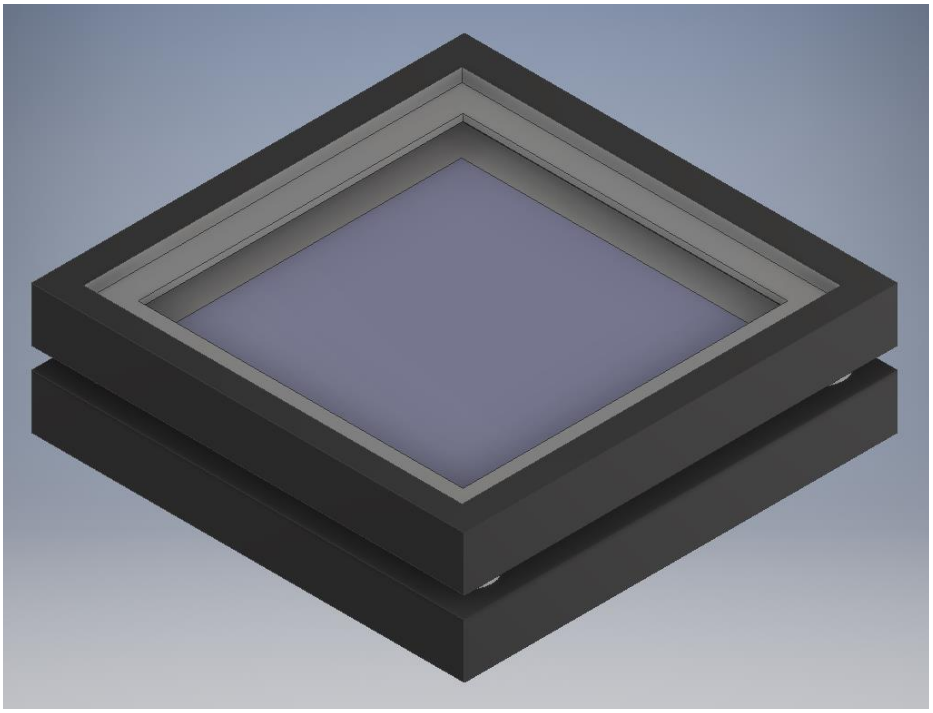
UCF Senior Design II
Energy Harvesting Platform



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1. Executive Summary

Electricity has become a basic necessity of life in today's world, and therefore, is in need of efficient and innovative ways to be produced. Several of the natural resources available are nonrenewable, requiring us to resort to other methods that provide constant energy. The use of wind power, hydroelectric power, and geothermal energy are dependable sources of energy while nuclear fission, fossil fuels, and coal are nonrenewable and will eventually become unusable.

These resources, some better than others, all have their faults. Fossil fuels and coal produce greenhouse gases which gets trapped in our atmosphere, thus raising the overall temperature of our planet. Wind farms require very long transmission lines seeing as most are built in open landscapes far away from cities and they also interfere with migration paths of birds. Hydroelectric turbines are very expensive and require the building of dams that disrupt the natural habitat for sea creatures.

However, there is a method of safely creating renewable energy that does not have any disadvantages and does not disrupt any natural habitats. In fact, it has the capability of producing an unlimited amount of energy. So, what can possibly provide that much energy? The answer is simple; humans. We can become our own source of electric power by doing what we do on a daily basis. Walk. This concept compliments the theory of crowd-sourcing as one of the most innovative ways to a goal that benefits people.

Using technology that converts mechanical energy to electrical energy, we can create and store that energy to use as a power source. The most effective way to apply this theory is to design a platform that people would walk over. It would use the pressure applied from the feet combined with the piezoelectric effect to create a voltage that can be used for several purposes such as charging a phone, lighting up street lamps or street signs, providing electricity for low power consumption devices, for entertainment purposes such as lighting up dance floors, or simply as a backup or emergency power supply. The tile platform design would be implemented as a sidewalk or pathway that could be placed in areas with high amounts of foot traffic such as amusement parks, shopping malls, zoos, and universities.

In addition to the electromechanical system, our design will incorporate the method of harvesting solar energy through solar panels as the platform. As a second source of producing energy, this method will make the design more efficient and result in the platform being a reliable source of power for the applicable uses mentioned before.

2. Project Description

This section describes the project as a whole. The section will include objective, requirements and constraints, house of quality, and basic insight into the hardware and software design.

2.1 Objectives

Our main objective for this project is to design an efficient source of renewable energy that can provide power for multiple uses. The secondary objectives include managing a low-cost design, high durability of the product regarding extreme weather conditions, convenient dimensions for the platform to fit in various places, and the sensitivity consisting of how much pressure would be needed to create a voltage. The objective regarding software would involve feedback from the system of productivity and efficiency displayed on an LCD containing information such as how much voltage is being obtained from each tile, the total amount of voltage produced, the amount of power supplied to use, and reading a pressure sensor to monitor the maximum amount of pressure that can be endured.

2.2 Requirements and Constraints

A few of the requirements and constraints to make the project successful is listed. A more specific Constraints and Standards section are provided in another section.

- Provide enough voltage to power a charger for a phone and LEDs
- Collect and provide data to users
- Dimensions within acceptable range to be placed in various areas
- Durable enough to withstand extreme weather conditions
- Product safety to be approved by government standards
- Longevity of rechargeable battery
- Placement in high foot traffic areas
- Cost effectiveness for manufacturing
- Investment in marketing
- Seamless design to prevent falling sensation

2.3 House of Quality

This section provides an engineering-marketing tradeoff matrix where customer desires and product engineering characteristics are identified and evaluated to aid in achieving an optimal design. Said evaluation observes the negative and positive correlations between each requirement, essential to design and development. The matrix can be seen below.

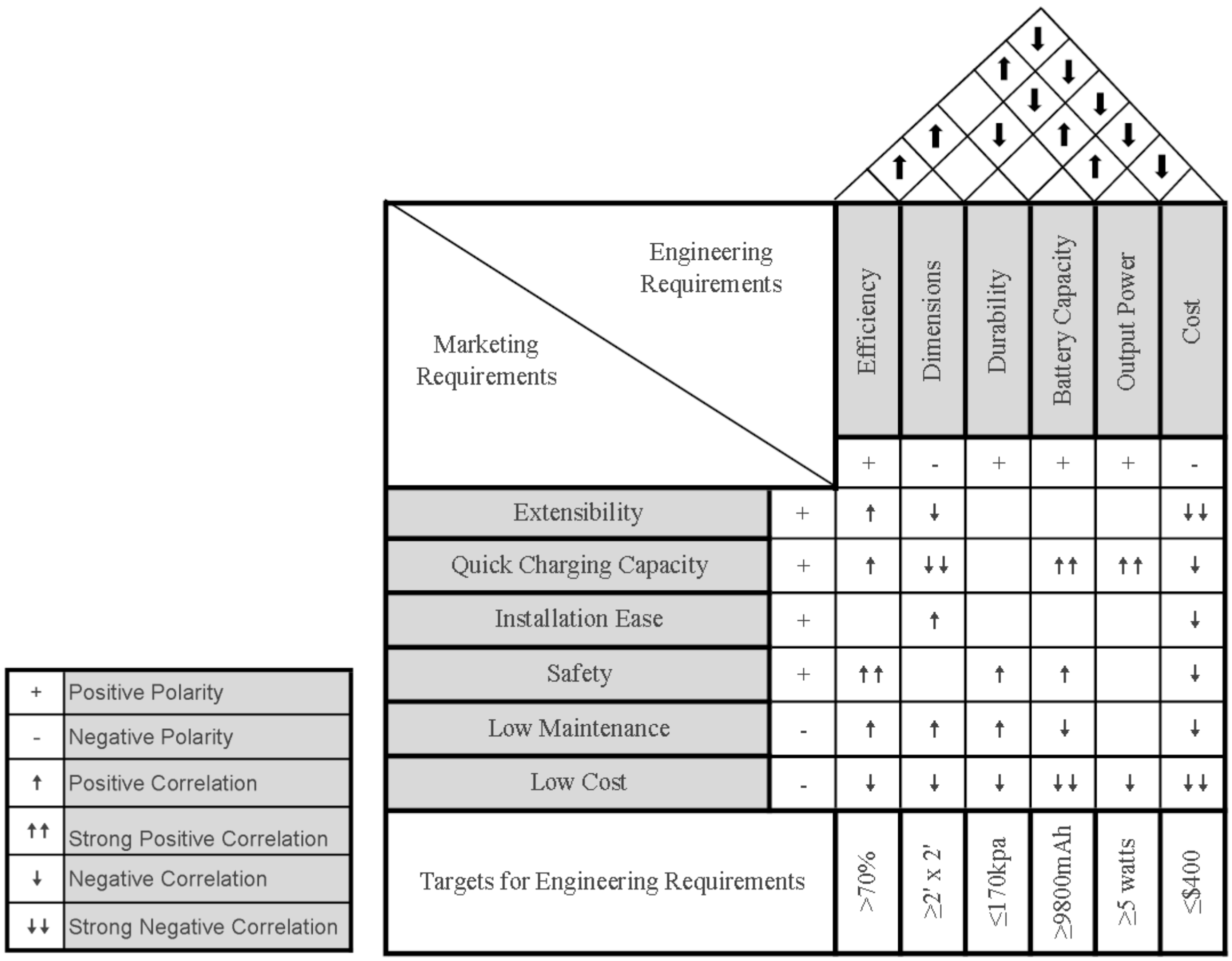

Figure 1. House of Quality

The engineering requirements shown were selected to achieve maximum performance with accurate pressure readings, enough energy storage to avoid compromising the product, and a design that varies in dimension to suit the location or environment it's in. The marketing requirements selected show key features for the product that offer longevity, safe energy input/output, productivity and convenience. These requirements are set for the purpose of achieving our set objectives for this product which are shown in previous sections of this document.

2.4 Flowchart for Software Program

This section provides an overview of the original software design used in this project, giving the user the ability to see through an LCD the power created from each platform energy sources. An updated version resides in the Software Design section 5.2.

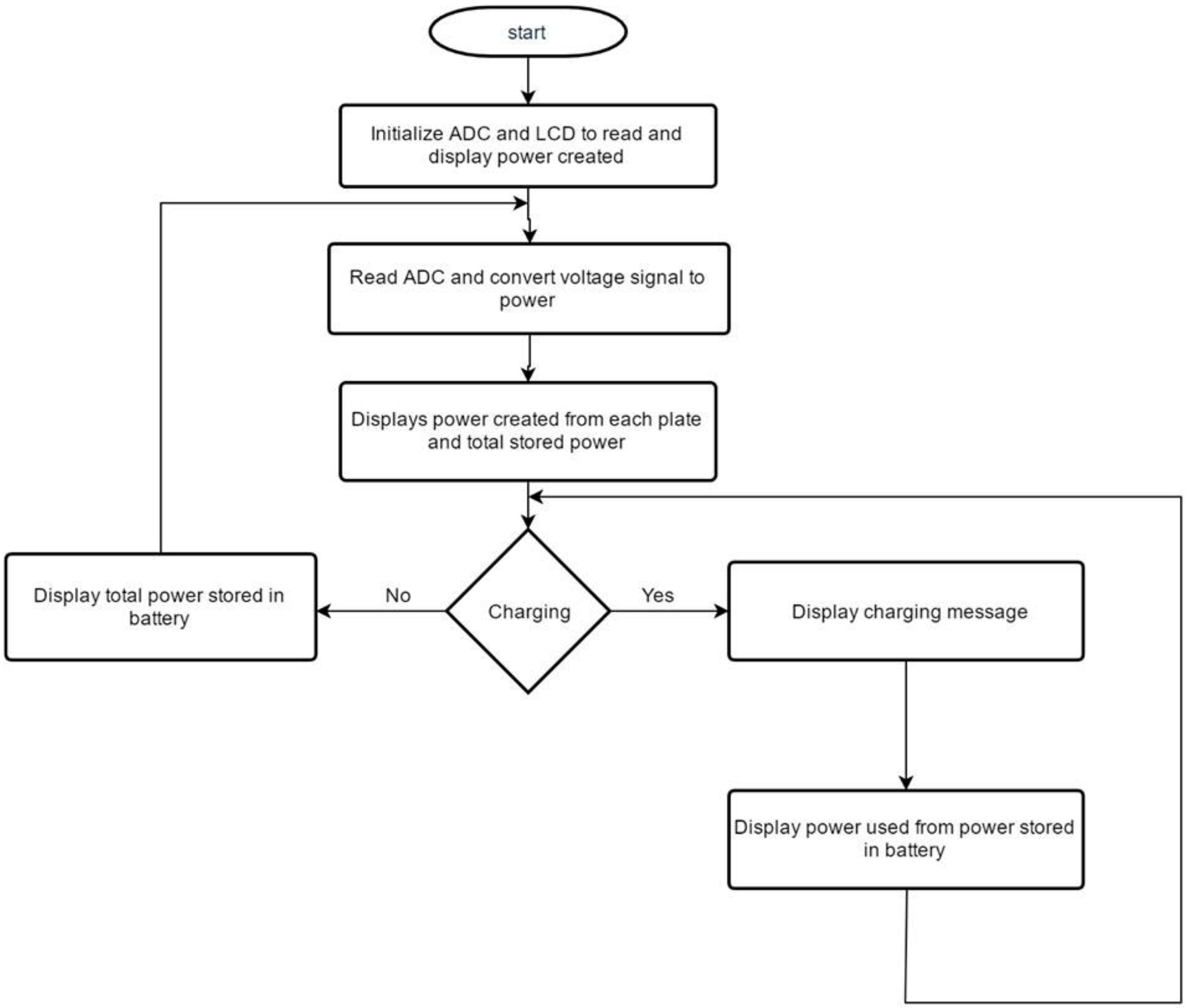

Figure 2. Basic Code Flowchart

3. Design Constraints and Standards

This section describes the constraints and standards for the platform and how it affects the overall system. This section also reviews and identifies similar standards and constraints related to technology used in the design.

3.1 Constraints

The Energy Harvesting Platform require various software and hardware constraints that needs to be addressed when designing the system. This section addresses those constraints to assist in helping the project become successful.

3.1.1 Safety Constraints

When considering implementing new technology, safety of the environment, and more importantly the people, must be placed first. The Energy Harvesting Platform are designed to be placed in the ground at the height of normal platform as to fit in the sidewalk. The difference is that the platform will compress by a few millimeters in order to produce energy using piezoelectric crystals.

The platform will be designed to be compressed, however, it will be designed to be barely noticeable to the person walking on the platform. It will have to be designed in a way as to not cause a break in balance and cause the person to fall due to the compression of the tile.

Another safety constraint is related to the weather. When it rains, the tile must be slip proof to prevent the person from slipping, tripping, and injuring themselves. Causing injuries, though unintentional, could lead to lawsuits and other complications that could be avoided through proper research and design.

Heat dissipation is also a concern for the Energy Harvesting Tile. The tile will be placed in the ground and the electronics will not be directly exposed to air, as designing a vent may cause rain damage to the electronics. A separate cooling system will be designed to prevent the system from over-heating and damaging the components. If the heating system is not designed carefully, the electronics may fry and cause a fire hazard, bringing harm to the surrounding area.

3.1.2 Economic Constraints

One of the most major constraints when designing the Energy Harvesting Tile is the cost to create the tile. Any idea has the potential to become great products, however, when starting this project, there is a limited budget on spending due to what the team can afford.

Another economic constraint is if the cost of production is too high, the cost of implementation will also be high, making the Platform less affordable. By making the production of the Platform as cheap as possible, the pricing of the platform will be more affordable and could also increase in profit for the company. Ideally, the production of the Platform will use only the best materials and components when creating and designing for best quality and performance. However, with limited budget, the Tile will need to be designed with a balance of quality and cost.

3.1.3 Environmental Constraints

As uses for renewable energy and environmental friendly technology grows, newer technologies need to focus on continuing this trend. The Energy Harvesting Platform are deigned to be a self-sustaining renewable energy production system that takes normally wasted energy and stores it for usage. The energy taken consists of solar energy and piezoelectric energy. Both of which are produced on a natural basis and does not cause harm to the surrounding environment. Though the Platform will be able to be installed on any flat location, ideally, the platform will be placed in locations with large amount of foot traffic while being exposed to sunlight. These locations could be school grounds, city squares, and commercial streets.

3.1.4 Ethical Constraints

The design of the Platform will be simple, but consists of none toxic materials as to not damage the surrounding area. It will also be designed in a way that does not cause danger or inconvenience to the people walking on or by the sidewalk.

Extensive research will be conducted in order to not violate any patent protection or infringe any copyright laws. Design concepts will not be used without proper crediting the original source.

3.1.5 Presentation and Testing Constraints

Each of the Energy Harvesting Platform are designed to be eight inches by eight inches. But the complete sidewalk is designed to have six to twelve Platform connected for increased power production. Single platform does not produce enough energy for the result to be immediately visible.

Relating to the economic and time constraints, the team does not have enough funding to produce six to twelve Platform to show the efficient result. Only one Platform will be created for the demonstration and presentation. If one of the Platform works, then the additional Platforms can be produced in the exact same way. As long as the components functions properly, all the additional Platforms will work fine.

During the presentation, the energy generated by using only a single Platform will be quite low. Therefore, the test will only consist of powering up the LCD display and light up a few low power LED lights to prove the system functions properly. The LCD will display the battery level and the charge produced by the piezoelectric transducers. The LED lights will light up when the Platform is pressed down.

3.2 Standards

Every product has a set of regulations and standards to follow, whether it’s set by the government or the company. These standards could set rules for international distribution, domestic distribution, or transportation safety. Standards are updated and modified as necessary through time as new technology becomes available and new sets of rules are required to govern them.

3.2.1 PCB Standard

The Association Connecting Electronics Industries, also called IPC, is a trading company which aims to standardize the production and assembly requirements of electronic equipment. The company creates many of the standards used by electronic manufacturing industries. The standards the company created include:

- Printed board
- Printed electronics
- Design standards
- Flexibility
- Assembly
- Electronic enclosures
- Embedded technologies

Commercial PCBs are required to follow a set of standards to ensure longevity and reliability of the product. The standard for printed board design is IPC-221B, which lists the general requirements for component mounting and PCB designs.

By following standards, the PCB for the project can help achieve desired design results. This will bring about the product's reputation, reliability, and profitability. Using international standards will also allow global usage without the problem of communication difficulty in the electronic industries around the world.

3.2.2 Power Supply Standards

Power supplies such as batteries could be a hazard if not carefully regulated when being transported. Each individual country have its own set of rules. When dealing with batteries, depending on the type, there will be different when storing and transporting the batteries. For rechargeable batteries, there are dangers of discharge and overcharge that could damage the batteries or at times make it explode. These rechargeable batteries tend to have an ideal storage range for safe storage which could increase battery life. The following table describes a few of the many standards designed for safe transportation for international trades and sales.

Standard Code	Type	Description
UN/DOT 38.3	Transportation	Part of the dangerous good regulations Self-certify standard Needs to pass a series of tests: • Altitude

		• Thermal • Vibration • Shock • External short circuit • Impact • Overcharge • Forced discharge
IEC 62133	International Compliance	Easier to pass than UN 38.3 Need to pass a series of tests: • Molded case stress • External short circuit • Free fall • Overcharge
UL 2054	US Devices	Involves about double the tests than UN or IEC requirements For lithium batteries, UL 2054 tests all components at cell level These tests include: • Seven electrical tests • Four mechanical tests • Four battery enclosure tests • One fire exposure test • Two environmental tests

Table 1. Power Supply Standards

3.2.3 IEEE Std 1013 TM-2007

This standard describes a recommended practice for using lead-acid batteries in stand-alone photovoltaic systems. It helps determine what size of lead-acid battery should be used based on design requirements. It does not, however, consider hybrid or grid-connected PV system, nor does it consider the installation, maintenance testing protocols or safety regulations associated with lead-acid batteries. Depending on what solar panels are chosen and what batteries are chosen in our design, this may affect the way we implement a charging system.

3.2.4 IEEE Std 1562 TM-2007

This standard is the IEEE Guide for array and battery sizing in stand-alone photovoltaic systems. This standard in conjunction with IEEE Std 1013 TM-2007 describes a method for sizing the PV array and battery for stand-alone PV systems. Although our design has another power source, this is a good standard to keep in mind when researching our design. We want to show that our design can be implemented using either input source as well as both of them working together.

3.3 Reliability

In today's society, every product being sold on the market needs to be durable and reliable, otherwise the company or producer will be sued. For protection against lawsuits, the Energy Harvesting Platform needs to be completely self-sustained, functional for the duration of our estimated life span of five years. The product will also have to function properly and have a meaning use to the company or person that decides to buy the product. Even if the product itself functions, but does not charge a phone or other electronic devices fast enough or at all, then it will be considered a failed product and create multiple complications.

If the product fails or is damaged in any way, we will need to be able to provide replacement or services to fix the damaged parts. Once every five years or so, when the estimated life-span of the Platform reaches its end, we will need to inspect the Platform and send in replacements. Although the estimated life is five years, most of the internal parts will still be functional. We will be able to salvage parts from previously used Platforms and create new ones from those parts.

By having the product reliable, consumers will be more willing to buy the product, thus increasing revenue and assisting in the economic constraint. By having more money, the Energy Harvesting Platform can be improved and upgraded, this will further benefit the company itself if the product continues.

4. Research

The world currently excels in placing ideas into production at a fast pace, and therefore, many ideas are already working products. Although a functional design exists, most of them almost always have room for improvement, and that’s where the innovation comes into play. Several companies have already produced energy-harvesting platforms that have successfully been placed in popular areas such as stadiums and schools, while others are still a work in-progress.

The concept of energy-harvesting through walkable platforms is still in the early stages of being used globally, and therefore, without much competition, the cost remains high. This is one of the main points to consider for our project, keeping costs low and making the platform affordable at a reasonable price. Most of this project’s goals are to incorporate modern, advanced technology so that the final product can be used long-term and provide more opportunities for modifications with a futuristic vision. Certain aspects from each of these existing products and projects are what influenced our design to consist of an improved method to harvest energy.

4.1 Existing Projects

This section describes some of the technology similar to the Energy Harvesting Platform that is currently being sold commercially. The technology was released relatively recently, therefore it is still not widely used throughout the world. The majority of the technology is being used in Europe. These technology, though already implemented, could still be improved.

4.1.1 Smart Floor Systems

The main aspect in the design for the platform is that it should be user-friendly, offering an experience of walking on an almost solid floor even though it’s being pressed down so the person does not experience a falling sensation. Some companies, like PaveGen, have come up with a design where the tiles that are stepped on are triangular with each tip connected to a support system that consists of the piezoelectric device. They believe this is a good design because it provides efficient weight distribution on any point of the tile so that it comes into full contact with any of the piezoelectric transducers under the three tips of the tiles when stepped on. Figure 4 and 5 shows what’s under the tile, where each tip rests on top of a piezoelectric transducer so that whichever tile is stepped on, it will still create a force on the device.

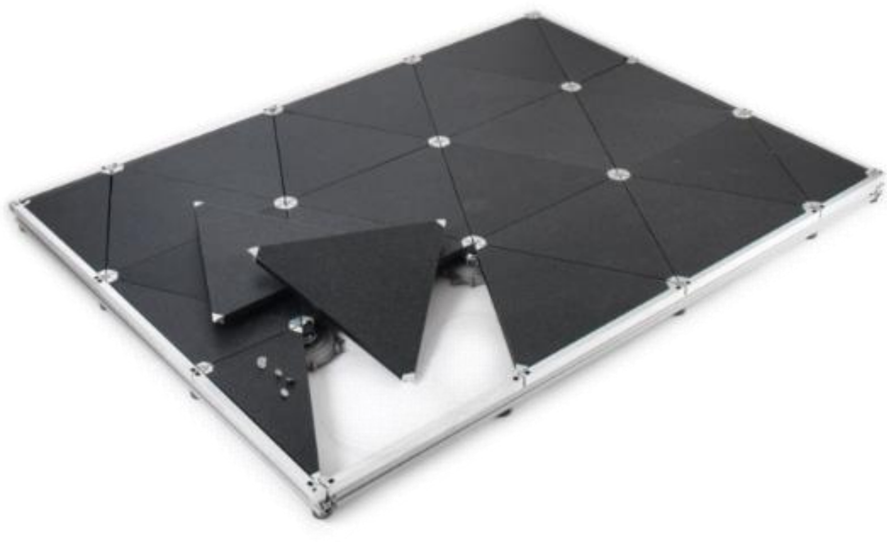

Figure 3. PaveGen Platform (Courtesy of PaveGen)

Figure 4. PaveGen Platform Parts (Courtesy of PaveGen)

This platform has certain smart features like tracking where exactly the person has stepped and how much energy was produced by that person based on how much they walked on it. Our design will incorporate monitoring certain information like how much energy was produced by the piezoelectric transducers. The downside to this design is that the only way it creates energy is limited to when people walk on it, therefore, its sustainability depends solely on high levels of foot traffic. The purpose of our project is to create a hybrid energy-harvesting platform which incorporates more than one source of energy, increasing the platform's productivity and output.

4.1.1.1 Energy Floors

Another company that has produced a successful design is Energy Floors which created a hybrid platform that consists of a full square tile on top of the piezoelectric device and a solar panel within the casing of the tile, as shown in Figure 5. This design has proven to be efficient because it has two sources of creating energy, when the tile presses on the piezoelectric device and since the platform is placed outdoors, it's getting solar energy from the sunlight.

Figure 5. Energy Floors Hybrid Tile Design (Courtesy of Energy Floors)

The concept of equal weight distribution on any piezoelectric device to obtain that maximum possibility of applying pressure combined with the additional method of having the tiles themselves harvesting energy through sunlight is what brought about our innovative design for a dual energy-harvesting platform. Having these two methods combined help increase the productivity of the platform since it is unconditionally collecting energy throughout the day due to the solar panel tiles, and additionally from foot traffic that would take place at any time of the day depending on where the platform is placed.

Energy Floors also has an indoor floor design which relies solely on footsteps, but the idea of having colorful LEDs inside the tiles is a great way to provide entertainment while also producing the desired energy, as shown in Figure 3. They have widened the use of these platforms to places such as dance floors where people are continuously generating energy while having fun which is a great idea. Another aspect of the project is to make a product that inadvertently generates energy while people are performing normal cardio activities. By improving the attractiveness of the results of walking on the platform, the productivity will increase.

Figure 6. Energy Floors Dance Floor (Courtesy of Energy Floors)

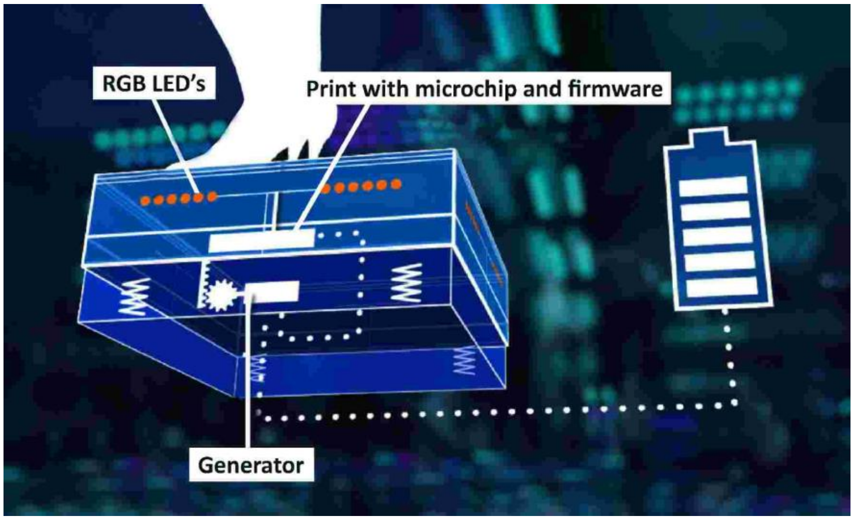

Figure 7. Energy Floors Dance Floor Concept (Courtesy of Energy Floors)

4.1.1.2 Walkable Photovoltaic Floor

Onyx Solar is a company that has also produced photovoltaic tiles that consist of similar design concepts to the others along with the fact that the tiles are made of anti-slip material which is very important for safety reasons. Having that type of material cover the tiles provides the design with security and people feeling safe when stepping on it, reducing the possibility of slipping or falling.

Figure 8. Onyx Solar PV Floor (Courtesy of Onyx Solar)

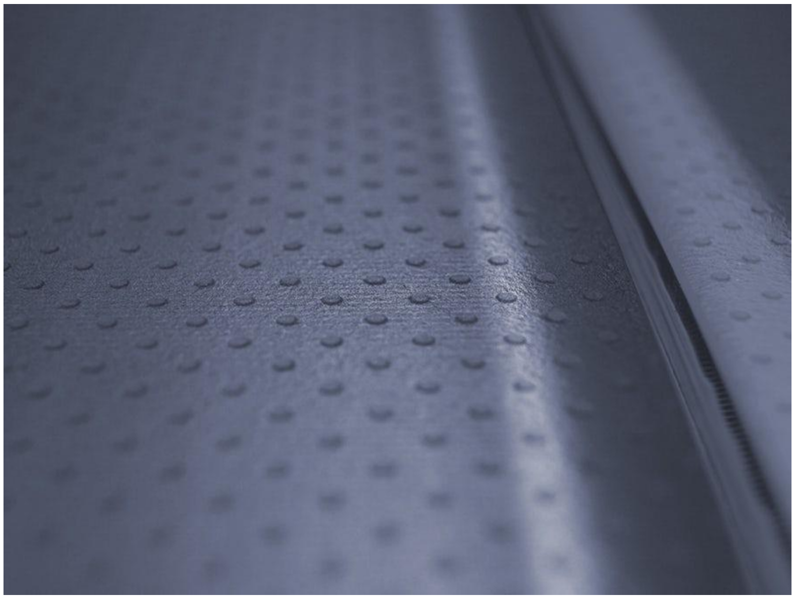

Figure 9. Anti-Slip Material (Courtesy of Onyx Solar)

Safety measures for the project design are one of the top priorities since the product is being used by people. The material chosen will also consider how weather effects the durability and if the platform is still safe to walk on after an event such as rain or snow.

Public use of products such as these create liabilities for companies, and therefore, require them to adhere to certain safety regulations. Part of the plan for this project is to recognize every possible way to eliminate safety concerns and create a seamless design that is safe and user-friendly.

4.2 Relevant Technology

This section describes the relevant technology used as part of the Energy Harvesting Platform. The Platform is a combination of these technology to make it more efficient and increase performance.

4.2.1 Piezoelectricity

The technology that makes it possible to convert mechanical energy into electrical energy dates back to as early as 1880 when French physicists discovered the piezoelectric effect. The piezoelectric effect generates an electric charge in response to applied pressure on the crystallized material. Its applications include the production of sound, generation of high voltages and electronic frequency generation.

In this project, its use of generating high voltages will be applied to the platform design. The piezoelectric component consists of a crystallized material, such as PZT (lead zircoante titanate) in between two metal plates with a wire connected to each plate.

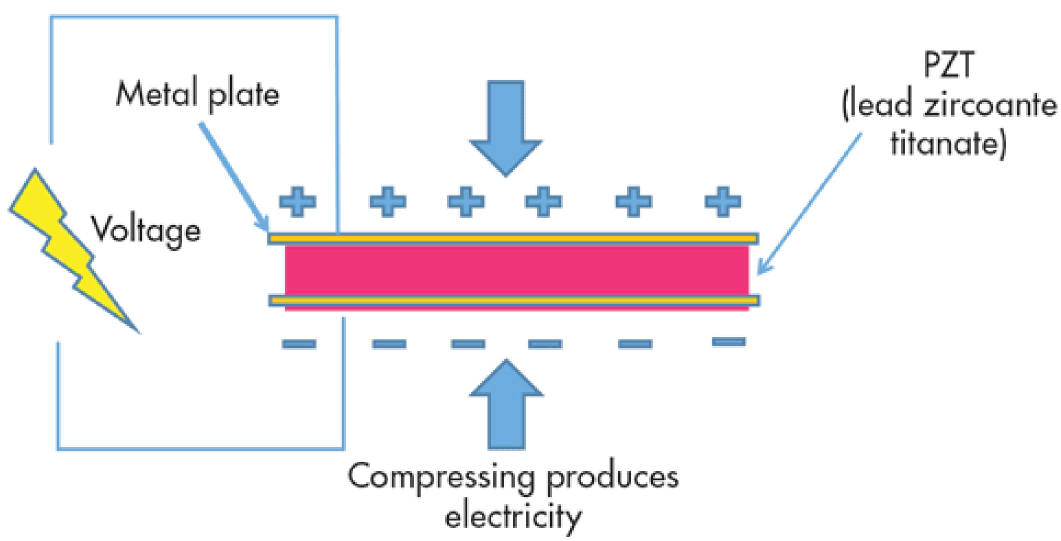

Figure 10. Piezoelectric Effect (Courtesy of ElectronicDesign)

The energy-harvesting platforms use a piezoelectric transducer to create the process of channeling the voltage created, from applying pressure to the crystallized material, to the component that would use the energy, such as an LED. This involves several other components such as regulators and converters, depending on what type of device is being powered by the source. The amount of voltage produced from this effect is variable depending on the amount of pressure applied to the crystallized material, and therefore, requires a component of adjustable regulation so that the correct voltage is applied to all the devices connected to it. To charge a battery, the number of piezoelectric transducers will be scaled to meet the voltage requirement. This is the main design concept of our project and the main source of generating energy since the productivity depends on footsteps which can happen at any time.

4.2.2 Solar Power

The second part of our design which makes it a dual-source energy-harvesting platform is the fact that along with using footsteps to generate power, the tiles will contain solar panels. Solar panels were invented after the discovery of the photovoltaic effect in 1839, which explains how electricity can be generated from sunlight. As photons from the sun hit the surface of the panel, they are absorbed and excite the electrons which causes an electric potential. The electric potential occurs when there is a separation of charges. Figure 9 shows the flow of charges in the junction and how they interact with the material of solar panels to produce the energy that is transferred to the light bulb.

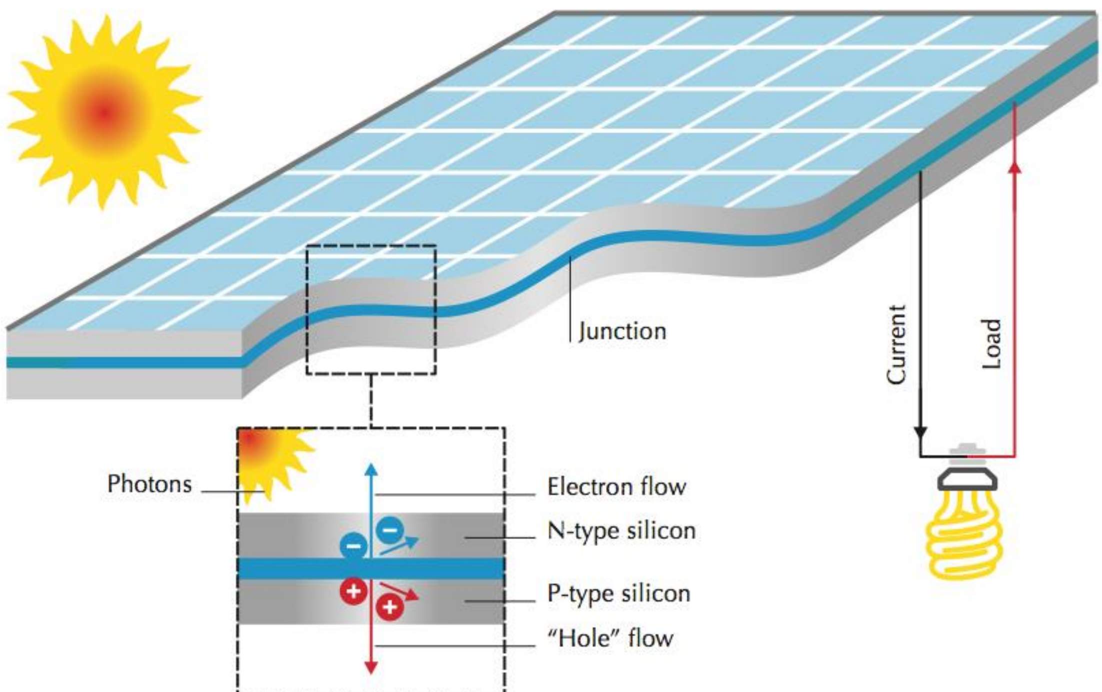

Figure 11. Photovoltaic Effect (Courtesy of IEA)

Solar energy is one of the more prominent and supported methods used globally in an effort to convert from fossil fuels to "green" energy. This method is vital to our design since we know that for about 12 hours on a clear day, the platform will be producing energy regardless of foot traffic. This helps increase productivity and provides the opportunity to use emerging technology that supports being self-sustainable and renewable energy which is environmentally friendly.

4.2.3 Rechargeable Batteries

There are several types of rechargeable batteries which can be considered for this project and that do not pertain to any prominent downside, like being outdated or high risk usage, such as Lead-Acid, Nickel-Cadmium (Ni-Cd), Nickel Metal-Hydride (Ni-MH), and Lithium-Ion (Li-Ion), and Lithium-Ion Polymer (Li-Po). All five types will be discussed to realize which battery is the best candidate that meets the project requirements and can be utilized efficiently in the design.

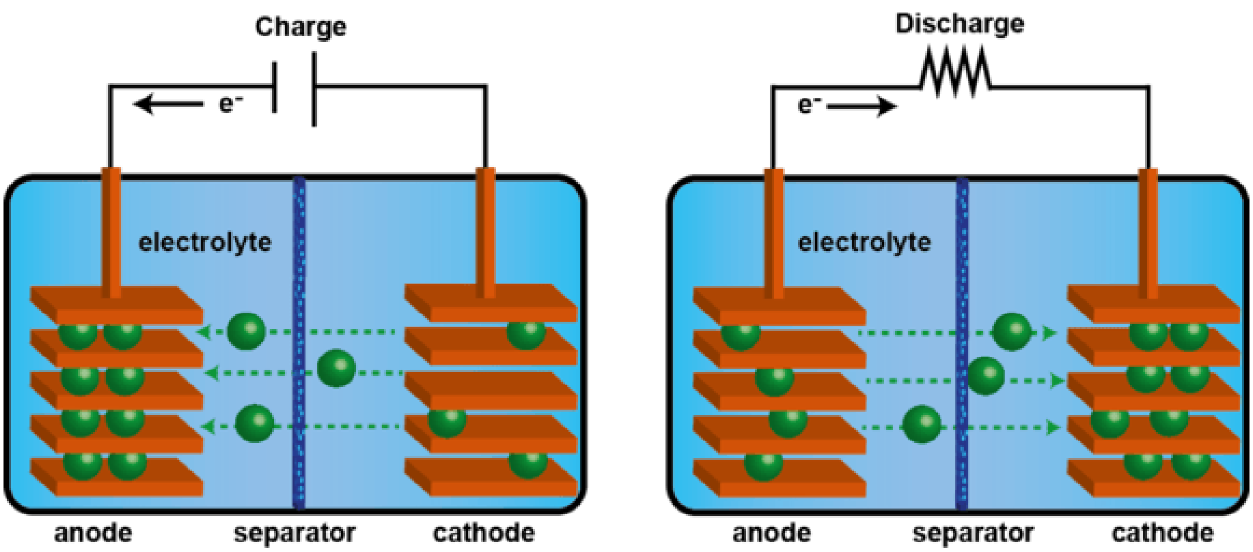

Figure 12. Rechargeable Battery Concept (Courtesy of The Conversation)

4.3 Hardware Components

This section compares the hardware components used for the Energy Harvesting Platform. These comparison allows the group to choose the best component while keeping to affordable price ranges.

4.3.1 Voltage Regulator

Another very important technology that will be used in this design is a voltage regulator. A voltage regulator is a circuit that's purpose is to maintain a certain voltage output, as long as it is greater than or equal to the input voltage.

This will be very useful since the piezoelectric transducers and solar panels will output very high voltages and if they are not regulated, will destroy the rest of the circuitry in the platform. Since the output voltages from the two sources are being directed to the battery and microcontroller, maintaining low voltages is absolutely necessary for the success and functionality of the design.

The voltage regulator will also serve as a protection device incase an unexpected amount of voltage is produced from the input and ends up being too high to manage before it reaches the battery or microcontroller.

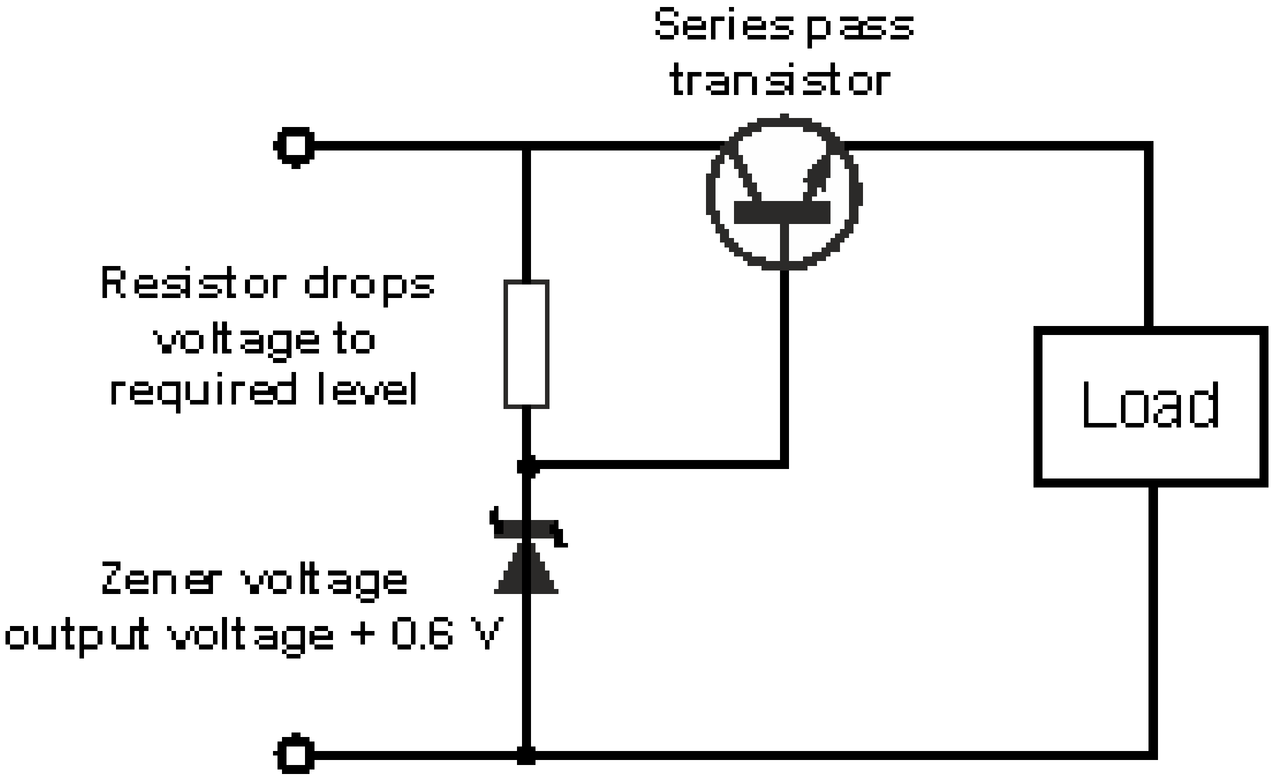

Figure 13. Voltage Regulator

Piezoelectric transducers produce a high AC voltage due to the fact that the amount of voltage is dependent on how much pressure is applied to the transducer, therefore, requiring a voltage regulator component so as not to overload the other circuitry. Solar panels produce a high DC voltage that also needs to be regulated due to the fact that the voltage is produced directly from sunlight.

4.3.2 Rectifier

The main components in the project design rely on DC voltage. The solar panel input voltage is already DC and therefore, does not need any modifications. The piezoelectric transducers on the other hand, require an AC to DC conversion. This is possible using what's known as a rectifier. Rectifiers turn AC voltage to DC by using a set of diodes that force the current to flow in a single direction, usually positive, and thus, creates the output as shown at the bottom of the figure below.

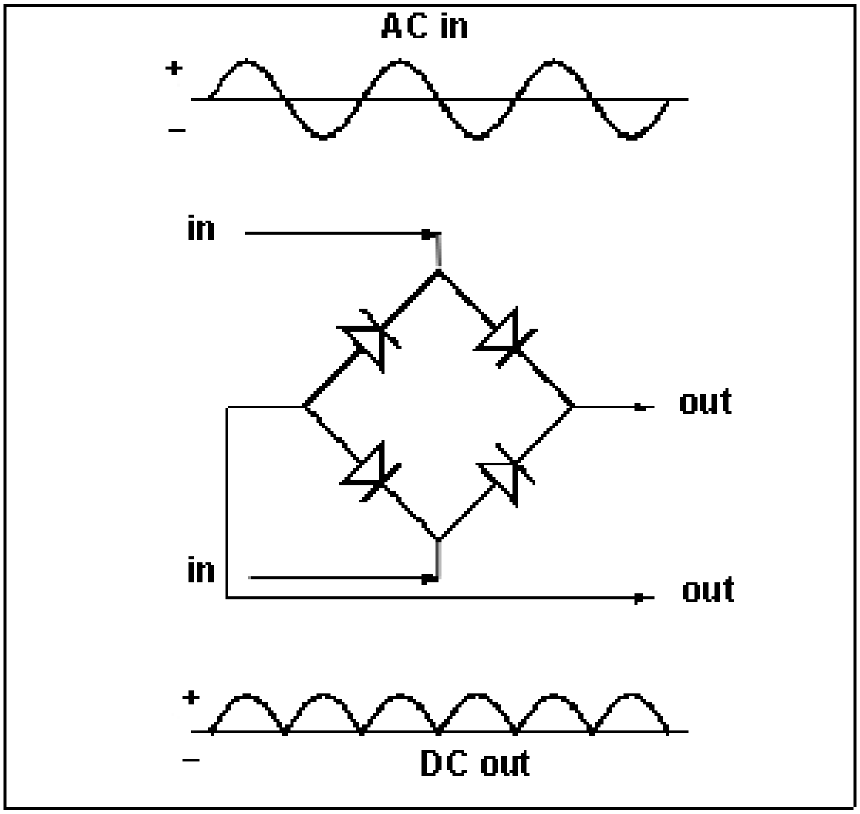

Figure 14. Rectifier

Rectifiers are a useful technology in AC to DC conversion which is required for this project to function correctly due to the requirements of certain components in the circuits. The efficiency of rectifiers is never 100% though, due to a small amount of AC power that gets through the diodes.

Another downside to rectifiers is that although it is mainly converting AC to DC, it consists of the basic concept of voltage drop, due to the fact that the diodes require a certain voltage to turn on and allow the rectifier to work. This is a very important part that needs to be taken into consideration when designing the circuitry so that the required voltage to charge the battery and power the microcontroller are achieved even with the loss of voltage due to the conversion.

4.3.3 Microcontroller

Microcontrollers are programmable units that typically have components you can find in a computer such as CPUs, memory, input/output peripherals, etc. Many microcontroller units (MCUs) can be embedded in other consumer products such as cell phones, automobiles, household appliance, video game consoles, etc. They can range in size, shape, performance, efficiency, etc. Microcontrollers can be 8 bit, 16 bit, 32 bit and even 64 bit. Microcontrollers can be programmed to do a multitude of tasks.

Microcontrollers can be very customizable. We can add a variety of inputs such as buttons, switches, and sensors. We can also add output devices such as an LCD display, buzzers, LEDs and more.

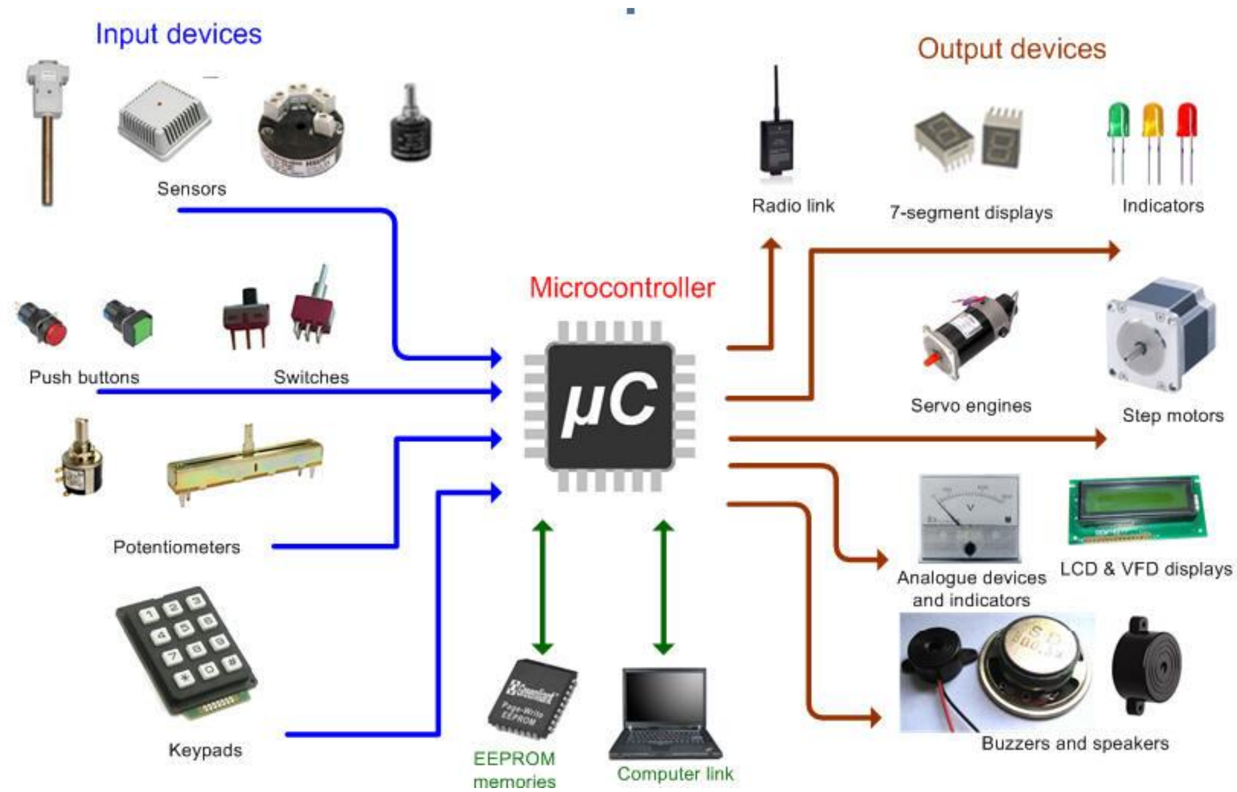

Figure 15. Versatility of Microcontroller (Courtesy of Barcelona Tech)

The purpose of having a microcontroller for this project allows a combination of tasks to be executed and monitoring of all the currents and voltages being produced throughout the circuit. The design requires ADC inputs which can only be done using a microcontroller along with having input and output measurements be displayed on an LCD which will be programmed from the MCU. The LEDs being built into the tile will also be programmed by the MCU to light up when the tile is stepped on.

The microcontroller will also be responsible for the control of the recharging of the Li-Ion batteries. Due to safety measures, a switch will be implemented along with a voltage/current monitor for the batteries so that the charging is shut off once the batteries reach their maximum charge capacity. The MCU can be used to determine the rate of self-discharge of the batteries during idle times when there is no charging/discharging being done.

The Energy Harvesting Platform will use a single microcontroller interfaced with an LCD display for the purpose of providing the user with a real-time count of the power produced per plate and the power stored in the battery bank used. This microcontroller will take the created analog signal from the sensors and convert it to a digital signal that can be displayed providing information on the product's performance. Given there will also be a charging station to go along with the platform, the LCD will display when a device is charging, not charging and how much power is consumed from the battery bank. Several different microcontrollers and LCD character displays are evaluated to find the one right for this specific application. Simple circuit design is also delved into to successfully feed the signals into the microcontroller without compromising the integrity of the device.

4.3.3.1 Microcontroller Options

This section goes into detail on the different microcontrollers offered in the market from different manufacturers and within the same company. An overview of the specifications as well as a comparison between models is also shown in this section. The selection will be based primarily on an efficient Analog-to-Digital converter, a clock frequency of at least 16 MHz, low power implementations and a reasonable price.

4.3.3.1.1 TI MSP43X Series

This family of 16-bit MSP microcontrollers created by Texas instrument provide for ultra-low power applications with a sensible price tag. Apart for providing a variety of low power modes, CPU speeds up to 16 MHz, it also provides a 10-bit ADC with up to 12 analog channels.

4.3.3.1.1.1 MSP430G2 LaunchPad

The LaunchPad is a kit assembled by Texas instrument for the purpose of providing the programmer all the necessary tools to start developing on the MSP430 devices. The kit primarily provides a development board, the MSP-EXP430G2, and two MSP430 flash-based microcontrollers, the MSP430G2553 and the MSP430G2452. Moth microcontrollers will be evaluated in the following sections. Apart from providing low power applications at a low cost, the kit provides an on-board emulator for programming and debugging the device with a PC through a USB, ideal for customizing the device to the desired application. Other features are included such as programmable buttons and LEDs, but these are of little importance to our project.

4.3.3.1.1.2 MSP430G2553

This device features a 16-bit RISC CPU and is the first device provided with the LaunchPad kit, with the microcontroller standalone price of $2.50. Key specifications include a 10-bit 200-ksps Analog-to-Digital convertor, internal frequencies up to 16MHz, and low supply-voltage range from 1.8 V to 3.6 V. Regarding memory, this device exhibits 16KB of flash memory and 500B of RAM. Other specifications for this device include ultra-low power consumption with the use of 230µA at 1MHz, 2.2 V, when in active mode, serial ports for features such as UART, SPI and I2C, and 20 GPIO pins. As established by the company, this device is mostly used for low-cost sensor systems that capture analog signals to convert into digital signals for data display. This proves the device a great option for the program.

4.3.3.1.1.3 MSP430G2452

This device is a slightly downsized version of the MSP430G2553. It also features a 16-bit RISC CPU with a frequency up to 16 MHz and is the second device featured in the Launchpad kit. Unlike the previous microcontroller, this one only provides 8KB of flash memory with 250B of RAM. Along with a slightly lower power consumption than the MSP430G2553 in active mode of about 220µA at 1MHz, it also carries16 GPIO pins, 8 less than the previous device. But given there is little difference, the previous device will be considered over this one.

4.3.3.2 PIC16(L)F1885X/7X

PIC16(L)F1885X/7X is a family of microcontrollers manufactured by Microchip Technology Inc. which provide very low power applications for a wide range of general purposes, as well as communication and analog peripherals to suit the developer's need. These devices feature analog, communication and core independent peripherals to satisfy general purpose or dedicated applications. Apart from these features, there also CRC.SCAN, Windowed WDT and HTL which provide added safety features for those who are looking for a more secure design. Other features are included in this device of microcontrollers that provide for great operating speeds, configuration, usability, and overall optimized performance.

4.3.3.2.1 PIC16F18877

This device is overviewed as it is featured in many related projects to our design. This microcontroller is an extremely low power device that provides a wide variety of features for high efficiency and many applications at a price of $1.89 per unit. This device runs on operating speeds of 32 MHz with operating currents of 8µA at 32kHz, 1.8 V. IT also provides other power saving modes to optimize performance. It also holds an operating voltage range of 1.8 to 3.6V.

Considering memory, this device provides up to 56 KB of flash memory with up to 4 KB of SRAM. It also carries many core independent peripherals ranging from digital to analog. A key feature is the provided 10-bit ADC with computation with 35 channels. Other notable features are up to 36 programmable I/O pins, serial communications that support EUART, two SPI, two I2C, and others. Several Capture/Compare, PWM and timer modules are also present in this device.

With all these features, and an optimized performance, this device provides for a good option when deciding on a final device.

4.3.3.3 ATMEL AVR ATMEGA SERIES:

Atmel megaAVR is a family of microcontrollers manufactured by Atmel, currently owned by Microchip. This family of microcontrollers are the ideal choice for robust designs offering a wide selection of memory capacities, pins and peripherals. This high integration circuit reduces time and cost by simplifying design and lowering power consumption. It also provides advanced analog capabilities with modules such as ADC, DAC, low power comparators, and others that help eliminate the need for external components.

4.3.3.3.1 ATMEGA328/P

This device features a high performance low power 8-bit AVR RISC-based architecture and encompasses a variety of features to suit different applications at a price of $1.90 per unit. This this device is manufactured by Atmel and is quite prevalent in many project designs due to its straightforward implementation. Along its low price, it runs with a frequency up to 20 MHz and provides for very low power consumption with 1.8V at 1MHZ. It is used in programmer boards such as Arduino NANO and Arduino UNO.

Its active mode consumes 0.2mA at 1 MHz, 1.8 V, and operates on a voltage range of 1.8 to 5.5V. apart from this, it offers 6 low-power modes to provide for a more optimized performance. Memory offers up to 32KB of flash and 2KB of RAM. Included is 28 GPIO pins with 23 programmable I/O lines, of which 15 are digital pins and 8 analog pins. A plethora of peripherals are offered as well. Of high importance is the 10-bit 15kSPS ADC with 8 channels.

Other peripherals such as serial communication, e.g. UART, SPI and I2C, timer/counters and analog comparator are also provided. Following are several microcontroller-based boards that are useful for testing out the ATMEGA328/P implemented in the design for this project.

4.3.3.3.2 Arduino NANO

Arduino NANO is one of a family of programmable boards based on the ATmega328 microcontroller, which it was just presented. This board is a compact version of the Arduino Uno given its PCB size of 18x45mm, clocking speeds up to 16 MHz. There is a total of 14 digital pins that can be used as input or output, operating at 5 V, with some pins having specialized functions such as serial connections, external interrupts, PWM and a pin to control an LED. Apart from a couple other pins on the board, there is also 8 10-bit analog inputs that work with a reference voltage. These can be used to employ the ADC needed for this project. The board can also be programmed through a preset “Arduino” software hence providing for easier configuration of the device. Given its smaller size, it is useful for smaller implementations.

4.3.3.3.3 Arduino UNO

The Arduino UNO is another programmable board based on the ATmega328 microcontroller, and it runs similarly to the Arduino NANO, but with newer integrated features along with a bigger size of 53.4V68.6mm. Other than the already set features on the Arduino NANO, the ATmega328 included comes preburned with a bootloader that allows you to upload new code to it without the use of an external hardware programmer, which eases the process of configuration.

4.3.3.3.4 ATMEGA2560

This is another high performance, low-power 8-bit AVR RISC based microcontroller, a more robust version of the ATMEGA328/P with a price of $12.70 per unit, and is provided in the Arduino Mega programmer board. This device provides CPU speeds up to 16 MHz, with 256 KB of flash memory and 8 KB of RAM. It provides an operating voltage range between 1.8 to 5.5 V. With a total of 86 programmable I/O lines, it provides 54 digital pins and 16 analog pins, more than enough to provide for this project.

Considering its low-power consumption, its active mode consumes 0.5mA at 1MHz, 1.8 V, which is slightly larger than the ATMEGA328/P, still making it a competitive device. It also includes the same low-power saving modes mentioned in the previous device. Apart from providing a higher quantity of the same peripherals such as more serial communication ports and bigger analog channels it provides a 16-channel 10-bit ADC

Given the extensive capacity of this device over the ATMEGA328/P, it seems a reasonable choice as it provides plenty of room for configuration. But for the purpose of this project, it proves to be a waste in resources and technology as it provides much more than what will be needed and will never be used, hence it will not be considered for the final choice.

4.3.3.4 STM32L053x6/8

This family of microcontrollers manufactured by ST Microelectronics combine the high-performance ARM® Cortex®-M0+ 32-bit RISC core with an extensive range of enhanced peripherals and inputs and outputs for various applications. Apart from high-power efficiency, it provides several analog and digital features, as well as advance communication interfaces, among other features.

4.3.3.4.1 STM32L053C8

This microcontroller offers a high performance 32-bit RISC CPU operating at speeds up to 32MHz of frequency at a price of $4.03 per unit. This device offers an ultra-low power performance of 88μ/MHz when in active mode, offering an operating voltage range of 1.65 to 3.6V. Memory provides up to 64 KB of flash and 8 KB of RAM with a 20-byte back up register and 51 high speed GPIOs. Another important feature is it offers a pre-programmed bootloader, which eases configuration for the programmer.

Considering peripherals, it provides a vast amount of optimized analog and digital interphases. Key peripherals which provide useful to the project include the provided 12-bit ADC 1.14 MSPS with up to 16 channels. Other peripherals include ultra-low power comparators, several 16-bit timers, 8 times the peripheral communication interfaces such as USART, SPI and I2C. It as well supports an LCD driver for up to 8x28 segments.

Taking all these features into consideration and the highly optimize design it provides, as with the ATMEGA2560, this device used in our design will provide wasteful as many of these excellent features are not necessary and may seem as overkill. Even though it offers a lower price per unit in comparison to the ATMEGA2560, it is still unnecessary to implement and will not be considered in the final choice.

4.3.4 Microcontroller Comparison

Before establishing comparisons, here is a final look at some of the specifications for each microcontroller, which will help narrow the decision so the comparison can be done on project application specifics.

Microcontroller	Main Clock Speed	Main Memory	Secondary Memory	Communication Module	Additional Modules
MSP430G2553	16 MHz	0.5 KB	16 KB	USCI	ADC, Comparators
MSP430G2452	16 MHz	0.25 KB	8 KB	USI	ADC, Comparators
PIC16F18877	32 MHz	4 KB	56 KB	USCI	ADC[2], DAC, Comparators
ATMEGA328/P	20 MHz	2 KB	32 KB	USCI	ADC, DAC, Comparators
ATMEGA2560	16 MHz	8 KB	256 KB	USCI	ADC, CC Mode, PWM, Comparator
STM32L053C8	32 MHz	8 KB	64 KB	USART	ADC, DAC, low-power comparators

Table 2. Microcontroller Comparison

After overviewing several different optioned brought up by investigation and/or group preference, a few devices are selected to compare some of the mentioned features to reach a final choice on the best microcontroller to implements towards this project. The comparison in this case will be done between three devices, the MSP430G2553 from Texas Instrument, the PIC16F18877 from Microchip, and the ATMEGA328/P for Atmel.

4.3.4.1 ADC Specifications

One of our major concerns in this project is to have an efficient ADC that is accurate, without compromise budget or wasting added resources. Given an analog signal will need to be measured and converted to a digital one for display and efficiency tallying, a precise component will prove important. Below we can see the differences in this analog peripheral per microcontroller.

As it appears, the PIC16F18877 provides for 35 channels for the peripheral, but for our project, it is unnecessary to include this many. There is also no specific sampling rate present in the data sheet, only the ADC clock sources per device frequency, which makes it hard to compare to the other devices. Other than that, the MSP430G2553 clearly delivers a faster sampling rate of 200kSPS as opposed to the 15 kSPS the ATMEGA328/P provides and therefore is more efficient.

4.3.4.2 Cost

Another important feature to inquire about a device is the pricing on each unit given most projects run on a limited budget, as well as providing a low-cost device affordable to buyers who wish know the product's productivity. Below is a small table comparing prices for each microcontroller.

From the specifications, we first observe the PIC16F18877 comes at the lowest price of $1.89, and with the many features it provides it seems like the best choice, especially when comparing the substantial price increase when choosing MSP430G2553, $2.50 as opposed to the ATMEGA328/P, $1.90. Given the close price between the bottom two microcontrollers, the choice can be left to the programmer's preference to have extra features that the PIC16F18877 can offer or have the ability to easily program the device, which ATMEGA328/P tends to provide by the vast amount of information available and the programmer-friendly environment.

4.3.4.3 Power Consumption

Given the microcontroller will have its own external power source such as a small battery, it would be ideal to wave a low-power consumption device so as to elongate the operational life of the battery before the need to replace it.

It is observed by the specifications that all operate under the same lowest voltage of 1.8 V, but the PIC16F18877 has the lowest power consumption as it draws less current at each megahertz, 0.032 mA. The other two microcontrollers see a 24.2% decrease in consumption, whereas the second least power consuming, between ATMEGA328/P and PIC16F18877 we see an 83.3% decrease in consumption over the making the PIC16F18877 the better choice at reducing power consumption.

4.3.4.4 Clock Frequency

Clock frequency determines the speed of the processing unit and hence determines the time onto which instruction is executed and the amount of cycles it takes per second. The energy harvesting platform will be constantly inputting analog signals into the microcontroller and thee user will need to have real time tracking of the power that is being generated after each step, continuously updating. Though a large processing frequency is not necessary, we still need to keep in mind the products needs and boundaries.

When comparing the speeds mentioned earlier, the MSP430G2553 shows to be 50% slower than the PIC16F18877 which is a significant difference in terms of the amount of clock cycles performed, while the ATMEGA328/P is only 38% slower and a much more feasible downgrade. It can clearly be seen that the better choice is the PIC16F18877, but there raises the question for the need for so much speed for the project's implementation.

4.3.4.5 Memory Capacity

For this section, the focus will mainly be centered on flash memory and RAM. For the Energy Harvesting Platform, the program will need to constantly calculate and display values, read analog signals and control LED lighting. The need for Flash and RAM will depend on the complexity of the program and the product activity, i.e. the amount of data constantly received.

Form the specifications the PIC16F18877 provides a larger memory capacity in both flash memory and RAM, especially when compared to the MSP430G2553 where there is a vast difference. Between the MSP430G2553 and the ATMEGA328/P we see a 50 % decrease in flash and an 87.5% decrease in RAM.

4.3.4.6 General Purpose Input/Output

For the Energy Harvesting Platform, there will be many sensors connected in series who will feed electrical signals to the power bank and the microcontroller for reading. Another connection will be established with the power bank itself to provide the user an accurate reading of the energy stored in the bank. This implementation does not require a great deal of pins, but non-the-less its worth comparing what is offered.

Yet again it is observed how the PIC16F18877 excels over the other two microcontrollers offering 36 pins, but for there is no need to have that many pins in the design. It is also important to observe the maximum voltage the pins can withstand as this project calls for electrical signals to be constantly feed through the analog pins and an awareness of limits prevents from possibly damaging the board. In this case, the ATMEGA328/P is a better choice as it provides more than enough pins and the ability to withstand 6 V to any pin.

4.3.5 Microcontroller Selection

A final overview of the specification comparison is shown here to better choose the best microcontroller for this project. Here are numerical values to the already describes specifications which were used to both compare and determine the needs for this project. As well as determining the needs, considerations on unused technology are also taken place to increase design efficiency with only the necessary specification.

Specifications		MSP430G2553	ATMEGA328/P	PIC16F18877
ADC	ADC Bits	10	10	10
	ADC Channels	8	8	35
	Sample per Second (kSPS)	200 kSPS	15 kSPS	Not Found
Cost	Price Per Unit (USD)	$2.50	$1.90	$1.89
	Price Increase	32.28%	0.529%	0%
Power Consumption	Power Consumption (mW)	0.414 mW	0.360 mW	0.0576 mW

	Lowest Operating Voltage (V)	1.8 V	1.8 V	1.8 V
	Current at Active Mode at 1 MHz (mA)	0.230 mA	0.200 mA	0.032 mA
Clock Frequency	Clock Frequency (MHz)	16 MHz	20 MHz	32 MHz
Memory Capacity	RAM (KB)	0.5 KB	2 KB	4 KB
	Flash Memory (KB)	16 KB	32 KB	56 KB
GPIO	Pin Count	20	32	36
	Max Voltage Applied to any Pin (V)	3.9 V	6 V	3.9 V

Table 3. Microcontroller Selection Comparison

When evaluating several different microcontrollers, our investigations took us to three different possible choices for our design. The MSP430G2553 from Texas Instrument, the PIC16F18877 from Microchip, and the ATMEGA328/P for Atmel. While evaluating them through the most important aspects through our design, the seemingly best choice is the PIC16F18877 as it displays a variety of optimized features that allows the user for plenty of room for configuration. But while evaluating the constraints and needs of the project design, most of those features will remain unused and will therefore be wasted technology, making the choice a less efficient one. Hence, overseeing this microcontroller as a possible choice.

The other two microcontrollers do not display great dissimilarities between each other, but under further consideration, the ATMEGA328/P is a much better choice. When comparing prices, there is a much lower price to be paid for greater featured offered, this goes towards a higher memory capacity, GPIO pins, frequency and less power consumption. Though the ATMEGA328/P has a slightly less efficient ACD peripheral, the benefits outweigh the setback. Another important feature is the maximum voltage that can be applied to the pins, which varies significantly and makes it easier to downsize on resistance needed to regulate any incoming electrical signal.

The most important factor in choosing the ATMEGA328/P microcontroller is the popularity it carries through the market, which can provide the programmer with plenty of information towards any implementation, configuration and troubleshooting that can happen at any given moment, ideal for beginner to intermediate programmers. This makes the ATMEGA328/P microcontroller the ideal choice.

4.3.6 LCD Display

For this project, an LCD display will need to be interfaced with the microcontroller to display the power generated by the piezoelectric sensors in the platform, as well as displaying the total power stored in the battery bank.

4.3.6.1 Overview

A liquid-crystal display is an electrically generated image shown on a flat panel display using light-modulating properties of liquid crystals. With the use of backlights or reflectors, images can be produced onto the screen in either color or grayscale. Depending on the type of display, arbitrary or fixed images can be displayed which will affect the needed resolution. When considering LCD displays, one considers the desired implementation as well as compatibility with the microcontroller and a reasonable price. Apart from these specifications, one must also interface the LCD with the microcontroller to successfully control it and configure it to the necessary application.

4.3.6.2 LCD Module Types

When selecting an LCD one must determine what the product does, what the output will be and how it needs to be done, along with any preferences or specifications that need to be met. There are several different types of LCD displays that can be implemented, which vary on the application and personal preference. Most of today's LDC displays are what are called active matrix LCDs that display high resolution, defined colors and some at a low power. The main scope of the product is to display simple values and power status, so high resolution is not necessary. For this project a comparison is done between graphic and character LCD modules to determine what's best for our design.

4.3.6.3 Graphic vs Character LCD

The section compares the differences between graphic and character LCD displays. Based on these differences and variations, the group will be choosing the one that best fits the idea of the Energy Harvesting Platform.

4.3.6.3.1 Size Variations

Sizing is a variable requirement which depends both on the type of data, the amount of data and the designer's preferences on how it is displayed. There is a variety of different sizes for both graphic and character LCD modules. Graphic modules have one large grid of pixels and vary in resolution and physical size. Different resolutions render changes in image sharpness and content displayed. This provides for the option to customize the displayed data and any images when necessary. For character modules, the sizing is controlled by the amount of characters needed to be displayed per column and row. This LCD is a more robust way of displaying data and focuses on the content rather than the visual display. Consequently, the bigger the physical size of the LCD, the more characters that can be displayed at once. If any information does not fit, one must configure such display to scroll the data, is permissible by the program. Given graphical LCDs tend to be gigger in size, some project with space constraints may benefit from character LCDs and will not have to compromise their budget in the process.

4.3.6.3.2 Text Displaying

Most character LCDs have a fixed font type and a character generator, preprogrammed font tables that displays up to 224 different symbols and characters. Graphic LCDs use dot matrix patterns to display both text and simple bitmap images. Some graphic LCDs include controllers with their own internal font while others require sending a bitmap to the display.

4.3.6.3.3 Interface

To successfully link an LCD with a microcontroller, modules come with a controller that sets interfaces tailored to specific processors. One of the most useful interfaces for microcontroller connection is a serial interface which can be done by Serial Peripheral Interface (SPI), the Inter-Integrated Circuit (I2C), or synchronous serial interface. The serial interface uses one data bit to write to the display Another Interface consists of the parallel interface, which uses multiple data pins and control lines to send signals to control registers to read/write and display data. Although both are frequently used, the serial interface provides for a slower connection than the parallel interface. A few other interfaces are available that utilize communication protocols and USB. In both LCD types these interfaces are available.

4.3.6.3.4 Other Deciding Specifications

Some important features to consider when deciding on LCD types. These are pricing and ease of integration. Pricing is a key feature as it varies greatly on the size and resolution, the type of LCD, the interface and the added features such as lighting and colors. Ease of integration is another key feature as it provides the programmer for an easier integration time. In these cases, the character LCD provides for a more cost-effective device, where added features can be obtained while still staying within budget. Given we have a short budget and little experience with LCD interface and configuration, using a character LCD will be more beneficial towards the project.

4.3.7 Options for Character LCDs

Given the project will implement a character LCD, there are difference choices form which to choose from ranging from size to backlit screens that provide for better reading. For the project design, a substantial amount of data will need to be displayed. For this there are several options to choose from. In terms of size most modules range from 8x1 character displays to 40x4. There are a range of different manufactures that provide these modules at different cost per specifications. For the project, larger LCD modules will be observed and compared. Apart from costs and sizing, extra features should also be compared to arrive at the best option.

4.3.8 Comparing Character LCDs

This section provides a comparison on the many features provided on a character LCD module. Several different specification comparisons are provided, but a selection will be done mainly based on size, price and interface type.

4.3.8.1 Size Comparison

Size will be dependent on the amount of data needed to display and cost constraints. An ideal amount of characters to display per coulomb is 4, which gives a good amount of data to display vertically. This also gives a better view of what's displayed without the feeling of clumped up information. When choosing the amount of characters to be displayed horizontally, the most displayed characters at once would be ideal but that requires incurring a higher cost for the device. Different horizontal lengths can be analyzed and compared by observing modules and their basic costs to determine the optimal choice. If a smaller size is what is the best option, then built-in features need to be configured in, added so that the data can either be scrolled, prompted to display individually by pressing designated buttons or intermittently displayed using timers that change the data displayed every certain time.

As expected, with bigger size comes higher prices which makes programming configurations that much more important. There are some bigger sizes offered by a few companies of 40x8 and 104x4, but these inquire costs between $100 - $200 per unit, which is too high of a price. After observing the different sizes and prices offered, a 20x4 character count seems to be a good choice and a good compromise in both size and price. And as seen in the market, different prices are offered between providers/manufacturers that give spending options depending on the willingness to spend on extra features.

4.3.8.2 Interface Comparison

Given an initial comparison has been done towards the serial and parallel interfaces, a quick mention will be said towards deciding the specific interface to connect the selected ATmega328p microcontroller. Here the choice will be geared towards parallel interfacing as it provides quicker data transfer, ideal for real time status. This interface is also the standard for character controllers.

4.3.8.3 Module Backlighting and Viewing Modes

This project implements a design that will mostly be implemented outdoors, but can also be used indoors. Given there is fluctuating ambient light, Transflective viewing mode is the most suited as it employs both Reflective and Transmissive types that use ambient light to illuminate the display when ambient light is present, and the use of internal backlight when indoors. For the backlight, a white LCD lit screen is preferred to avoid any issues when color viewing and keep a neutrality in the design.

4.3.9 Selected LCD Module

Before arriving to a selection, an overview of several offered modules are seen in Table 8, showing the difference in features and how the character count affects the pricing. Since the preferred interface will be the parallel, all viewed LCDs will be interfaced in this manner.

What is heavily taken to account when making a decision is the character count which determines what can be displayed simultaneously and pricing, of which variates heavily depending on the manufacturer and the module size. These two aspects works against each other set limitations for choosing a product.

After evaluating the many options available in the market, a Transflective 4x20 character LCD will be chosen for the design, as shown in the table below. This provides for a comfortable space to view the displayed data, which with a little configuration can be adapted to display subsequent data by command. With a white transflective LED backlit screen the display can be seen easily and clearly, as well as still providing visibility for when located outdoors. By choosing the aforementioned size, costs will be lower while still providing a decent number of features. And with a thorough search and comparison of offered price, the best choice can be achieved.

Character Count	Cost (USD)	Cost Average (USD)	Interface	Colors	Polarizer
16x4	$9.82	$14.20	4-bit/8-bit Parallel	Yellow-Green	Transflective
16x4	$10.87		4-bit/8-bit Parallel	Negative Blue	Transmissive
16x4	$18.00		4-bit/8-bit Parallel	Yellow-Green	Transflective
16x4	$18.10		4-bit/8-bit Parallel	Yellow-Green	Transflective
20x4	$19.10	$16.42	4-bit/8-bit Parallel	Gray	Transflective
20x4	$13.84		4-bit/8-bit Parallel	White	Transflective
20x4	$18.75		4-bit/8-bit Parallel	Gray	Transflective
20x4	$13.98		4-bit/8-bit Parallel	Black on Gray	Transflective
40x4	$25.20	$22.81	4-bit/8-bit Parallel	Black on gray	Transflective
40x4	$22.50		4-bit/8-bit Parallel	No Backlight	Reflective
40x4	$23.04		4-bit/8-bit Parallel	Black on Gray	Transflective

40x4	$20.50		4-bit/8-bit Parallel	No Backlight	Reflective

Table 4. Cost Comparison

4.3.10 Piezoelectric Sensor

One of the biggest design considerations for this project is the piezoelectric transducer. This component will be the main power supply for the hardware and circuitry in the tile, so it is necessary that the conversion between mechanical energy and electrical energy is as effective and efficient as we can make it. In addition to researching preexisting piezoelectric transducers, we will also look at researching the components that make up the transducer and designing our own. Here are a few companies that sell piezoelectric components.

4.3.10.1 APC International, Ltd.

American Piezo has a variety of piezoelectric ceramic crystals, ranging in sizes, shapes and sensitivities. Looking at their disc selection, they offer options with diameters ranging from .25” (6.35mm) to 2” (50.8mm) and thicknesses ranging from .008” (.2mm) to .4”(10mm). This company also has an interactive calculator on their website that can calculate the frequency constant, capacitance, static voltage, etc., depending the size and material of the chosen piezoelectric disc. In addition, they also have prices listed on their website and advertises fast delivery options for their products.

4.3.10.2 TRS Technologies

TRS Technologies also offers piezoelectric materials in a wide variety of sizes and shapes. Their products include single crystal PMN-PT piezelectrics, high sensitivity soft PZT piezoelectrics, high powder hard PZT piezoeletrics and a few more. Their disc diameter ranges from 5mm to 30mm and the thickness can range from .1 to 12 mm. This company does provide a table of material specification, however prices are not listed and asks the customer to contact them for a quote. An advantage for this company is that they offer to work with customers to design and develop components to match the tolerances and requirements of the customer’s application. They also advertise quick delivery times on their website.

4.3.10.3 Omega Piezo

Omega Piezo is another company that specializes in piezoelectric products. Much like TRS Technologies, they do not have their prices listed, and they offer custom device development. They do list some properties of crystals on their website, but encourages the customer to contact them for quotes and delivery information.

4.3.10.4 C. B. Gitty

C. B. Gitty is a company that sells cigar box guitars, parts and accessories. One of the accessories they sell is piezo discs which are used for guitar pickups. They offer packages that come with 3, 6, 12, 25 and even 100 piezo discs and they are very cost friendly. You can purchase a pack of 12 piezo discs for the same price as one or two efficient ones and we'll be able to generate more power.

4.3.10.5 Murata

Murata is another manufacturing company that produces high quality piezoelectric transducers. The 7BB Series, which is the piezoelectric disc with lead wires attached to it, was another candidate for the project design. After purchasing a sample of the product, we concluded that the high quality piezoelectric transducers from Murata would be our selection since their prices are reasonable and the quality withholds as advertised by the manufacturing company after several stress tests, which it passed, compared to other products like the ones sold by C.B. Gitty which cracked when applied with the same pressure as the ones by Murata. The only downside to the piezo discs by Murata are the weak solder points, but those can be fixed with a little extra soldering. Overlooking that minor flaw, Murata's 7BB Series piezoelectric transducers are going to be placed in the final project design.

4.3.11 Designing a Piezoelectric Sensor

This section describes different ways to design a piezoelectric sensor. The piezoelectric crystals could be self-produced or bought at certain stores. The advantages and disadvantages

4.3.11.1 Crystals/Rochelle Salt

The main advantage for using this type of crystal is the ability to produce it ourselves. Using baking soda, cream of tartar (potassium bitartrate) and water, we are able to grow our own crystals. We wouldn't have to worry about long delivery times, or the possibility of crystals being out of stock. If we ever need any more piezoelectric crystals, we have the ability to make more. However, the disadvantages are that we would need to experimentally discover the design specifications regarding maximum pressure it can withstand, the voltage difference it can create/how much energy it can produce, etc. Another downside is that it is comparable in cost to existing crystals. The main reason to discard this idea is because we cannot make ideally sized and processed crystals in comparison to company made crystals. After following the instructions, this is the product that will create the crystals:

Figure 16. Rochelle Salt After One Day

4.3.11.2 Quartz

Quartz has also been known to have piezoelectric properties for a long time. Quartz can be found in many applications today, one example being a quartz clock/watch, where the reverse-piezoelectric effect uses electrical energy from the battery to regulate a crystal oscillator in order to maintain accurate time.

4.3.11.3 PZT (Lead Zirconate Titanate)

An advantage to using PZT over quartz is that “PZT can produce more voltage for the same amount of applied mechanical stress” [6] More advantages of PZT ceramics include that they are “physically strong, chemically inert and relatively inexpensive to manufacture” [7] As noted earlier, TRS Technologies has many piezoelectric components that utilize PZT which furthermore shows its desirability.

4.3.11.5 Piezoelectric Discs Selection

As far as the piezoelectric transducers go, we can go with a few piezo discs that are very efficient, or we can go with a lot of piezo discs that we can connect in series and in parallel. Ultimately, we believe having more piezo discs connected to each other will produce more power than just one small disc in each corner. Having more piezo discs will ensure that when pressure is applied to any given part of the tile, we will be able to harvest some energy from it.

It is a known fact that the greater the bending/distortion of a piezo disc, the more energy that can be harvested from it. However, the tradeoff is that this also increases the risk of breaking/cracking the disc. Even if the discs do not get to the point where they might start cracking, constantly being distorted a great amount will take a toll on the durability of the disc and the disc with face a shorter lifespan. One possible solution is having many piezo discs arranged in such a manner where each only bends a small amount but can produce the same, if not more, amount of energy than a few discs facing greater distortion.

4.3.12 Rectification

The next step in this design to implement a rectifier that will convert an AC signal to a DC signal. While the simplest rectifier (half wave) only allows the diode to conduct for part of the waveform, we want to utilize a design that can convert the negative values as well. One design consideration we have to look into is that the AC input may be unpredictable and the amplitude and frequency may vary from cycle to cycle.

4.3.12.1 Half Wave Rectifier

A half wave rectifier can be made using a diode. A diode opposes current in the opposite direction. When connected to an AC signal, a diode allows current to pass when the voltage is positive and above 0.7V and will not allow current to pass when a negative voltage is placed across the leads.

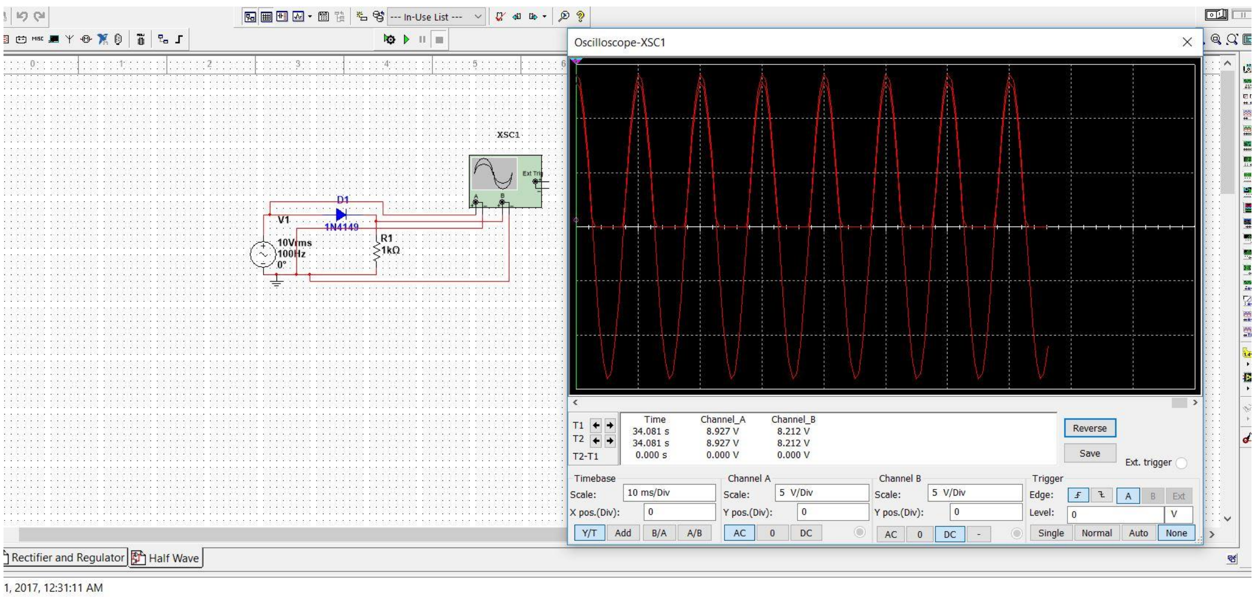

Figure 17. Half Wave Recitifier

A half wave rectifier can also include an op amp as well. One benefit is that there is not forward voltage drop and more stable against reverse bias. However, op amps do require external DC voltage supplies.

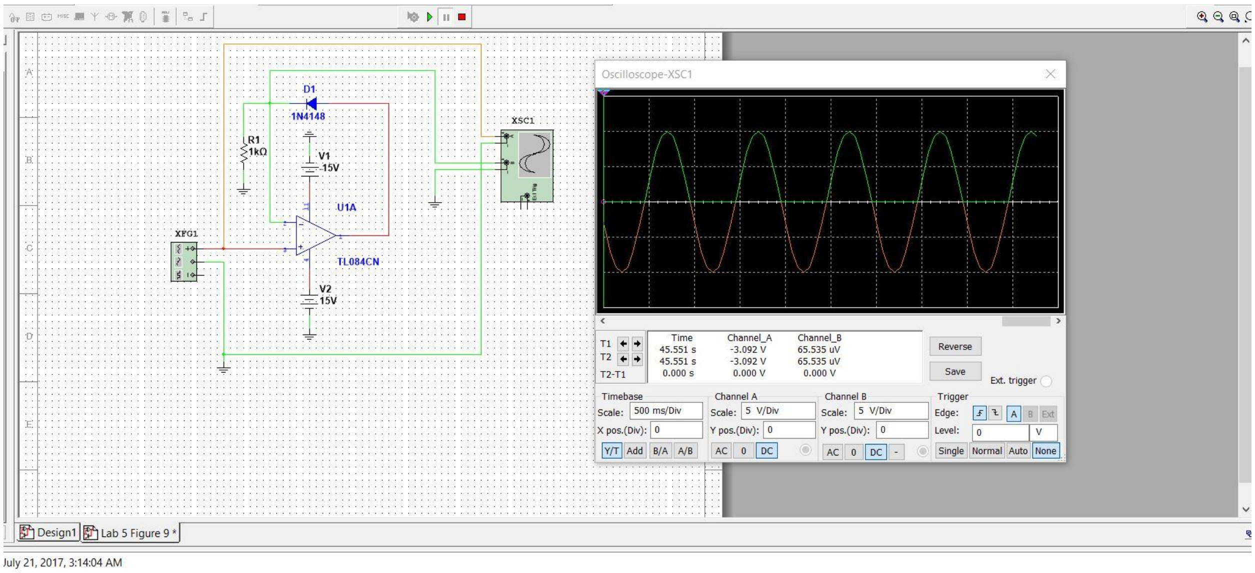

Figure 18. Half Wave Rectifier Using Op-Amp

The input voltage is denoted with the yellow sinusoidal wave while the output is shown in green. As mentioned previously, there is no voltage drop in this design and the negative AC values become a DC zero.

4.3.12.2 Full Wave Bridge Rectifier

A full wave bridge rectifier utilizes 4 diodes, each half cycle utilizing two diodes each. A capacitor will be added in parallel with the load to help smooth out the AC voltage. With the right capacitor value, our AC voltage will be smoothed out enough to mimic a DC Voltage. Another focus would be to research robust diodes that have a low cut-in voltage. We want to ensure our system is sensitive enough to detect small deflections in the piezoelectric transducer. Silicon diodes typically start conducting around .7 volts while Germanium is around .3 volts.

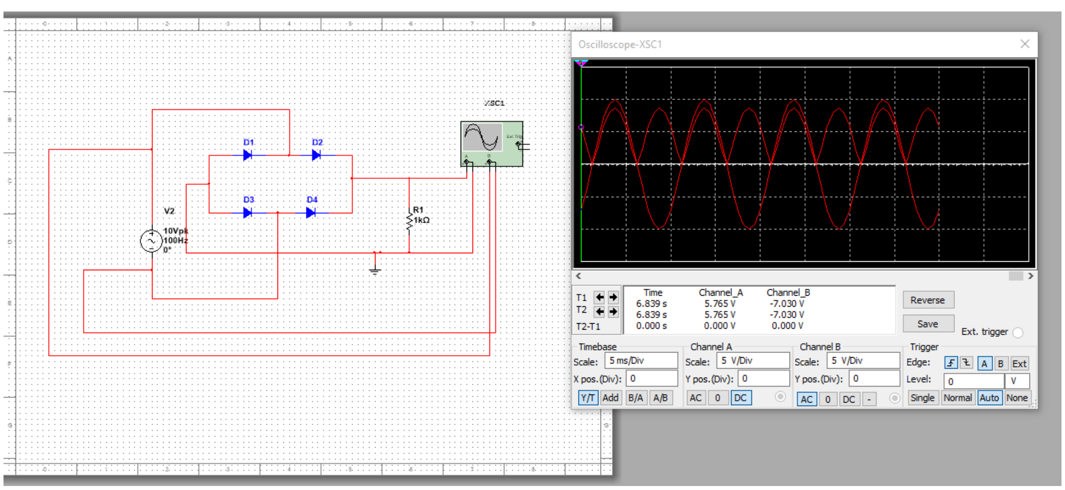

Figure 19. Full Wave Bridge Rectifier Without Capacitor

As we can see, the rectifier converts all the negative AC values into positive values. There is also decrease in gain due to the load resistor. Adding a capacitor in parallel to the resistor leads up to the following schematic.

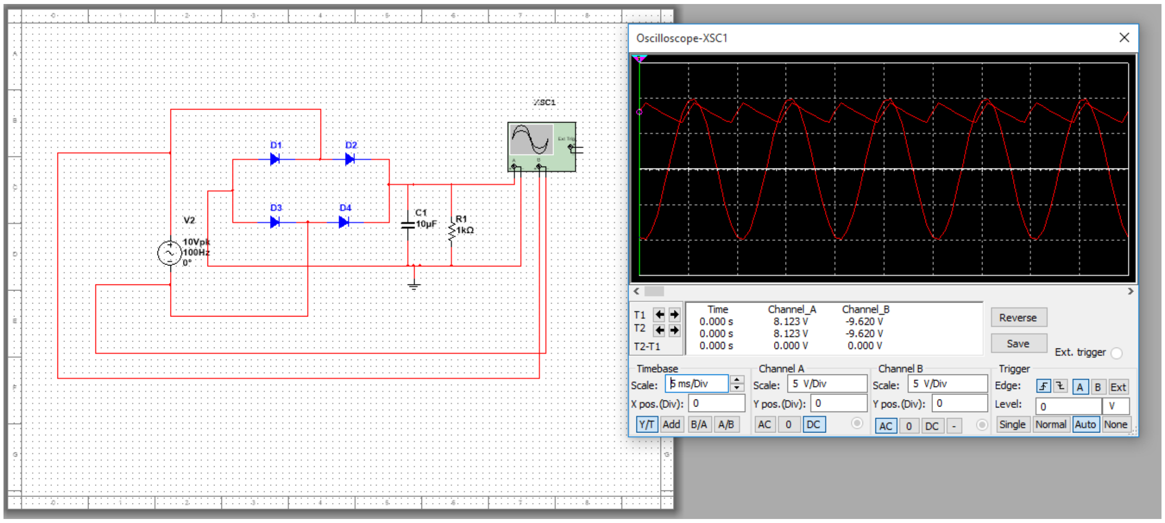

Figure 20. Full Wave Bridge Rectifier with Small Capacitor

To get a better DC approximation, we can increase the capacitor value to help smooth out the AC voltage. The following schematic demonstrates that.

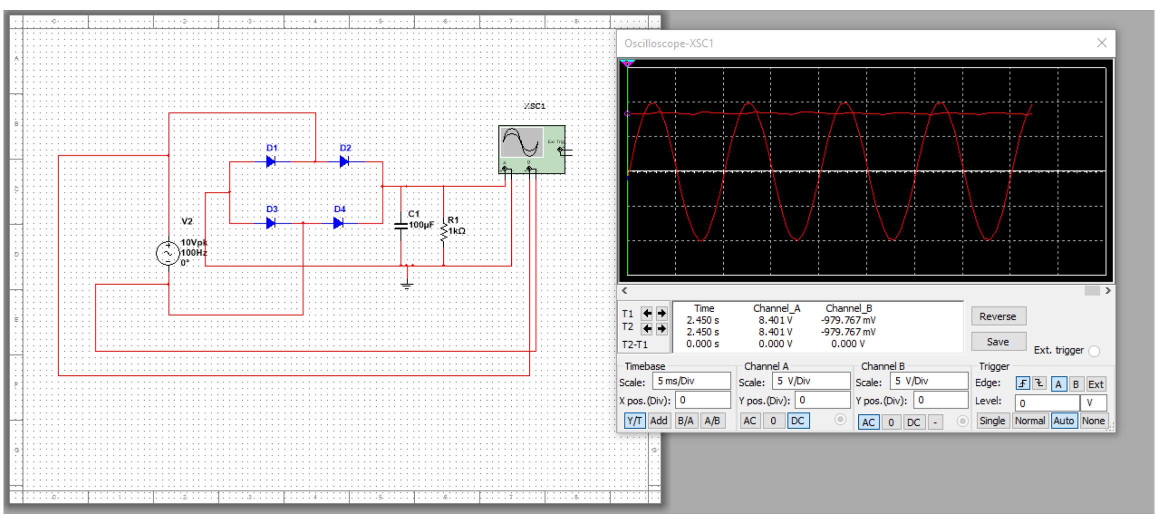

Figure 21. Full Wave Bridge Rectifier with Large Capacitor

4.3.12.3 Villard Cascade Voltage Multipler

The Villard Cascade is a circuit that utilizes two capacitors and two diodes. Using the following configuration shown in figure 19, it can take an AC voltage as input and transform into a DC voltage with twice the original input voltage

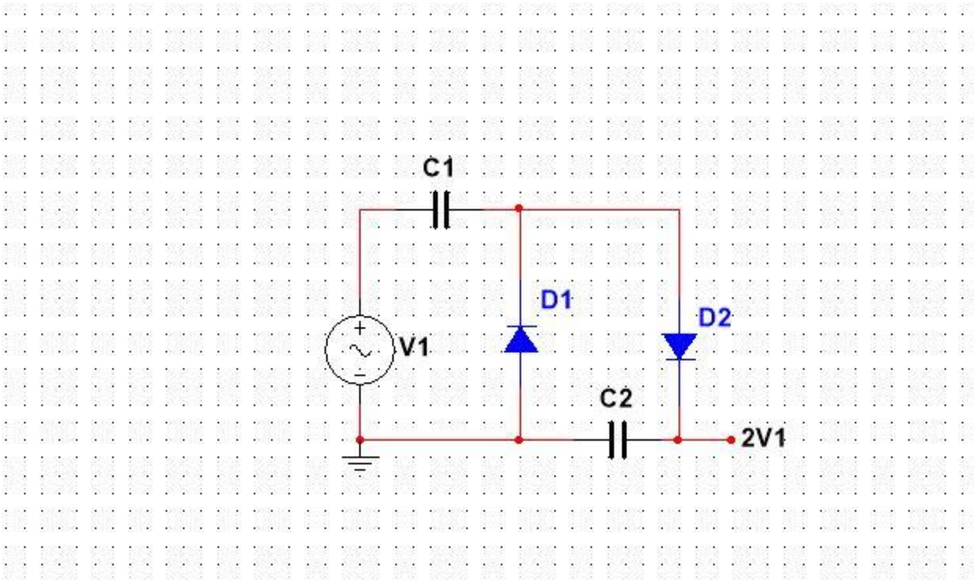

Figure 22. One Stage Villard Cascade Circuit

The advantage to using this type of multiplier is that we are able to amplify the output DC voltage by connecting more stages to the original circuit. The gain is calculated as the input voltage multiplied by two times the number of stages. For a three stage circuit shown in figure 29, we can see the gain for each stage.

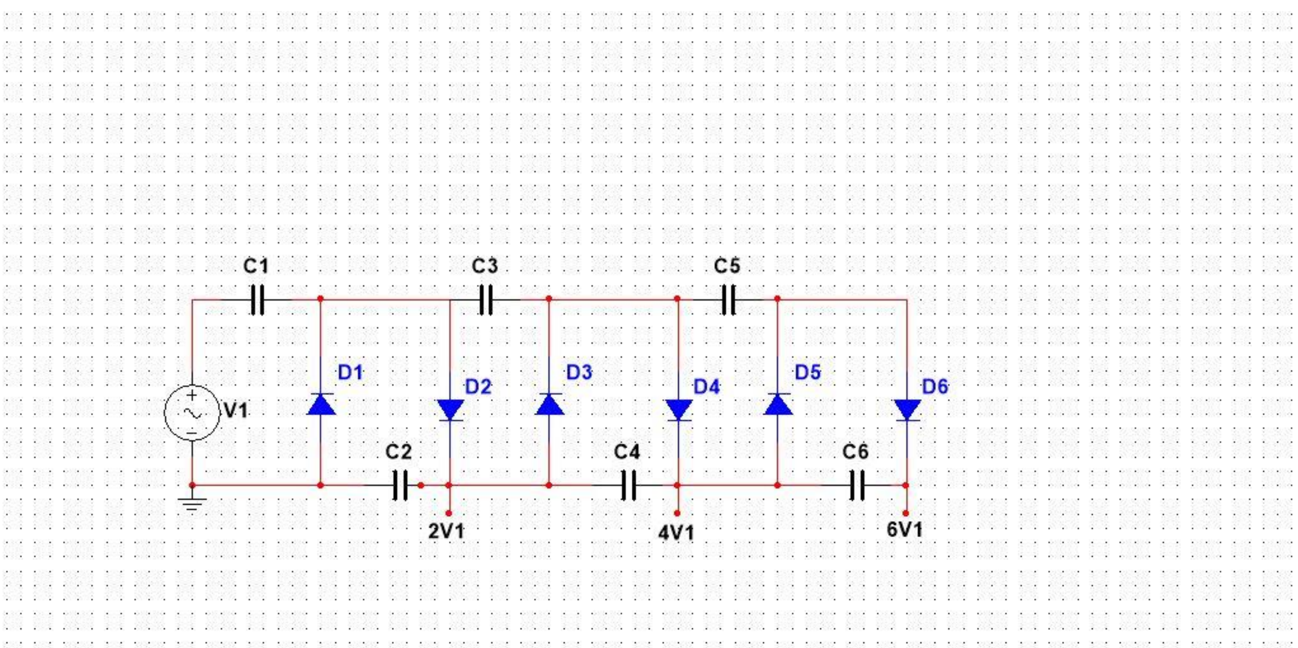

Figure 23. Three Stage Villard Cascade Circuit

The disadvantage of this topology is that there will be a voltage drop associated with each stage, and it can be calculated by the following formula:

$$\Delta V = \frac{1}{fC}\left(\frac{2}{3}n^3 + \frac{1}{2}n^2 - \frac{1}{6}n\right)$$

where f = frequency of input voltage,
C = capacitance values
n = number of stages

The frequency of the input voltage is inversely proportional to the voltage loss, and also happens to be to be a factor that can be random and unpredictable, so this tradeoff definitely needs to be taken into consideration.

Seeing how both of these rectifier configurations both involve diodes and capacitors, researching which diodes will work best for this project. While premade bridge rectifiers exists and have been looked at, creating our own rectifier using diodes that best suit our application might prove to be the best option.

4.3.12.4 Bridge Rectifiers

Some bridge rectifiers are already made so that working directly with the individual diodes is not necessary. That datasheets will provide what the forward voltage drop will be so we can calculate the output voltage based on the input voltage. These specialized components will ideally be more space efficient than setting up four diodes, a capacitor and a load resistor.

4.3.12.4.1 HD01

The HD01 is Bridge Rectifier manufactured by Diodes Incorporated that offers a low forward voltage drop of 1V. The average forward rectified current is listed as 800mA. The dimensions for this component is roughly 5mm x 6mm which happens not to be very space friendly for our PCB. This component only contains the four diodes that create the bridge rectifier and will need an external capacitor the smooth out the AC voltages to DC.

4.3.12.4.2 MB1S

The MB1S is manufactured by Fairchild and boasts a high surge current absorption. It takes up 35mm^2 and has a forward voltage drop of 1.0V and has an average rectified forward current of 500mA. The maximum input voltage this component can handle is 70V_{RMS} and features low-leakage current.

4.3.12.4.3 DF06

The DF06 is a bridge rectifier that offers a maximum RMS bridge input voltage of 420V and DC Reverse Voltage of 600V. It also has an average rectified forward current of 1.5A and a forward voltage drop of 1.1V. The reverse current is rated at 5µA.

4.3.12.4.4 LTC3558-1

The LTC3588-1 is a nanopower energy harvesting power supply by Linear Technology. This IC has a built-in rectifier as well as regulator. It outputs up 100mA burst current and has selectable output voltages of 1.8V, 2.5V, 3.3V and 3.6V. It has a 950 nA input quiescent current and can input voltage ranging from 2.7V to 20V.

Bridge Rectifiers	HD01	MB1S	DF06	LTC3588-1
Forward Voltage Drop	1V	1V	1.1V	Built-in regulator (Selectable output voltages)
Maximum Input RMS Voltage	70V		420V	
Size	5mm x 6mm	7mm x 5mm	13mm x 13mm	3mm x 3mm
Average Forward Rectified Current	800mA	500mA	1.5A	100mA
Cost	$0.46	$0.40	$0.52	$4.96

Table 5. Bridge Rectifier Comparison

The above table compares a few characteristics of premade bridge rectifiers. While most offer a low forward voltage drop, the size of these components proves to be very large and a better design might call for creating our own rectifier. To do this, we will need to research different diodes that we could use in place of the rectifier.

4.3.13 Diodes

This section describes some of the diode choices to be considered during the design of the Energy Harvesting Platform.

4.3.13.1 1N4148

Having some familiarity with the 1N4148, we will explore its characteristics and see why it’s so widely used. This diode has a maximum forward voltage of 1V and a breakdown voltage of 100V. It also has an average rectified output current of 150mA. The black cathode band indicates which pin is the negative polarity.

4.3.13.2 1N4001-1N4007

The 1N4001 through 1N4007 are general purpose plastic rectifiers, that are typically used in bridge rectifier applications. The 1N4001 has a maximum repetitive peak reverse voltage of 50V while the 1N4007 has a VRRM of 1000V. The 1N4001 only has a maximum RMS voltage of 35V while the 1N4007 can reach values up to 700V. All diodes in this series have an average forward rectified current of 1A and a maximum instantaneous forward voltage of 1.1V. The 1N4001 as well as the 1N4007 produced by ON Semiconductor sells for as low as $0.18.

4.3.13.3 MBR1060

The MBR1060 is a Schottky Barrier Rectifier. A Schottky diode has many advantages over a standard silicon diode including low turn on voltage (0.2 to 0.3V), fast recovery time and low junction capacitance. In addition, Schottky diodes offer a lower voltage drop across the terminals, ranging from 0.15 to 0.45V as opposed t0.6V to 1.7V with normal diodes. [11] It has maximum forward voltage of .95V and an average rectified forward current of 10A. It offers low power loss and high efficiency and also happens to be very cost friendly, with one costing $0.93 for one, or ten costing $0.77 each.

4.3.13.4 FSV1045V

The FSV1045V is an ultra-low VF Schottky Rectifier and offers a small forward voltage drop of only .41V. while outputting a current of 10A. That value becomes even smaller, around 0.18V, at an operating current of 1A. This component is also very low profile, boasting heights of only 1.1mm and also only sinks 18mA reverse current at high temperature.

Diode	1N4148	MBR1060	1N4007
Reverse Voltage	75V	60V	1000V
Average Forward Current	150mA	10A	1A
Peak Surge Current	2A	150A	30A
Forward Voltage	1V	0.7-0.95V	1.1V

Table 6. Diode Comparisons

4.3.13.5 Rectifier Selection

The rectifier that will be implemented will be the full wave bridge rectifier. The components needed include four diodes, a capacitor and a resistive load. Schottky diodes are going to be utilized due to their low forward voltage drop and their fast recovery characteristics. A lower voltage drop across the diode is associated with a decrease in power loss and better efficiency. Fast recovery means the diode turns off faster “when a reverse charge is imposed across the junction”. [20]

The MBR 1060 is a Schottky Barrier Rectifier will be used in our design. This diode has a low turn on voltage of only 0.2 to 0.3V and a forward voltage drop of 0.15 to 0.45V. This proves to be very useful because even with only a small amount of pressure applied to the piezoelectric transducer, we can ensure that the cut in voltage of the diodes will be met and that the rectification process will start to occur.

As seen in the simulation figures, a capacitor needs to be added to help smooth out the AC voltages into DC voltages. The larger the capacitor values are, the smoother the curve will be. The reason for this is that larger capacitors discharge slower over time, so that in between pulses, the ripple becomes less and less. However, if the capacitors become too large, the capacitor will draw too much current and/or will take too much time to fully charge. The capacitor values that will be used in our design will either be 470 microfarads or 1000 microfarads. The final value will be determined after breadboard testing and result of the simulation.

A resistive load will also be placed in parallel with the capacitor. The load dissipates some of the extra power surges that might occur due to the rectification. The load can come in the form of a resistor, an active component or even another stage in the circuit. Our design will incorporate a load resistor as well as another stage. The resistance will be experimentally determined using simulation software and the next stage in this the voltage regulators.

4.3.14 Voltage Regulators

A voltage regulator will be employed to generate a fixed output voltage. This is to ensure that the pins of the microcontroller don't get burned out. We also want to make sure that is efficient and does not consume too much power.

4.3.14.1 Linear Regulator

Linear regulators tend to be very inexpensive and are great for powering low powered devices. However, the tradeoff is that they are not very efficient, with typical efficiencies around 40% or lower. [14] Power losses come in the form of waste heat, so the higher the voltage drop between input and output are or the bigger the current load is, directly impacts how much heat may be generated. A linear voltage regulator requires a minimum input voltage to work since there is going to be a voltage drop across it. For example, an LM7805 linear voltage regulator requires at least an input of 7 volts and from there will output a maximum of 5 volts.

4.3.14.1.1 LT3086

The LT3086 is an adjustable linear regulator that acts a voltage controlled source. It takes a wide input voltage range (1.4V to 40V) and can output a constant current of up to 2.1A and a constant voltage up to 32V, which is determined by an output resistor. At 2.1A output, this device typically has a dropout voltage of around 0.33V but may reach values of about 0.55V. Since the voltage is directly proportional to the current, the value of the dropout voltage decreases as the load current decreases.

4.3.14.1.2 LM 7805

The LM7805 is the one of the most well-known voltage regulator, it has an output current of 1.5 Amperes and the output voltage will be around 5V where the input voltage may vary from 7V to 25V. The higher the input voltage, the more heat that is generated. Using the formula P=I*V, we can easily see the wasted power can range from 3W to 30W. This is very inefficient and would require a heatsink to get rid of the waste heat.

4.3.14.1.3 LM317

The LM 317 is an adjustable voltage regulator. As with any linear voltage regulator, the input voltage has to be greater than the desired output voltage due to the voltage drop across the regulator. Again, if there is a significant voltage drop, a lot of waste heat is going to be generated. However, the output voltage is function of the constant voltage output and two resistors connected between the output and adjust pins and ground. So to create a smaller voltage difference, you can increase the output voltage by changing the resistor values.

An additional note to mention is that any linear voltage regulator can be made to be adjustable. Even though some regulators explicitly mention that they are adjustable, like the LM317, it requires a particular setup that uses a resistor divider. Adding this configuration to any linear voltage regulator will allow for adjustability. [17] This has been shown in experiment 4 of the Electronics II lab here at UCF, where this additional circuitry allowed the LM7805 to be adjustable. [18]

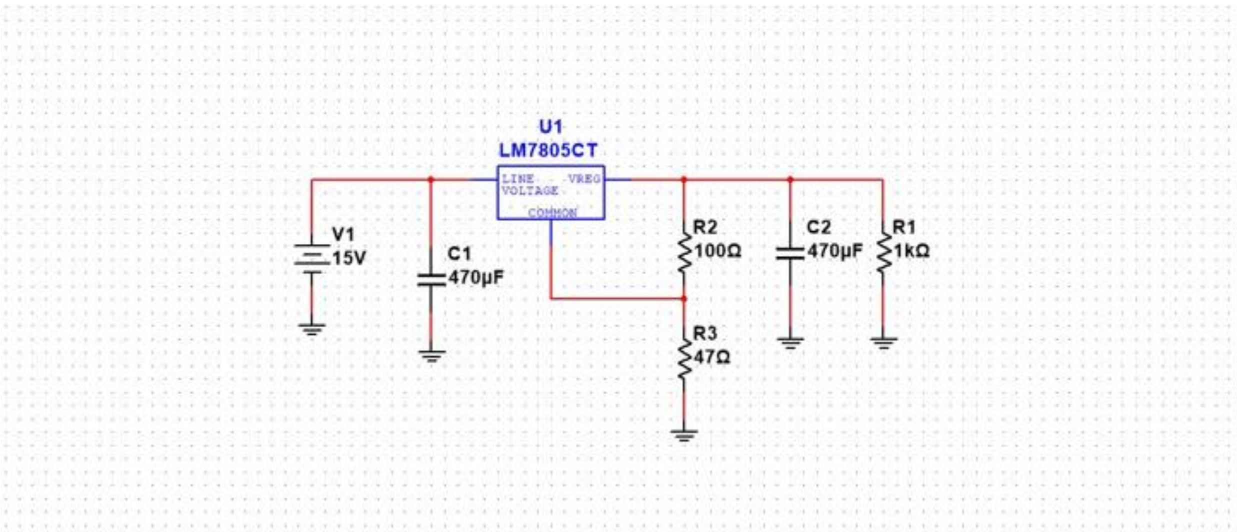

Figure 24. Making the LM7805 Adjustable

4.3.14.1.4 LT 3032

The LT 3032 is a low dropout linear regulator. It is a dual regulator which accounts for the positive and negative dropout voltage. It can take a input range from 2.3V to 20V and outputs a current of 150mA. It offers fixed output voltages; 3.3, 5, 12, and 15V. This regulator also offers low quiescent current per channel and low noise.

Regulators	LM7805	LM317	LT3032
Input Voltage	7-27V	3-40	2.3-20V
Output Voltage	5	1.25-37V	3.3V, 5V, 12V, 15V
Quiescent Current	4.2mA	N/A	30µA
Output Current	<1.5A	<1.5A	150mA

Table 7. Linear Regulator Comparisons

4.3.14.2 Switching Regulator

Switching regulators can typically have 85% efficiency and have more complex circuitry than linear regulators. Internal circuitry uses feedback from the output to maintain or obtain the desired output voltage. A few different switching regulators that exist are buck (step down), boost (step up) and buck-boost. We are going to primarily focus on buck-boost (step down/step up) switching regulators due to the fact that our input voltages will be variable and inconsistent, and at any given time, the input voltage may be higher or lower than our desired output voltage.

4.3.14.2.1 LM2576-ADJ

The LM2576 switching regulator is a step down voltage regulator that can take inputs up to 45V and depending on the model, can output 3.3V, 5V, 12V or adjustable. The adjustable version is the one that is used in the lab and by varying the load resistance, we get different output voltages. For example, we utilized a 16k resistor and varied the input voltage between 7V and 25V and received an output voltage of roughly 5V.

4.3.14.2.2 TPS63070

The TPS63070 is a buck-boost switching regulator that takes an input range from 2V to 16V and regulates that to 2.5V to 9V. It also has an output current of 2A. According to its' datasheet, this device also has a 95% efficiency and a quiescent current of 50 microamps. It is also very low cost, with prices as low as $1.15 for large quantities to $2.88 for smaller quantities on the TI website. However, it is large component with dimensions being 2.5mm by 3mm.

4.3.14.2.3 LTC3119

The LTC3119 is a switching regulator offered by the company Linear Technology. It's input voltage can vary from 2.5 to 18V and the output voltage from .8V to 18V. After it is started up, "operation is possible with input voltages as low as 250mV." [22] This will prove very advantageous for our project because this has implications we will still be able charge a battery even after the pressure applied to the piezoelectric transducer has stopped. The downside is that this component is very large (4mm by 5mm) and would take up almost a quarter of our PCB.

4.3.14.2.4 AnyVolt Micro

The AnyVolt Micro is a step-up/step-down switching DC to DC converter manufactured by DimensionEngineering. It can take inputs ranging from 2.6V to 14V and can output voltage in that same range. The maximum output current is 500mA, and that value decreases for any output voltage larger than the input voltage. The output voltage is set by a potentiometer and can be adjusted by rotating the screw on the side on the component. This component is very costly and sells for $19.99 on their website.

Regulators	LM2576	TPS63070	LTC3119	LTC3115-1
Input Voltage Range	7-45V	2-16V	2.5-18V	2.7-40V
Output Voltage Range	3.3, 5, 12, or ADJ	2.5-9V	0.8-18V	2.7-40V
Quiescent Current	5mA	50µA	35µA	30µA
Output Current	3A	3.6A	5A	2A
Feedback Voltage	1.23V	800mV	795mV	1V

Table 8. Switching Regulator Comparisons

4.3.14.3 Voltage Regulator Selection

The voltage regulator chosen for this design is actually the same IC used for rectification in the previous stage. The LTC3588-1 has a built-in regulator with selectable voltages of 1.8V, 2.5V, 3.3V and 3.6V, with the last one being chosen for our design. The next stage involves lighting up LEDs that will be around the sides of the tile and with each DIP LED having a forward voltage drop of around 2.2V, we can ensure that the LEDs will light up once the circuit is turned on from the piezoelectric discs.

4.3.15 LED

LEDs constitute a crucial part of many designs as it provides for visual representations of events, lighting needed for pathways, forms of advertisements which catch the eye from far away, or a means to provide better readability to a display. There are many different LED lightings in the market which suit different implementations. To provide an aesthetical appeal to the design of this project, and widen the possible market for the product towards places such as night clubs, LEDs are added to the platform as an extra feature.

4.3.15.1 What is an LED

An LED is a light-emitting diode, a semiconductor light source typically with two leads. The semiconductor is composed of a p-n junction diode emitting light when activated. This permits current to flow in one direction.

4.3.15.2 Types of LEDs

There are many different types of LEDs ranging from shapes, sizes, colors and efficiency. There are three different categories that LEDS fall into. These are miniature, high power and application-specific. Depending on the application the appropriate one is selected.

4.3.15.3 Miniature

The most common type of LED is the miniature as it is features in many hand-held devices such as cellphones, calculators and others. It is also most commonly seen in many microcontrollers as built-in LED light that serve for notifications, confirmation of successful code or for visual purposes. These LEDs come in a variety of output currents and are great for smaller applications.

4.3.15.4 High Power

These LEDs provide for higher amounts of light emitted per second, reaching over several thousand lumen. Unfortunately, these are prone to overheating due to their great power consumption, and if not properly heat sinked, it can pose a dangerous implementation. These are often found in mechanical and industrial devices where larger powerful applications are needed. The high power makes it ideal for such jobs as it provides for higher performance.

4.3.15.5 Application-Specific

These LEDs are dedicated designs to fit the applications purpose. Generally, these are seen in signs used for advertisement as well as other applications. Bicolor LED light which use three leads and emitting dies to cast the different colors per the lit die. The tricolor also uses three leads and two dies, but the combination of anode and cathodes allow for more than one die to be lit simultaneously producing three colors. The RGB LEDs use red, green and blue light emitters which allow for a combination of colors and brightness modulation that result in precise color combinations. Other LEDs such as alphanumeric and LED bulbs are also used and prevalent in the market.

4.3.15.6 Single DIP LEDs vs Integral LED Strips

Dual package technology is very widely known as it is one of the older, but prevalent designs. This type of LED is frequently used in many signs and displays commonly seen. This LED woks with two leads, one a cathode and anode. In most cases, the simpler designs only display a single color, though further designs of this technology offer the bicolor and tricolor that provide more variety, as previously mentioned.

The LED strip is a RGB LED in the majority of the cases. This device works differently as there are three colors to work with. Each color has its own lead wire, which if interfaces with the board and n-channel MOSFETs can be modulated to exhibit different colors. Given the design constraints, a LED strip proves to be more convenient as it provides connected LED lights, a flexible mount that can be attached to any surface and the color variety that adds higher appeal to the design. The DIP LEDs will need individual connections and the product casing will need to allocate space for the lights as well as the many wires that will go with it. For this reason, a LED strip served as the optimal choice.

4.3.15.7 Types of LED Strips

A variety of LED strips are offered depending on the application and the constraints for the project. DC flex strips run on 12 V_{DC}, come coated with a silicone covering which provides for waterproof applications and are easily installed with 3M adhesive. The AC LED flex strips run directly form an outlet, and provide the waterproof casing and 3M adhesive. This LED is not considered as our circuits will process DC voltage. LED rope lights are omni-directional LEDs encased in the standard rope light packaging. The last to view is high power LED strips come mounted to rigid strips with on board drivers and circuitry. These last two showcase designs that are neither flexible nor seamless and takes out from the presentation of the product hence will not be observed.

4.3.15.8 LED Drivers

LED drivers consist of the constant-voltage driver and the constant-current driver. These are important as they regulate the power that goes into your LED and convert the system voltage form AC to DC. These drives deliver constant voltage and current, which may be required for some strips that would overload otherwise and burnout. Constant-voltage drivers provide a fixed voltage of either 12 or 24 V. Constant-current drivers provide a constant current that is not affected by the changes in voltage. These are useful to prevent burnouts, provide a constant brightness, control, flexibility and better performance. Although some companies provide resistor limiters to protect and enhance the LED's performance, drivers are still a good option for controlling the operating parameters of the LEDs.

4.3.15.9 LED Lengths, Brightness and Colors

Although these specifications are not as important towards the selection, there is also a broad selection. Ideally a choice is made not with much focus on the length of strip, but at the quantity of LEDs in the strip. Especially since the design requires a smaller strip to be implemented. A decent amount of lumens around the range of 200 is sufficient enough to provide for enough brightness. And since the LED strip will just power on and off, there is no specific preference on color.

4.3.15.10 Further Choice Considerations

Many LED strips are rated for 12 V and require a constant-voltage driver to maintain the designated voltage, something to consider when using array LED's. When modifications are made, most strips have designated areas onto where they can be cut without damaging the internal circuit. Depending on the physical casing, measures need to be taken to conceal any visible wiring, excess strip or driver to keep the design clean and seamless. On and off switching will also affect how the LEDs are placed and designed. This will be talked about in further sections as there are desired performances under given circumstance.

4.3.15.11 LED Choice

After evaluating the available relevant LEDs offered, the project design needs to incorporate LEDs that are low power but are bright enough to be viewed in light or dark conditions. Single Dual In-Line Package (DIP) LEDs are used for this design and each side of the tile will contain 4 to 5 LEDs. These LEDs will all be placed in parallel, so when the voltage regulator from the previous stage outputs 3.6V, all of the LEDs will be able to flash.

LED String Type	Operating Voltage (V)	LED Count per meter	Light Color	Additional Features
Segmented Flexible LED Circuit	24	60	White	Waterproof, flexible, constant current
Flexible LED Circuit	12	12	White	Flexible, wide PCB,
Waterproof Flexible LED Circuit	12	60	Varied	Customizable, flexible, waterproof
Current Control LED Strip Light	24	60	RGB	Easy install, Cuttable segments
Full Color Flexible LED Circuit	12	48	RGB	DMX 512 compatible, flexible
Driverless RGB LED Strip Light	12 V	300	Blue	Driverless, cuttable segments, customizable

Table 9. LED Comparison

4.3.16 Solar

The secondary power source comes a solar panel that will be underneath the platform. The platform will have a transparent casing that will allow sunlight to pass through and will displace electrons with photons and ultimately generate current. The power generated from the photovoltaic cells might have to go through a voltage regulator depending on the voltage rating of the solar panel, and from there will charge our battery. The biggest constraint we face is size, we would like a solar panel small enough to fit inside our 12”x12” tile.

Figure 25. Solar Panels (Courtesy of Inhabit Internet Brands Inc)

4.3.16.1 ACOPOWER 10W Monocrystalline Solar Panel

ACOPower offers a solar panel whose size is 11.5” by 11.7” that can output 10W at a maximum. It offers a peak voltage of 12V and a peak current of 830mA as its name suggests. The price is $29.95 and offers enough power for all the hardware components.

4.3.16.2 5W 12V Framed Solar Panel

This solar panel is offered from the same manufacturer as the previous one. It offers a maximum power of 5 Watts, where the voltage at maximum power is 17V and the current at maximum power is 290mA. The dimensions of this panel is 11.63” x 10” x 0.67”. This product is offered at $39.95 on their website.

4.3.16.3 2 Watt Solar Panel

This solar panel is manufactured by Voltaic Systems has peak voltage of 6V, peak current at 378mA which puts the peak power at 2.27W. The dimensions are 135mm x 112mm (5.3in x 4.4in), which means we can fit two of these in one tile. The cost for the unit is $29.

4.3.16.4 SLP003-12

This solar panel is manufactured by Solarland USA and has an output power of 3W. It's max output voltage is 17V while its maximum current is 180mA. The size of this panel is 7.4" x 7.68" x 0.67" and sells for $16.53. While having a maximum output current is a consideration in our design, 180mA might not be enough to charge a battery in a time efficient manner.

4.3.16.5 Nuzumas 3W 12V 250mA Mini Solar Panel Module

This solar panel can produce 3W of power and has square dimensions. It measures 145mm x 145mm (5.71" x 5.71") and is sold on Amazon for $12.99. It is made from a polycrystalline structure, which is not as efficient as monocrystalline but it's a good price for its specifications.

4.3.16.6 Solar Cells and Manufacturing Technology

There are several different solar cells that are made up of various types of materials that make them efficient in one way or another. The types of solar cells available vary in cost, efficiency of absorbing solar radiation, energy efficiency, and the semiconductor structure of the panel. Many of the photovoltaic panels that are used in modern designs consist of a silicon base, but they are also able to consist of non-silicon semiconductor material. The current research and development of solar cells has led to a secondary device technology called thin films.

Most of the research and tests still rely on silicon photovoltaic solar cells, but evidently, there is an increase in focus on thin film photovoltaic solar cells and they will overcome silicon photovoltaic solar cells in performance and production in the near future. Both types of photovoltaic solar cells are able to be categorized as split mono-crystalline or polycrystalline subcategories. The main focused material in mono-crystalline thin film solar panels is gallium arsenide (GaAs). The main focused materials in polycrystalline thin film solar panels are copper indium gallium selenide (CIGS), cadmium telluride (CdTe), and amorphous silicon (A-Si). These materials will be described more in-depth to help determine which type of photovoltaic solar cell would best be suited for the type of project design[40].

4.3.16.6.1 Mono-crystalline Silicon

Mono-crystalline silicon solar panels, or single-crystalline silicon solar cells, are widely used in the solar panel manufacturing industry. They are one of the few most reliable and dependable materials currently used in solar panel design. Mono-crystalline silicon panels are made from a mono-crystalline silicon seed that is dipped into a melted mass of high-purity poly-crystalline. The mono-crystalline seed is slowly pulled to form a single-crystal ingot. The ingots then get cut into very small wafers. These types of silicon wafers are used for semiconductor device fabrication. These technique is called the Czochralski process[40].

Mono-crystalline silicon is very dependable since its structure is uniform molecular which makes it obtain an efficiency of 15-18%, which exceeds the energy conversion efficiency of the other types of photovoltaic cells. Maintaining high efficiency shows that the mono-crystalline will obtain a high amount of watts of power per square foot which is the objective. Coincidently, this kind of photovoltaic cell is one of the more expensive types because of its high pure silicon content and its almost perfect chemical structure. These kinds of photovoltaic solar cells are challenging to install because of their fragile state. Mono-crystalline solar panels have proven to have the longest life span based on the fact that they have been in use for the longest time. Although that may be true, the rise of new solar technology associated with materials has forced the price of mono-crystalline solar panels to be reduced because of the new competition of more efficient types of material[36].

4.3.16.6.2 Poly-crystalline Silicon

Poly-crystalline silicon panels consist of silicon that is not in its pure form. The poly-crystalline solar cells are manufactured in two different ways. They are either sliced from poly-crystalline silicon blocks or produced from a method called ribbon growth. To form the poly-crystalline blocks, an ingot casting process initiates and then the raw material is heated under a vacuum. The silicon blocks are sawed into bars and then into the poly-crystalline wafers that are used in the photovoltaic solar panels. The ribbon growth method doesn't require the bars making it cheaper to manufacture since it eliminates an extra step in the process. The silicon material is grown as thin sheets with the thickness required for making photovoltaic solar cells[36].

Compared to the mono-crystalline photovoltaic solar panels, poly-crystalline tends to be a lot stronger and their size can be reduce into one-third less of the mono-crystalline material. The price per watt of the poly-crystalline material tends to be less, compared to other photovoltaic solar cells, but is also less efficient because the silicon isn't pure. The efficiency of the poly-crystalline photovoltaic cell is about 13-16% which turns out to be somewhat lower than the mono-crystalline material. Poly-crystalline photovoltaic solar panels have shown to be the lowest priced solar panel currently available in the solar panel market. This is a viable candidate for our project since it is cost effective, although we would have to compensate for the reduced efficiency[36].

4.3.16.6.3 Amorphous Silicon (a-Si) Thin Film

Amorphous Silicon solar cells, (a-Si) is one of the most recent forms of solar energy technology. From the beginning of the 90's, it has become very popular in thin-film solar technology. Amorphous silicon is designed as slim layers that are attached to glass substrate. Amorphous silicon is able to be really thin because it has a very high solar radiation absorption rate. The material is consequently put in the middle of two thick glass panels to protect it which results in the entire component being heavy. There is also a more recent method that thin film is being produced which consists of thin laminate material instead of glass. Using the laminate allows for increased flexibility of the amorphous silicon and subsequently allows it to be easy to mount on uneven surfaces[36].

The main downside to the amorphous silicon thin film panels is that its energy efficiency is extremely low, between 5-9%, which is lower than both the crystalline silicon panels.

Since its efficiency is about half that of the crystalline silicon panels, and along with the fact that the efficiency will still reduce over time, this type of material is not a strong candidate for the project[40].

4.3.16.6.3 Copper Indium Gallium Diselenide (CIGS) Thin Film

Along with the previously mentioned solar panel material, there is the CIGS thin film solar panel, which consists of copper, indium, gallium, and selenium. Sharing a similar design to the amorphous silicon thin film, this one also is layered on a glass substrate. The reason why all these elements were put together to make one material is that when combined, they produce a high solar radiation absorption rate. This compound of elements is capable of absorbing up to 90% of the solar spectrum of light. It is unnecessary to have as much of this material for light absorption it is very light and thin in comparison to crystalline silicon panels[37].

The energy efficiency rate for the Copper Indium Gallium Diselenide thin film solar panel is the highest so far out of all the materials discussed so far at 19.9% in the National Renewable Energy Lab. Even though it has a high efficiency rate, the main problem is that producing it is only possible with more than 500 degrees Celsius to produce the film which makes it significantly dangerous to use. Hydrogen selenide is also required in the production of the film. This is a very toxic gas and contributes to the danger of the production method of this thin film. This material is not a sufficient candidate for the project since it is expensive due to the complex method and environment involved in production of the CIGS solar panel[40].

4.3.16.6.4 Cadmium Telluride CdTe Thin Film Panel

The Cadmium Telluride (CdTe) thin film is made up of elements cadmium and tellurium. This material is somewhat relative to the CIGS thin film since it has a high absorption rate of about the same 90% of solar radiation. The energy efficiency for Cadmium Telluride is 7%-12%, which is still well below the efficiency of the two silicon materials initially discussed. The photovoltaic solar cell is produced by using a method of depositing the Cadmium Sulfide (CdS) and then using a space vacuum process to also put in the Cadmium Telluride (CdTe)[37].

Due to the production method of this type of thin film, it turns out to be less expensive than the previous thin films. One of the downside of CdTe thin film solar cells is that the cell itself is that the performance is unstable. High temperature and dim light is the ideal criteria for this type of photovoltaic solar cell to excel in its performance. It is known that the material Cadmium is toxic, and therefore, is another dangerous form of production. The similar complexity of production for this thin film also doesn’t make it a good candidate for the project design[40].

4.3.16.6.5 Gallium Arsenide GaAs Thin Film Panel

The last thin film panel being discussed consists of gallium Ga and arsenic As. These two elements combined create yet another toxic production environment and therefore the cost is high. This thin film panel has an energy efficiency rate between 25%-30% which has turned out to be the highest on out of all the thin film panels previously discussed. Gallium Arsenide panels have a proper band gap and that results in the high efficiency rate. Gallium Arsenide also happens to be resistant to radiation damage which makes its durability level high compared to the other panels[38]. Unfortunately, the cost of having this type of feature is high and along with the expensive production method, this thin film panel is too expensive for the budget of this project. The most viable option for the type of solar panel material that would be cost effective and provide this project with the specifications that it needs has turned out to be Poly-crystalline silicon solar panels and that is what will be used for this project[39].

4.3.16.7 Solar Panel Selection

Our selection for solar panels resulted in the purchase of the ACOPOWER 10W Monocrystalline Solar Panel Module. For it's price and size, it can output 830mA of current while it's competitors could not provide half of that. It also comes in a square shape, which happens to be perfect for our design of a square tile.

4.3.17 Voltage Regulator – Solar

As discussed earlier in this documentation, we mentioned the advantages and disadvantages of linear and switching voltage regulators, as well as the purpose in using them. The design of the project requires a constant 5V output in order to power the microcontroller, LCD display as well as the battery and charging cable. The output of the solar panel chosen is over 14V or can be under 5V on cloudy days, so the design preference for voltage regulation should have buck and boost capabilities. Another important aspect in design consideration is having Maximum Power Point Tracking (MPPT) in our circuit to ensure the maximum energy harvesting from the solar panel.

4.3.17.1 LT3652

This is an integrated circuit with a built in MPPT. It offers a maximum charge current of 2A but can be programmed using a very small resistor. It can be configured to terminate charging when the current falls below 1/10 of the programmed maximum. It also can take input voltages ranging from 4.95V to 32V.

4.13.17.2 LTC3130-1

The LTC3130 is a buck-boost converter that can take input voltages from 2.4V to 25V and has a programmable output voltage. It also offers MPPT, however the MPPT system on this IC is programmed externally. Using a resistor divider network of either two or three resistors, if the divider voltage drops below a set voltage, the inductor current limit will be reduced to servo Vin to the programmed minimum voltage. This IC has the capability to output up to 600mA, and as mentioned earlier, the output voltage will be programmed to output 5V.

4.13.17.3 Voltage Regulator Selection – Solar

Component selection for this design proved to be very difficult. Both of these ICs were purchased and tested with our solar panel, however, when connected to the next stage (charge controller, microcontroller, LCD display), the energy quickly dissipated and none of these components worked properly. The component selected was the LTC 3115-1 as discussed earlier in the piezoelectric voltage regulator subsection. It's a standard buck-boost DC-DC converter, encompasses the voltage range of the solar panel and is able to output a constant 5V output.

4.3.18 Charge Controller

Charge controllers prevent the overcharging of batteries as well as block reverse current. Ideally, we would like current to flow from our input, whether it be from the piezoelectric discs or the solar panels, to our output, which in our case is the battery. Although some electrical components have protections against reverse current, the components in this design can only withstand reverse current on the order of milliamps before they start to get damaged. Overcharging the battery is something else that should be avoided due to the fact the internal components will heat up and get damaged. Different types of charge controllers will be discussed for the design of this project.

4.3.18.1 Shunt Charge Controller

A shunt charge controller allows current to flow into a battery until it reaches a voltage set point. The voltage set point is determined by the voltage rating of the battery at full charge. At this point where this voltage is met and the battery is fully charged, the current will then travel through a shunt transistor to prevent any more current to travel to the battery. When the battery voltage drops below its voltage set point, the current will then be allowed to travel to the battery, and the shunt transistor will be inactive again until the set point is reached again. The following figure shows how it works with photovoltaic input but can also be utilized with our piezoelectric input as well.

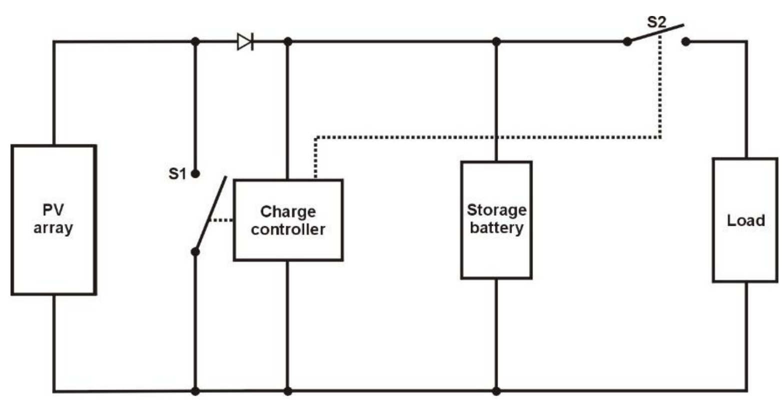

Figure 26. Shunt Charge Controller (Courtesy of HK RE Net)

4.3.18.2 Series Charge Controller

A series charge controller uses a regulation device in series with the input to control the charging of the battery. This typically utilizes a relay to open and close the circuit between the battery and the input. The series controller takes advantage of using open-circuits as opposed to short circuits as seen with shunt controllers. However, the purpose remains the same; once the battery voltage reaches a set voltage point, the controller disconnects from the battery to prevent overcharging, and when it falls below that, it reconnects the battery and allows it to charge.

4.3.18.3 PWM Charge Controller

Pulse Width Modulation charge controllers send short charging bursts or pulses to the battery instead of a steady flow of current. This allows batteries to be more fully charged with less stress on the battery. PWM controllers aim to extend and optimize battery life instead of focusing on efficient power transfer. PWM controllers also tend to be much more inexpensive than MPPT charge controllers.

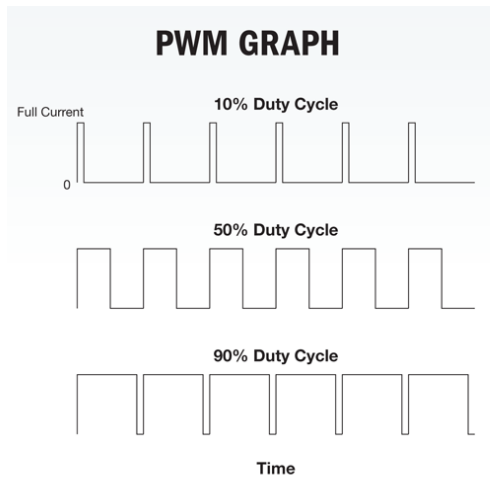

Figure 27. Pulse Width Modulation Duty Cycle (Courtesy of homepower.com)

Depending on the battery charging status, the PWM charge controller might send out short quick pulses as demonstrated by the 10% duty cycle if the battery is close to being fully charged, or longer bursts like the 90% duty cycle if the battery needs to be charged a lot. The pulses may not be cyclic as shown in the figure and the width of each pulse will be dependent on status of the battery.

4.3.18.4 Charge Controller Selection

The charge controller that we've decided to go with is the MCP73833. This device is a standalone lithium-ion/lithium polymer charge management controller and is designed specifically for the batteries offered by this company, which includes the battery that was chosen for our design. It offers 2 JST connectors to connect the battery and the input power source, as well as a mini-USB connector that will allow us to charge a phone as well. The standard output current through the mini USB connector is 500 mA but can be adjusted to 1A for faster charging. The recommended supply voltage is 6V and the output voltage is 5V.

4.3.19 Battery

The next step after converting solar energy into electrical, is charging a battery. As discussed before, a battery recharges using current, and output of PV cell happens to be DC power. Judging by the size of the solar panel that will be used (less than 12” x 12”), it's safe to say that the current output will not exceed any limitations a battery might have regarding charging rate.

4.3.19.1 Lead-Acid Batteries

One type of rechargeable battery that has been used for over 100 years is the Lead-acid battery. This battery's main use is in providing power to electronics in automotive vehicles. The method to recharging this battery is by converting mechanical energy to electrical energy. The input voltage is AC and requires a rectifier and regulator to produce the DC voltage which charges the battery. This is exactly what our project consists of, and therefore, would be a viable candidate for use in our design.

An advantage that lead-acid batteries have over the other three batteries, is that they are built with a durable design to tolerate physical impact. This is important to note since weather conditions and geologic faults of where the tile platform is placed will affect the condition of the battery over time. The cost of lead-acid batteries tend to be lower than that of Li-Ion, for example, depending on the length of use.

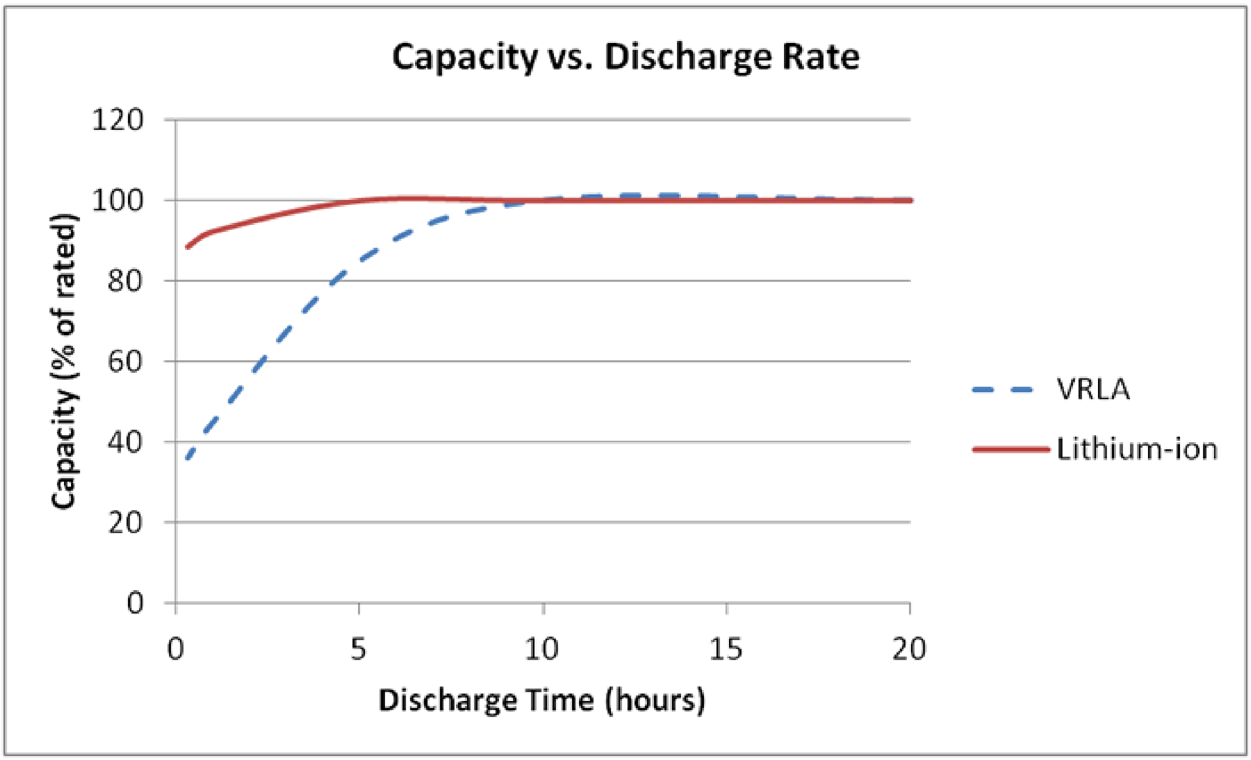

Figure 28. Capacity vs. Discharge Rate (Courtesy of Electropaedia)

Lead-acid have a downside of low cycle life and therefore, need periodic replacements compared to Li-Ion which can last a lot longer. They also are unable to use fast-charging for the last 20% of capacity and because of that, take longer to charge than other batteries. Compared to Li-Ion batteries, as shown in Figure #1, lead-acid batteries have a lower discharge time which means that Li-Ion can provide better use for discharge that occurs within 10 hours, which is more than enough for our design since we plan to use a 4400 mAh and it wouldn't take that much time to discharge.

4.3.19.2 Lithium-Ion Polymer (Li-Po)

Lithium-Ion Polymer (Li-Po) is another type of rechargeable battery that is commonly used to power modern electronic devices. The main difference between Li-Ion and Li-Po is the chemical structure where Li-Po uses a polymer electrolyte, hence the name, and Li-Ion uses common liquid electrolyte. The two batteries are very similar and therefore, there is not much to compare other than the fact that Li-Po batteries have a higher specific energy. With this advantage comes the disadvantage that it costs more and that is why Li-Ion is still the better option compared to Li-Po rechargeable batteries.

4.3.19.3 Terms and Definitions

Before discussing the batteries, a few terms will be addressed to aid in a better understanding of the information provided and explanation of the characteristics of rechargeable batteries.

- Cell - a device capable of supplying the energy that results from an internal chemical reaction to an external electric circuit.
- Battery - composed of one or more cells, either parallel or series connected to obtain a required current/voltage capability (batteries comprised of series connected cells are by far the most common).
- ESR (Equivalent Series Resistance) - the internal resistance present in any cell that limits the amount of peak current it can deliver.
- The Amp-hour capacity of a battery (or cell) - the amount of current that a battery can deliver for 1 hour before the battery voltage reaches the end-of-life point.
- "c" rate - a current that is numerically equal to the A-hr rating of the cell. Charge and discharge currents are typically expressed in fractions or multiples of the c rate.
- The MPV (mid-point voltage) - the nominal voltage of the cell, and is the voltage that is measured when the battery has discharged 50% of its total energy.
- EODV (End of Discharge Voltage) - the measured cell voltage at the end of its operating life is called the (some manufacturers refer to this as EOL or End of Life voltage).
- Gravimetric energy density - a measure of how much energy a battery contains in comparison to its weight.
- Volumetric energy density - a measure of how much energy a battery contains in comparison to its volume.
- Constant-voltage charger - a circuit that recharges a battery by sourcing only enough current to force the battery voltage to a fixed value.
- Constant-current charger - a circuit that charges a battery by sourcing a fixed current into the battery, regardless of battery voltage.

All graphs, charts, and definitions used in this section are provided by courtesy of Texas Instruments[35].

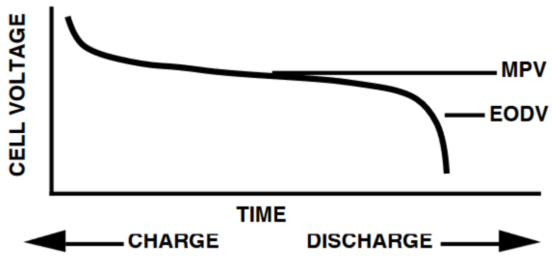

Figure 29. Battery Charge/Discharge Curve

The curve shown in Figure 11 portrays the charge and discharge of the battery cells over time. The MPV indicates the voltage level of the battery cell at 50% while the EODV indicates the voltage level of the battery cell below its operating point. An important aspect to consider when designing the MPV is to make sure that the discharge curve is as flat as possible which means that there is less voltage variation, resulting in more efficient and steady discharge. This graph will be used to compare the three batteries in terms of their charge and discharge stability [35].

4.3.19.4 Energy Density

The physical properties of a battery greatly affect the durability and efficiency of how much energy is provided to the product that requires the power since it consists of material, temperature tolerance, and resistance.

CELL TYPE	NI-MH	NI-CD	LI-ION
GRAVIMETRIC DENSITY (W-HR/KG)	55	50	90
VOLUMETRIC DENSITY (W-HR/L)	180	140	210

Table 10. Energy Density

From the information given in Table 2, Li-Ion batteries can evidently provide energy for a longer time than Ni-Cd and Ni-MH based on the physical properities and ability to be designed much lighter than the other two batteries. It can also be inferred that Li-Ion can run twice as long with the same battery weight as the others. This feature of Li-Ion would serve a very useful purpose seeing as it would not add much weight to the energy floor if it is also considered to be a portable platform that can be placed anywhere[35].

4.3.19.5 Discharge Stability

Voltage stability is a very important characterisitc of batteries to examine when considering which one fits the criteria of being efficient when discharging.

While a single Li-Ion cell has a nominal voltage of 3.6V, it is three times that of a single Ni-Cd and Ni-MH battery and therefore, it's charge capacity prevails since less cells are required for providing more voltage. Figure 12 shows that one advantage of the Nickel-based batteries is that they have a flatter curve. This concept was discussed previously and states that a flatter curve means less voltage variation and better discharge stability and effeciency[35].

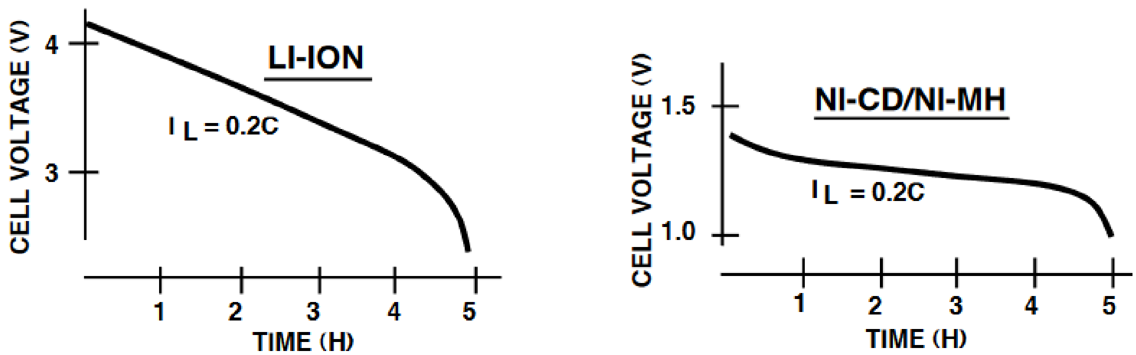

Figure 30. Discharge Curve

4.3.19.6 Current and Self-discharging

All rechargeable batteries have an Equivalent Series Resistance (ESR), and that controls the maximum current for a battery. From the basic equation, V = I x R, where V is voltage, I is current, and R is resistance, this shows that there is a voltage drop internally due to the current flowing through the ESR.

There is also power dissipation that can be shown with the equation $P = I^2 \times R$, where P is power. The Li-Ion has a higher ESR than the Nickel-based batteries and therefore, this is considered a disadvantage for the Li-Ion although it wouldn't have much of a negative effect in most uses.

Taking into consideration that the platform will be self-sustainable and left alone for long periods of time, a battery that has a low self-discharge rate will be vital to the success of the design. This will allow it to be independent from the city power grid since even if left alone without any recharging in cases, such as no foot traffic or cloudy weather, the battery will not completely discharge and render the product unusable.

The self-discharge rate of the three batteries shown in Table 3 clearly prove that a Li-Ion battery would fully support a contingency plan for the unpredictable weather and lack of foot traffic. Temperature plays an important role in having an affect on the discharge rate and therefore, even with higher temperatures, the Li-Ion battery will still last longer than the Ni-Cd and Ni-MH[35].

CELL TYPE	NI-MH	NI-CD	LI-ION
SELF-DISCHARGE @ 20°C (%/MONTH)	20-30	15-20	5-10

Table 11. Self-Discharge Rate

4.3.19.7 Recharge Time and Cost

The battery is going to be used to power everything inside the platform and thus, needs to be able to recharge in a specific amount of time to stay constant with the output power that it provides to all the components. If its output power is greater than the time it takes to recharge it, the battery would die constantly and that would not support the concept of the design being self-sustainable[35].

CELL TYPE	NI-MH	NI-CD	LI-ION
TYPICAL SLOW CHARGE TIME (HRS)	12 - 36	4 - 10	(SEE TEXT)
TYPICAL FAST CHARGE TIME (HRS)	1	0.25 - 1 (SEE TEXT)	1.5

Table 12. Recharging time

To market the product correctly and make it cost-efficient to potential buyers and investors, the price of each battery needs to be taken into consideration along with the other aspects. Even though the Li-Ion battery is more expensive than the Ni-based batteries as seen in Table 5, it still provides a higher charge capacity and slower self-discharge to maintain a feasible self-sustaining criteria.

CELL TYPE	NI-MH	NI-CD	LI-ION
AVG COST	$70	$50	$150

Table 13. Battery Cost

4.3.19.8 Li-Ion Battery Charger

Li-Ion batteries require a specific charger that monitors the input voltage and provides charge current protection so that the battery does not get damaged. Since the Li-Ion battery was selected for this project, whichever actual battery is purchased requires the battery charger specific to it since that charger would already monitor the specifics of that battery. This charger will be specifically designed to handle the transfer from the input voltage to the battery charging without any harmful effects or damage to the battery.

4.3.20 Current limiter

Another aspect that needs to be considered is a current limiter. After voltage regulation, depending on the current output of the regulator, it might need to be modified before reaching the charge controller. Batteries recharge based on current and too much current can cause internal components in the battery to heat up and get destroyed. The tradeoff becomes charging time and output current. For example, Apple's lightning cable charges at 2.1A at 5V. The battery capacity for iPhone 7 Plus is 2900mAh, which means that this phone can be fully charged in just over an hour. Theoretically, you could fully charge this phone faster, but that would involve increasing the output current of the charger and that might destroy internal components that haven't been tested to the extra heat. Depending on the output of the voltage regulator and the specifications of the battery we choose, a current limiter may or may not be needed. The following circuit is an example of a current limiter:

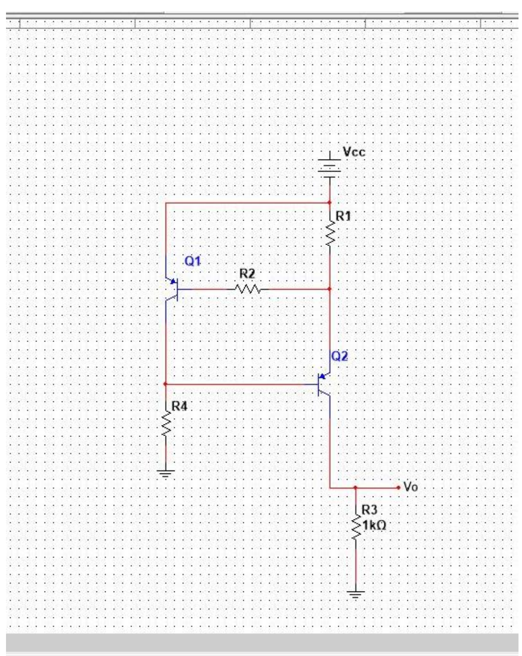

Figure 31. Current Limiter using two PNP BJT transistors

As seen in this circuit, the input voltage is a constant DC voltage. If this stage were to come after a rectification and then regulator stage, the input would indeed be a DC voltage and the current would be determined by R1 (called the sense resistor). Some switching regulators produce a constant voltage as well as a constant current, which would eliminate the need to add these extra components.

4.3.21 INA219

The INA219 us a current and shunt power monitor interfaced with the I^2C peripheral. This integrated circuit monitors shunt voltage and bus supply voltage from 0-26 V, as well as provides with current monitoring to provide power calculations. Programmable conversion times and filtering also include its variety of functions as well as providing 16 programmable addresses to implement multiple modules of the like.

This integrated circuit provides an internal A/D converter, a 10 to 12-bit, which reads analog signals created by a source and converts them into digital data. Furthermore, there are registers which allow for configuration of the A/D resolution which provide measurement accuracies within 0.5%. PGA functions are also provided for the use of larger shunt voltages where calibration is possible.

The structure of the module consists of 8 pins. The IN+ and IN- pins serve as the positive and negative differential shunt voltage analog input. The GND and Vs are the ground and power supply which is 3 to 5 V. The SCL and SDA are the serial bus clock line and the serial bus data lines that connect through the I^2C interface. Finally, the A_0 and A_1 are the address pins, which correspond to the slave addresses of each module. This is useful when using multiple modules as the system provides 16 different slave addresses.

This module is chosen as it provides high accuracy measurements of voltage, current and power. There is also room for design configuration, A/D resolution configurations to improve accuracy and can serve as a base for later measuring battery states and health. Another reason to implement this IC into our design resides in the amount of documentation available and the relative ease in implementation which makes this ideal for troubleshooting or mass implementation of multiple modules.

4.4 Casing Material Options

In today's society, the people have access to a wide variety of resources and materials to work with when designing and creating their idea. In terms of the Energy Harvesting Platform, the endurance of the materials is required to last for an extended time. Normally, pavements and sidewalks only need to be replaced once every fifteen to twenty years, however, due to the amount of pressure the Platform have to go through, and the lifespan of the electronic parts, its lifespan will be limited to less than a decade, only about five years. Although usage after that timeframe is theoretically possible, for safety reasons, it will be recommended to be changed after five years of use. Making the Platform last as long as possible will create more revenue as well as making a profit for the buyer in the long run, as the cost of the Platform and the installation cost will be lower than five or so years of electricity bill. This will increase the possibility of the consumer buying more of the product.

Materials	Pros	Cons	Cost
Plastic	Easily obtained	Melts under heat	Low
Ceramic	Extremely durable Heat resistant Stain resistant Easy to maintain Lasts longer than all other floor coverings	Expensive to install Heavy Could break under too much pressure	Low
Vinyl	Good for high traffic areas Durable Ease of Maintenance	Must be installed over smooth underlayment Lasts about 10 years	Low
Wood	Easily obtained Easy to work with	Could have water damage if not correctly designed with protection	Low
Metal/Stainless Steel	Durable Easy to maintain	Heavy	High

Table 14. Casing Material Comparison

Above is a comparison of different types of materials that could be used as casing for the Energy Harvesting Platform. Each type of material has its pros and cons in material type and cost. As some of the materials, such as metal and stainless steel will need to be custom ordered through third party companies, there will be an increase in cost and wait time for the order to be sent to us. Even though sending out and custom ordering the casing will allow us to have a durable, long last casing, if there are any errors in the original design, the process will need to be repeated and cause and increase in cost.

4.4.1 Chassis Material Selection

There are multiple materials that makes up the parts for the chassis. The group chose to use wood, acrylic, wire spring, polylactic acid (PLA) plastic, and wood stains in the making of the Energy Harvesting Platform casing.

4.4.1.1 Wood Casing

The group decided to use wood as the main casing because it is cheap, easily accessible, and easy to work with. With the use of laser cutters, we are able to cut the wood into the desired shape and size in moments. We chose not to use metal because metal is difficult to mend without the proper tools. As we do not have access to plasma cutters and other mending tools, we cannot shape the metal into the correct dimension that we require. Although some laser cutters can cut metal, we do not have access to those on UCF campus. Sending the design out for someone to create the casing will require additional funding, which would exceed the group's budgeting.

The group chose not to use plastic because plastic is also difficult to mend. Another reason to not use plastic is because plastic could melt and warp under too much heat. For a technology that's left out in the sun, like the Energy Harvesting Platform, materials that melts or deforms cannot be used.

Although wood is easy to work with, it is important to understand its limitations as well. There are many types of wood that may be chosen.

Wood Type	Pros	Uses	Maintenance
White Cedar	Corrosion resistant Insect resistant Weather resistant	Fences Posts Canoes	Once a year
Jarrah	Does not decay Resist rotting Resist insects	Flooring Heavy Construction Furniture	2-3 times per year
Birch	Sold in sheet at craft stores and home supply stores Thin and easy to cut	Cabinets Flooring	Rarely

Table 15. Wood Type Comparison

All wood will soak in water and degrade as time goes on if not properly prepared and maintained. Depending on the different types of wood, the wood may discolor under the sun or go under corrosion in the elements.

White Cedar is recommended by wood workers for outdoor applications. This type of wood is easy to cut and shape, and the wood is naturally resistant to weather and insects and does not easily decay. This type of wood can last up to 25 years.

Another choice of wood is a red wood called Jarrah. This wood also resists insects, does not decay easily and resists rotting. This type of wood can last up to around 50 years. However, this wood discolors easier than other wood and require more maintenance.

Birch is also a commonly used wood. This type of wood, however, does corrode and is susceptible to insect attacks if protection is not properly set on the wood when completing the project. Although this wood is not widely used outdoors compared to White Cedar or Jarrah, the group chose this type of wood due to its availability, accessibility, and cost. Birch can be purchased in almost any craft or home improvement stores. The wood is already precut to thickness and size that is perfect for laser cutting. By laser cutting, we can save more time and money. By laser cutting, we can also create a prototype of the casing without first designing the casing in a 3D model program such as SolidWorks or AutoCad. In the decision to use Birch wood as our material, we need to use wood stains for proper protection from the elements and also insects. Although we are using Birch wood for this particular project and during the demonstration and presentation. We strongly suggest those who attempt to build the same project to use White Cedar, Jarrah, or any other wood more commonly used outdoors. Otherwise a better material, such as metal or stainless steel are preferred as the materials can last long periods of time. [30]

4.4.1.2 Acrylic Cover

The group chose to use acrylic as the top cover to allow sunlight to pass though for the solar panel to function. There are a few choices that could have been used for the cover, such as:

- Clear Acrylic
- Glass
- Polycarbonate
- Clear plastic

Glass would have been a good choice as glass is clear, transparent, and is usually scratch resistant. However, glass is fragile. The Energy Harvesting Platform is designed to be partly powered with piezoelectricity, meaning energy taken from vibrations and deformation of certain crystals. The Platform will be stepped on in large volumes in order for the piezoelectricity to produce enough energy to be useful. As glass is fragile and shatters under heavy force, it cannot be used for the project. Besides people stepping on the Platform, there may also be bikers, skateboarders, strollers, pets, or random falling debris may also cause enough force for the glass to break.

Polycarbonate is similar to acrylic, but much stronger and is shatter resistant. Being a sturdy thermoplastic, this material would have been ideal for the group to use as it is transparent and can withstand large amount of force without breaking. The downside to using polycarbonate plastic, and also the main reason why we discarded the idea of using this material, is that the plastic cannot be cut using laser cutters. When using laser cutters to cut polycarbonate plastic, the vapors are toxic. Being a thermoplastic, the plastic can withstand heat better than some other materials such as acrylic. Although very thin polycarbonate plastic can be cut, it will discolor terribly. The polycarbonate plastic can still be cut using standard glass cutting tools. However, that method is time consuming and not as precise as using laser cutters. The deformation may also cause fitting problems with the wood casing that is precut.

Clear plastic was also considered when the group planned the design of the casing. Plastic is also somewhat sturdy, and can withstand the foot traffic throughout the days. However, plastic cannot be used due to the reason it could not be used for the external casing, the plastic could melt or deform under constant heat.

Acrylic was chosen because it is transparent and sturdy. Although acrylic could crack under extreme pressure, layers of acrylic could prevent that kind of damages. Acrylic can be cut using the laser cutter, allowing us to get the precise dimension that we require for our Platform design. Due to the height of the acrylic compared to the wood, we decided to use two sheets of acrylic as the cover. This allows the top surface of the Platform to be flat and easy to step on. The two layers of the acrylic allows the acrylic to be sturdy enough to have pressure on it without the acrylic breaking. The diagram below gives a clear view of the pros and cons of the material choices.

Material	Pros	Cons
Glass	Transparent	Difficult to cut to without proper tools Easy to break
Polycarbonate Plastic	Transparent Sturdy	Cannot be cut with laser cutter Difficult to cut even with glass cutting tools
Clear Plastic	Transparent Easy to work with	Melts under too much heat
Acrylic	Transparent Easy to work with Sturdy when layered	Could get scratch marks Could break under too much pressure

Table 16. Casing Material Selection

4.4.1.3 Springs

The springs are used to compress and decompress the Platform in order to press the piezoelectric crystal down to a specific height without breaking the crystal. In terms of having compression and decompression, there were only a few choices we could make for this project. The group could only choose between using a normal wire spring or rubber springs. Both types of springs could be obtained and used.

Rubber springs work the same as any other spring in terms of compression and decompression. Rubber springs are better in the sense that rubber are more durable and can withstand rust and other types of corrosion. The group decided against rubber springs because of the spring casing that also needed to be designed to prevent over compression and damaging the piezoelectric crystals. The size of the rubber springs would require a larger size casing, increasing the overall size of the Platform itself. However, if the Platform is too large, the person stepping on the Platform may feel something is out of place as the compression will not be even throughout the Platform.

Wired springs are the most common springs that anyone can get. The springs work well and does not cost much. The group decided to go with this type of spring because the size is smaller compared to rubber springs. Designing and creating the spring casing is also much easier for this type of spring compared to rubber springs. This type of spring creates enough tension to allow a slower compression so the person stepping on the Platform does not feel too much compression, but also allows enough compression for the piezoelectric crystal to create voltage and current. This type of spring can also last for a few years without having to be exchanged if the spring is not kept in a compressed condition for long periods of time.

4.4.1.4 Polylactic Acid Plastic

Polylactic Acid Plastic, or PLA Plastic, is a plastic commonly used for 3D printing. The group chose to use this because 3D designing and printing certain parts are easier than spending time and trying to find premade parts that works well with what we need. We needed parts to use as the spring cover and also as rods to press down on the piezoelectric crystal.

For the spring cover, not only does it prevent the spring from moving out of place, the cover also acts as a stop for the compression. The group considered using PVC as the spring cover since PVC is sturdy and will not break. However, cutting and sanding four pieces of PVC down to the right size and height is almost impossible to do by hand. If the PVC are not at the correct height in all corners, the compression will be uneven, and may break one or more of the piezoelectric crystal. By 3D printing the parts, the parts will always be even. Each part can be individually designed to fit each section perfectly. If there are errors, we can easily redesign and reprint each part within a few hours. By 3D printing with enough surface area, the 3D prints can be sturdy, even withstanding a high volume of weight.

4.4.1.5 Epoxy Glue

As we are making the casing out of wood sheets, the layers will need to be glued and nailed together to prevent it from disassembling when in use. The design of the casing consists of many different types of materials, and each glue have its own specialty, wood glue for wood, white glue for paper, super glue when the project are to be kept forever. However, bonding different materials could require multiple glue or a certain type of glue. In our case, we decided to go with epoxy glue. Epoxy glue acts similar to normal epoxy, two different solutions are mixed together and cured for a strong bond. Unlike normal glue, epoxy will stick to almost any surface, allowing the bonding of any two surfaces. We also selected this type of glue because once epoxy cures, it leaves a clear, transparent glue. As we are mainly gluing the acrylic to the wood, this will prevent the glue from blocking light to the solar panel underneath. Another good reason to choose epoxy glue is that it is water resistant and also acts as a sealant. As we are gluing acrylic pieces in between wood pieces, the epoxy glue acting as the sealant will prevent us from having to apply additional preservatives to seal the surface from any water or weather damage.

Using Epoxy glue still has its drawbacks. Although epoxy is strong, it is not completely unbreakable. If the glue ends up not sticking to a surface, a large amount of residue will be left on the object. This residue will need to be peeled off or removed in order to successfully reapply another layer of glue. Another drawback is that epoxy glue takes long periods of time for drying. If the object is disturbed or the location where the glue is applied breaks contact, there will be a high chance of failure, and the coating will have to be reapplied.

4.4.1.6 Wood Preservatives

If we want to extend the lifespan of wood materials that is left outdoors which comes in contact with weather, we will have to place in proper protection for the wood. By selecting the proper type of wood preservatives, the wood can have an increase in lifespan. Like any products, however, there are benefits and drawbacks to each of the products, and each could cause problems. By using sealants such as wood stains, the stains will give some protection for the wood from the elements such as the heat and water. There are multiple types of wood stains and other preservatives to choose from. [31]

4.4.1.6.1 Polyurethane Sealant

One way to preserve the wood is to use polyurethane. Polyurethane is a type of thermoplastic polymer. This type of material will harden once it comes into contact with outside air. Some type of polyurethane requires extra heating to harden.

There are multiple benefits to using polyurethane sealant. Unlike epoxy resin, which needs a mixture of two solutions, polyurethane will harden automatically, allowing this to be a cheaper option. This sealant can be purchased from almost all home improvement stores such as Home Depot and Lowe's. Polyurethane is also scratch resistance and finishes with a glossy surface, making it look better than some other finishes.

Polyurethane is resistant to oil, grease, and water, allowing this material to be in fine condition even if left outside for long periods of time. Polyurethane also increases toughness as it has high tensile properties and is tear resistant. As it prevents liquid from entering and coming in contact with the wood, the material will still help insulate the wood casing from molding through water intrusion.

Another great reason for using polyurethane as the sealant is its ability to electrically insulate. If the electrical components were to accidentally come into contact with casing, the material will not conduct, thus preventing shorting of the printed circuit board or any of the other wiring. As compared to some metallic casing, using wood with polyurethane could help prevent some problems that may occur.

As with any material, there are drawbacks to using polyurethane. If multiple layers of polyurethane coatings are applied, any coating from the 2nd layer and on will need additional sanding due to coatings becoming brittle. Multiple layers also may not stick to the surface well, creating brittleness and decreasing impact resistance and durability. One way to prevent the polyurethane from drying out and becoming brittle is to maintain the outer coating by applying oil regularly. [32]

4.4.1.6.2 Epoxy Resin Sealant

Another way to preserve the wood is to cover the wood completely with a layer of epoxy resin. The resin will prevent the wood inside from coming to contact with the elements directly, thus lower the chances of damages. By selecting non-toxic, weatherproof epoxy resin, we could quickly seal the wood without any special tools or equipment.

There are multiple types of epoxy resin sealant to choose from. Each type of resin have its own intended use. Some are used for coating buildings, some for protection from chemicals, some for marine use, and others for small crafts.

Considering the Energy Harvesting Platform, which will be used outdoors, exposed to all sorts of elements, the resin will need to have the property of heat and water resistance.

Coating with resin will already increase its sturdiness, but if the resin has the ability to harden into something even stronger, it would greatly benefit the Platform.

Each epoxy resin will have its own ideal coating method. As epoxy resin usually consists of mixing two solutions, the resin and a hardener, the majority of the method of coating with resin is similar to painting. By differentiating the ratio between the resin and the hardener, the user can have softer or harder resin coating afterwards. However, if there are too much or too little hardener, the resin will either become too hard and brittle, or it will not cure and retain its semi-liquid shape.

The following figures outlines the drawbacks and benefits of some epoxy resin. The figures goes over what the type of resins are generally used for, the advantages and disadvantages of using said resin. [32]

	Amine Epoxies	Polyamide Epoxies	Amidoamine Epoxies	Epoxy Phenolics/Novolacs
Description	Form very hard, adherent films with excellent chemical and corrosion resistance. Amine cured epoxies are often used as protective coatings and linings in highly corrosive environments. Amine epoxies require care in handling since the amines can be moderately irritating to the skin, and may cause allergic reactions.	Polyamide epoxies generally offer the widest latitude in coating formulation. They are considered more resilient and flexible, and have better weathering resistance and a longer pot life than amine cured epoxies. Polyamide epoxies generally have less solvent and acid resistance than amine cured epoxies.	Amidoamines are reaction products of a polyamine and a fatty acid. Their properties generally fall between those of amines and polyamides. They have good water and corrosion resistance like amines, and good toughness like polyamides. They have relatively small molecular size giving them low viscosities and making them very good surface wetters.	These coatings allow wide range formulating latitude. Novolac epoxy resin increases chemical resistance and solvent resistance. Increasing the level of phenolic increases the chemical and solvent resistance, but the coating loses flexibility. Some phenolics require heat curing.
Advantages	• Excellent alkali and water resistance • Very good acid resistance • Excellent solvent resistance • Hard, abrasion resistant film • Excellent corrosion resistance • Excellent wetting of substrate • Chemical/moisture barrier	• Very good alkali and water resistance • Good acid resistance • Longer pot life than amines • Easy to apply • Cures more quickly than amines • Good weathering characteristics • Good film flexibility • Excellent adhesion	• Excellent surface wetting • Excellent adhesion • Excellent water resistance • Low viscosity • Longer pot life than amines • Good gloss retention	• High heat resistance • Excellent chemical resistance • Excellent solvent resistance • Excellent corrosion resistance • Hard, abrasion resistant film
Disadvantages/ Limitations	• Amines can be irritating/toxic • Relatively short recoat time • Relatively short pot life • Slower dry than normal polyamides • Chalks/may discolor	• Faster dry than amines • Chalks • High viscosity • Temperature dependent • Slow cure	• Slow cure • Fair color retention • Temperature dependent	• Some may require heat cure • Relatively slow air cure • Chalks/may discolor • Relatively brittle
Primary Uses • **Refer to product data sheets for specific use information**	• Severe chemical resistant coating • Barrier coating • Offshore structures • Storage tanks, structural steel • Bridges, power plants • Tank linings • Secondary containment	• Water immersion • General industrial • Offshore structures • Storage tanks, structural steel • Water/wastewater plants • Tank linings • Bridges, power plants • Secondary containment	• Barrier coating • Surface tolerant coating • Where chemical and moisture resistance is required • General industrial • Refineries • Bridges, power plants	• Severe chemical resistance • Tank linings • Secondary containment • General industrial • Refineries • Bridges, power plants
S-W Products	**Amines** Shelcote II Epoxy Shelcote II Flake Filled Dura-Plate UHS Tank Clad HS Epoxy Sher-Glass FF **Ketimines** Dura-Plate MT Macropoxy 920 PrePrime **Phenalkamines** Dura-Plate 235 **Water-Based** Water-Based Tile-Clad Zinc Clad VI Fast Clad DTM Waterbased Epoxy	Kem Cati-Coat HS Filler/Sealer Tile-Clad High Solids Recoatable Epoxy Primer Copoxy Shop Primer Zinc Clad IV Zinc Clad III HS Hi-Solids Catalyzed Epoxy Macropoxy 646 Fast Cure Macropoxy 846 Winter Grade Epolon II Primer Epolon II Multi-Mil Macropoxy HS Epoxy Pro Industrial High Performance Epoxy	Epoxy Mastic Aluminum II	Phenicon HS Epoxy Phenicon Flake Filled Epo-Phen Nova-Plate UHS

Figure 32. Epoxy Coating Comparison Chart, (Courtesy of Sherwin Williams Company)

	Siloxane Epoxies	Coal Tar Epoxies	Water-Based Epoxies	Epoxy Esters
Description	Siloxane epoxies are relatively fast curing coatings with excellent stain and mar resistance. They have excellent color and gloss stability. Siloxane epoxies are typically used in high performance industrial applications. Also acceptable for architectural applications.	Coal tar epoxies are a combination of a basic epoxy resin and coal tar. The coal tar is in the form of a semi-liquid pitch and blended with the epoxy resin. The curing agents for coal tar epoxies are usually either amines or polyamides. Coal tar epoxies offer excellent resistance to fresh and salt water and are highly resistant to cathodic disbondment.	Generally consist of a non-yellowing acrylic resin disbursed in water mixed with an emulsified epoxy resin. They are relatively hard, durable coatings with moderate chemical resistance. They offer good stain resistance, abrasion resistance and resistance to most commercial cleaning agents and sanitizers. They can be used over previously applied conventional paints to upgrade the surface for better performance without wrinkling, lifting or bleeding.	A combination of epoxy resin and alkyd resin resulting in an air-drying coating. Epoxy esters provide a hard, durable film ideal as a machinery finish. Recommended for general atmospheric use in areas not considered severely corrosive.
Advantages	• Very good weathering resistance • Hard, abrasion resistant film • Very good acid resistance • Excellent color and gloss retention • Relatively fast dry	• High film build with one coat • Excellent salt water resistance • Excellent water resistance • Excellent resistance to cathodic disbondment • Economical	• Good chemical and solvent resistance • Hard, abrasion resistant film • Upgrades conventional systems to high performance • Water clean-up, low-odor • No strong solvents • Good adhesion • Very long pot-life • Good weathering	• Hard, durable film • Easy to apply • One component • Good moisture resistance • Minimal surface preparation • Moderate cost • Low temperature application • Increased alkali resistance over alkyds
Disadvantages/ Limitations	• Solvent resistant • Heat resistant	• Not for potable water • Black color • Critical recoat time/ difficult to recoat • Fair solvent resistance • Chalks/browns	• Flash rusting on ferrous metal unless primed	• Fair solvent resistance • Poor weathering characteristics • Poor exterior gloss retention
Primary Uses • **Refer to product data sheets for specific use information**	• Bridges • Marine • High performance finish coating • Kennels, • Schools, jails, hospitals • High moisture areas • Stain resistant coating	• Liner for sewage treatment tanks • Not-potable water tanks • Pipe coating • Penstocks, dam gates • Offshore rigs • Paper mills • Chemical Plants • Secondary containment	• Light/moderate industrial areas • Tile-like wall coating • Schools • Hospitals • Food plants • Office areas • Kitchens • Hallways • Nursing homes	• Moisture resistance • Where odor or low temperature limitations prevent solvent-based epoxy use • Abrasion resistance
S-W Products	Polysiloxane XLE-80	Hi-Mil Sher-Tar Epoxy Tar-Guard Coal Tar Epoxy	Water-Based Epoxy Primer Water-Based Epoxy Pro Industrial Hi-Bild Waterbased Epoxy	

Figure 33. Epoxy Coating Comparison Chart, (Courtesy of Sherwin Williams Company) P.2

The figures cover a wide range of different types of epoxies as epoxies require a mixture of two types of solutions. If the proportions of the solutions are not mixed properly, the epoxy will not undergo the chemical reaction and harden over the surface of the wood.

One epoxy mentioned in the figure is the Epoxy Phenolics. This epoxy is also high heat resistance and has corrosion resistance. This epoxy is generally used in industries which may come into contact with chemicals. The drawbacks with this epoxy is that it will require heat cure, and the natural cure time is slow. This epoxy may also discolor and becomes brittle relatively easy. Considering the nature of the Energy Harvesting Platform, although this epoxy is heat and corrosion resistance, it is not suitable for what the Platform is intended for.

Another one of the epoxy discussed in the figure is the Water-based epoxy. This type of epoxy is hard with good weathering and also chemical resistant. Water-based epoxy is usually used on buildings, whether external or internal such as walls and hallways. This epoxy is usually used light or moderately. However, a drawback to using this type of epoxy is that it may wash off with too much water. Under severe rainstorms, the epoxy may be washed off, thus rendering the coating useless as it exposes the wood casing to water. Although this is good for use indoors, it will not be a good choice for the Energy Harvesting Platform.

A third one of the epoxy discussed in the figure is the ‘Solixane Epoxy’. This epoxy is heat resistant, can retain its color and gloss, and prevents weather damage. The epoxy dries fast, meaning it can be done within a few hours to a day, unlike some of the other epoxy, which may require an entire day to cure. The Solixane Epoxy can flood coat, meaning the mixture of the resin and hardener is poured directly onto the object a person is trying to seal and allow the solution to level out and dry on its own. As the solution levels out, there will be an even coating throughout the object. Although this method is generally easier than applying individual coating to each side and surface of the object, it does require some sanding for a smoother surface on the edges. Solixane Epoxy is mostly used for marine situations, meaning it can withstand up to most weathers and elements.

4.5 Maximum Power Point Tracking (MPPT)

Maximum power point tracking is mainly used with components such as solar cells to ensure efficient power transfer under any condition such as a cloudy day that would reduce the output of a solar cell. MPPT systems have the ability to increase the current output from the photovoltaic solar cells. The increased current is produced from the overload of voltage that the solar cells generate and is converted into an increased charging current. The MPPT keeps track of the varying sunlight intensity and the change in temperature of the solar cells.

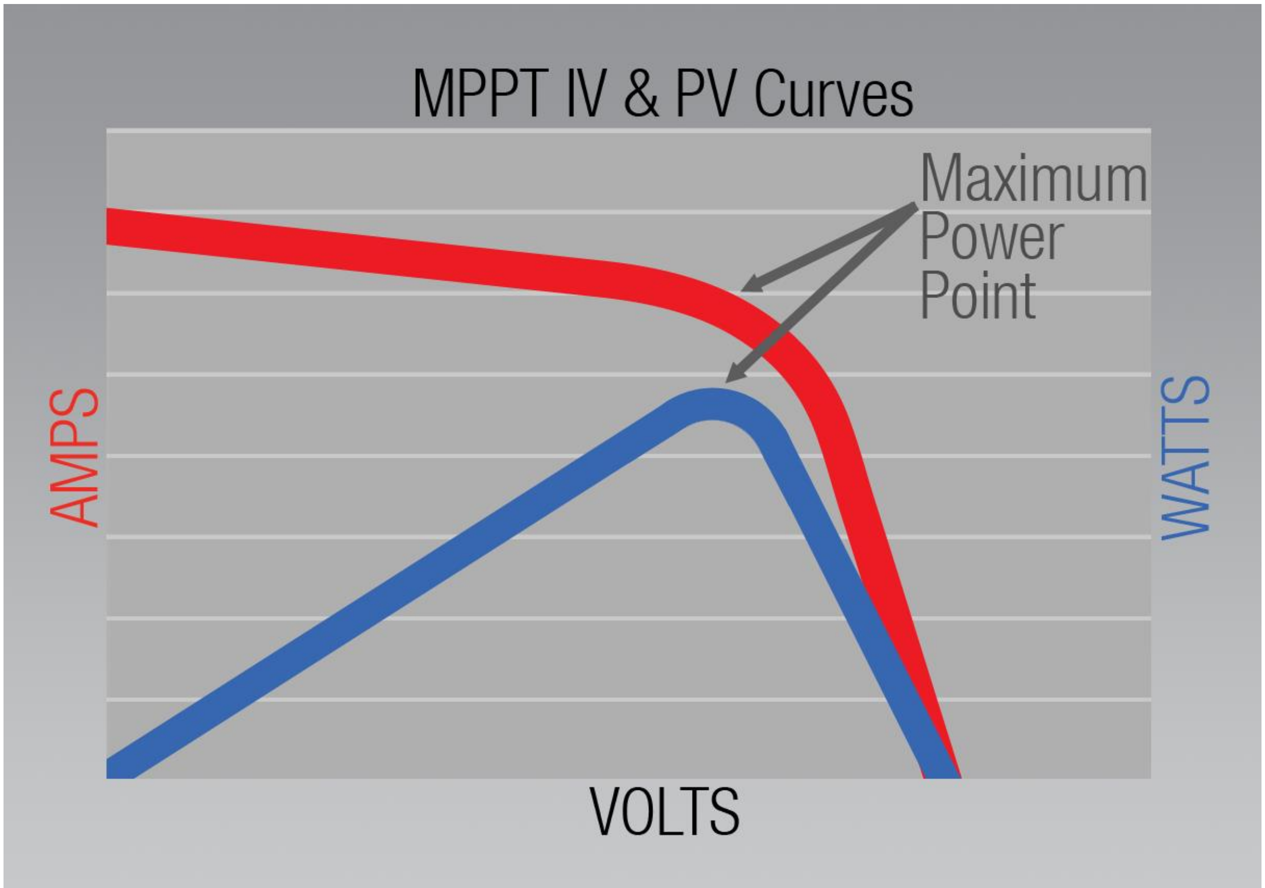

Figure 34. MPPT Curves (Courtesy of REDARC Electronics)

Maximum power point tracking monitors the voltage and current from the output of the solar cell and uses an algorithm to adjust the ratio. The solar panel produces nonlinear output voltages because of the combined effect of solar cells, solar irradiation, temperature and total resistance. The MPPT system tracks the output of the solar cells and applies the proper load to obtain the maximum power for a given environmental conditions. MPPT systems provide effective power transfer during non-ideal conditions such as in winter or on cloudy days, when the sunlight is not optimal for the solar panels.

4.6 Simulation Software

Before testing actual components, it's always a good idea to use software to simulate the circuit design and realize any faults before connecting real components and damaging them in the process if there are bad connections. There are several simulation software programs available, some which are free and others that are not, depending on what features they provide. The three most popular simulation software brands are NI Multisim, LTSpice, and Upverter. NI Multisim has a student version for 90% less than the retail cost while LTSpice and Upverter are for free.

All three types of software were used and tested on every aspect it would be used for involving this project. Every student working on this project has had previous experience with NI Multisim and therefore, it was the easiest to use. One feature noticed in NI Multisim that isn't included in the other two is the ability to automatically troubleshoot a circuit design. NI Multisim runs through several procedures to check parameters of the circuit design to make sure that everything is set correctly. The menu layout and what is available to see was lacking in the Upverter GUI compared to the other two.

Software	NI Multsim Student Version	LTSpice	Upverter
Price	$41.95	Free	Free
Troubleshoot Design Wizard	Yes	No	No
User-friendly GUI	Yes	Yes	No
Circuit runtime	Fast	Fast	Slow
Level of Accessibility	High	Medium	Low
Cloud Storage	No	No	Yes

Table 17. Simulation Software Comparison

Table 12 shows the comparison between all three simulation software brands. The time it took to run a circuit design on each software platform was timed and NI Multisim took the least amount of time. The method in which the workspace layout provided buttons to add different components and change settings was prevalent in NI Multisim compared to the other two.

The main advantage of Upverter was that it had cloud storage for the design files which meant it could be accessed from any computer that had internet connection and an internet browser that could load Upverter. NI Multisim and LTSpice are programs that need to be downloaded and installed onto the Operating System of the computer to run. Although LTSpice and Upverter have several advantages over NI Multisim, such as being free, the $41.95 for NI Multisim is a great investment since the features it provides is unmatched with the other two software brands.

4.7 Printed Circuit Board (PCB) Fabrication

The final design of all the circuitry after completing all breadboard tests will ultimately be produced as a Printed Circuit Board (PCB). A PCB is a board with printed connections between all the components in the circuit using a certain metal, typically copper (Cu), as a conductive track and pad for the component[41]. This is an alternative method for soldering individual wires together to make connections and has proven to be more efficient and a cleaner design.

The purpose of PCBs becoming the normalized circuit board design concept is due to the fact that they reduce the possibility of human error when making connections between components and provide precise measurements compared to freehand tracing and breadboard placements. The other issue is regarding unwanted capacitance between components that are placed to closely due to the exposed terminals and wires. Breadboards are usually for experimenting purposes due to the flexibility of changing the placement of components if necessary along with easy testing of individual components which is very useful in the experimenting stage.

Freedom of component placement and testing is now the norm for breadboards while PCBs are used as a final circuit board design. This allows for the guarantee of working components and proper placement since PCB design is quite expensive due to the fact that it is done by state of the art machines with high precision functions based on measurements that are as specific as hundredths of a millimeter.

Fabrication of PCBs is a complex process that takes several steps from creating the layout to submitting it to the manufacturer that produces the finished product. The process takes the steps listed below:

1. Schematic design using Computer-Aided Design (CAD) software; in this case, KiCAD was used.

2. Component selection and footprint assignment to prepare for PCB design.

3. A netlist is created with all the necessary connections between components.

4. The dimensions of the board and number of layers are decided.

5. The footprints are placed on the PCB and traces are routed.

6. Gerber files are created and sent to the PCB manufacturing company.

7. Assemble the components onto the PCB.

Following these steps will ensure a smooth process of PCB fabrication and producing the final product to use with the design. These are the required steps since the process begins from software and ends up in the final production stage as a hardware product.

4.7.1 PCB Design Software

The circuit design for this project is originally tested using breadboards and components with long leads. This must be converted into a Printed Circuit Board (PCB) since it takes up less space and the components that go on the board are soldered on by surface mount and are a lot smaller than regular components used on breadboards. There are several PCB design software brands that match the needs of this project, but the three most common ones used are KiCAD, EagleCAD, and Altium. KiCAD is a free community-based, open-source, software while EagleCAD and Altium require a purchase. Altium does not provide prices unless they are contacted by phone which most likely means that the software is expensive. EagleCAD requires a subscription which can be monthly, or every 1-3 years.

Software	KiCAD	EagleCAD	Altium
Price	Free	Subscription	Unknown
User-friendly	Yes	Yes	Unknown
More than 4 layers	Yes	No	No
Limited Schematic Sheets	No	Yes	Yes

3D View	Yes	Yes	Yes
Cross-platform Import/Export	Yes	Yes	Yes

Table 18. PCB Design Software Comparison

KiCAD has been used by one of the students and therefore, can be reviewed accurately. Most importantly, it is free software which means it doesn't add any cost to the project expenses. It is easy to use and has very many basic and useful features. The hotkeys and shortcuts are easy to learn and it has everything you need to make a basic PCB design. This software allows making boards that are 1,2,4,6, and 8 layers, while the paid software like Altium and EagleCAD only allow up to 4 layers.

EagleCAD provides varying number of schematic sheets depending on which subscription is chosen and Altium provides a fixed number of schematic sheets as well, while KiCAD is unlimited. All of them have the ability to view the PCB design in 3D with the components placed on the board to view what the actual PCB will look like. Another great feature that they all have is the ability to import/export common file extension associated with schematic and PCB design files.

4.7.2 Surface Mount Technology

One of the methods to designing PCBs is deciding which type of component to use. The two types of components are surface mount and through hole. The difference between the two will be discussed more in depth as this section will provide information about the surface mount technology used for such components.

Surface mount components were introduced for PCB design since they are constructed in a more efficient manner and provide flexibility when determining the number of layers a board will have. They are focused on compact design regarding length, width, and pitch, and usually can be the equivalent of several of the same individual component that would be used on a breadboard. They are a better option than through hole components since they allow for easier tracing on the PCB without any obstacles since the traces can be fully routed on both sides of a two layer board without being confronted with the holes.

Most of the components available today as breadboard or through hole are usually for testing purposes only. The surface mount technology has provided PCBs with a more professional design and allow at least twice as many components on a two layer board since they would not come into contact with each other as through hole components would.

Due to the flexibility that surface mount components provide for PCB design, they are the most viable option for when components are purchased for placement on the PCB. This option reduces obstacles, although the cost is higher than through hole. Surface mount components were chosen for this PCB design.

4.7.3 Through Hole Technology

The other type of component that can be used in mounting components on the PCB is through hole. This type of technology was the original way in which PCBs were assembled due to the fact that the boards only consisted of printed traces with copper while the placement of components were dependent on where the holes were drilled for the through hole components. This was less complicated and more cost effective at the time and therefore, it only made sense to not look into something like surface mount technology.

With technology improving and becoming more advanced, through hole components are becoming outdated because although they are cheaper, they still require to be hand soldered to the PCB, thus reducing productivity. The amount of time it takes to assemble a PCB with surface mount components is a lot faster and therefore, allows for a higher productivity rate[41]. Through hole components were not chosen for this project because they do not provide for a professional design and require unnecessary labor to hand solder the components to the PCB while surface mount can be done by machines.

4.7.4 Layers and Vias

One of the steps previously mentioned in the process to design a PCB is deciding the number of layers the board will have. This is a very important decision because along with the complexity of the board and how flexible the design can be, the number of layers also determines the cost of the board; the more layers, the higher the cost due to the amount of time and the process in manufacturing the PCB.

This project requires a circuit design that allows for all the components to be placed on one side of the board, although the complexity of routing traces is what leads to the decision of a two layer board. It is commonly known that the traces are like wires and therefore cannot intersect if they do not connect to the same component, so how is the obstacle avoided? The answer is to go around an already placed trace. To do this, the second layer of the board is required and a machine will drill a conductive hole, called a via, through the board to the other side to allow the trace to continue around the other one[41]. Another via can be placed a certain length away to bring the connection back to the top layer of the board so that it can still be connected to the component it was originally intended for.

This project consists of a certain number of components that, although can fit on one side of the board, the complexity of the connections requires a two layer board. This option has proven to be most accommodating so that there is flexibility in routing the traces throughout the board, including the other side if necessary.

4.7.5 Solder Paste

Solder paste is used in PCB design for surface mount devices because it provides efficient application of solder to the necessary component pads and reduces any failures caused by solder wire texture. Solder paste is usually the better option when surface mount components are placed on the PCB and a reflow oven is used to set the components into the solder. This method is a clean and useful way to assemble PCBs and offers the least amount of human error involved in applying solder to components which is a very important part of the design because it greatly affects the conductivity of connections with components.

The PCB that was created for this project is demonstrated with the application of solder paste to provide proper conductivity and reduce the possibility of short circuit failures due to the form that solder from solder wire take when heated up with a soldering iron. The bubbles that expand from this method contribute to possible improper connections and therefore, hand soldering was not used on the PCB unless absolutely necessary, which was only required for one of the components which needed to be a through hole due to the function of that component for the PCB design to be as close as possible to the breadboard testing that was conducted earlier on in the project timeline.

4.7.6 Stencils

Once the PCB is manufactured, the placement of components on it will be the next step. In order to do this in an efficient way, a stencil must be purchased with the PCB order. A stencil is provided with cutouts of all the pads and areas of the PCB which requires solder paste. This allows for easy access to solder paste application and that there are no short circuit connections accidentally created by human error of placing solder on each individual pad by hand.

The stencil is a very useful tool in that it provides a simple, yet effective, way of applying the solder paste required for the pads on the PCB. This method saves time since the solder paste is applied over the stencil so that it only rests on top of the areas that components will be mounted to. This step is required before placing components because surface mount ones are still placed on the PCB using solder just like through hole, the only difference is that they don’t need to be hand soldered.

The PCB for this project requires a stencil since it uses surface mount technology and therefore, a stencil must be purchased with the PCB order from the manufacturing company.

4.7.7 Pick and Place Machine

After using the stencil to apply the solder paste mask, the PCB is ready to have the surface mount components placed on it. The most common way of doing this is to hand solder the components, but since several surface mount devices are really small, as in just a few millimeters wide, it tends to be somewhat difficult to accurately place components onto the pads that have the solder paste applied to them already.

This is where a pick and place machine came into consideration. A pick and place machine functions exactly as its name represents. The machine picks up a component that has been put inside of it, and places it on the corresponding pads. These machines cost thousands of dollars because of the complexity of their functionality. They are highly efficient and can place thousands of components on a PCB within one hour.

The machine consists of a feed for the components and a conveyor belt in which the PCB travels on. Nozzles pick up the necessary components, by rotating them to the correct orientation as well, and place them on the PCB in the designated area with the pads. There are self-correcting procedures for placing the component the right way on the PCB by using computer vision to analyze pictures that are taken of each component to determine any errors or misshaped components [43].

The reason this method was chosen for this project is because a group member has access to a pick and place machine at their internship which they have been given permission to use for this project regarding the PCB design and assembly.

4.7.8 Reflow Oven

The final part of PCB assembly is setting the components into the solder paste by the only known method, heating up the solder to a certain temperature where it becomes part solid part liquid and the leads on the component sink into the solder and onto the pads. The components are then fastened to their fixed position after the solder cools down. This method is done in two different ways, using a soldering iron which requires hand soldering, or a reflow oven. As discussed previously, hand soldering is a method which was focused on being avoided due to the high human error rate of creating failures such as short circuits or misplaced components.

The method chosen for this step in the process is a reflow oven. A reflow oven is basically an oven which heats up to a specified temperature to allow the components to sink into the solder paste and connect to the PCB designated pads and therefore be connected through the printed copper trace on the board. There are several different zones in the oven which allow for the control of different temperatures based on a profile that is made using the interface for the oven [43].

A reflow oven was used for this project because it offered a more precise and efficient way of setting the components into the solder paste on the PCB compared to hand soldering which involves unnecessary complications due to human error.

4.8 PCB Vendor

Once the PCB design is complete using the software, the design files must be submitted to a PCB manufacturing company which makes the board the way it was designed using the files from the PCB design software. All companies are capable of providing the same quality for the PCB manufacturing, but the price difference depends on several other aspects such as location, number of layers, shipping cost, quantity of boards included in the price, and customer rating. The few most known PCB vendors that will be considered for this project include PCBWay, ExpressPCB, 4PCB, PCB International, and Gold Phoenix PCB.

Vendor	PCBWay	ExpressPCB	4PCB	PCB Int.	Gold Phoenix
PCB Cost	$20	$166	$33	$189	$100
Shipping Cost	$41	N/A	$138	$100	N/A
Location	China	USA	USA	USA	China
Customer Rating	High	High	High	N/A	High

Table 19. PCB Vendor Comparison

The PCB costs are based on the PCB being 2 layers. The other vendors turned out to be significantly more expensive and it would be unnecessary to use any of them instead of PCBWay seeing as most of them match PCBWay in customer ratings and although some of them are located in the USA, purchasing the PCBs from a vendor in China has proved to be the most cost efficient for our project budget and expenses. The other advantage of purchasing from PCBWay is that we have the possibility of having them sponsor us based on their judgement of our design, which would mean that we would receive free PCBs from them for the project. From the research conducted regarding which PCB vendor meets our needs, we have concluded that PCBWay has the least expensive option for a quantity of 5 PCBs along with the surface mount stencil that is used to apply the solder paste onto the board.

4.9 Components List

This section describes the major components that the group will be using to create the Energy Harvesting Platform.

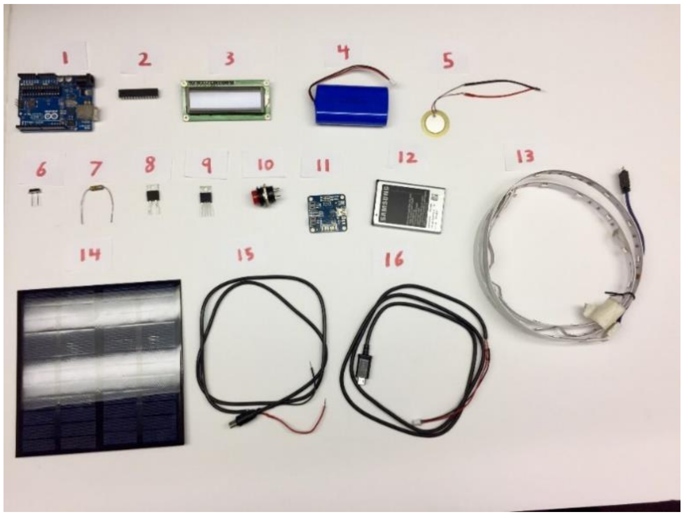

Figure 35. Major Components List

#	Name	Amount	Description
1	Arduino Uno	1	The Arduino will be used to control all the software parts of the Platform. It will read and display the power harvested and battery level.
2	ATMega328P	1	The ATMega328 is the microprocessor.
3	LCD Display	1	The LCD will be used to display the power harvested and current battery level.
4	Li-Ion Battery	1	The Li-Ion battery will store the power harvested and allow devices to be charged.
5	27mm Piezoelectric Transducer	12	The piezoelectric transducer produces power when pressure is applied. The power produced is stored in the li-ion battery.
6	16 Mhz Crystal Oscillator	1	The oscillator generates oscillating currents or voltages by nonmechanical means.
7	100mH Inductor	1	The inductor provides inductance and equilibrium reaction.

8	MBR1060: Schottky Barrier Rectifier	5	The rectifier converts an alternating current into a direct current.
9	LM2576 ADJ: Step Down Voltage Regulator	1	The voltage regulator limits the voltage down to a certain volt, prevents too much voltage from frying the Arduino.
10	Round Momentary Push Button Switch	1	The momentary switch powers connects the LED wiring when pressed. This allows the LED to light up when the Platform is pressed.
11	USB Li-Ion Battery Charger	1	This battery allows the battery to be charged while an external device is also being recharged.
12	Phone Battery	1	This battery is used in place of external devices being charged.
13	LED Strip	1	The LED is placed in as an extra effect.
14	Solar Panel	1	The Solar Panel harvests solar power to charge the battery.
15	USB Mini B with Exposed Wires Connector	1	The mini USB is used to charge the battery.
16	USB Micro B with JST Connector	1	The micro USB cord is used to charge external devices.

Table 20. Major Components List

This component list only consist of the major components, parts such as wires, resistors, and capacitors are not shown or listed.

5. Project Design

This section describes the hardware and software components considered and selected for the Energy Harvesting Platform. This section includes:

- Hardware and Software block diagrams that shows the function of the overall system and subsystem.
- Specific components selected and the reason why those specifications are important to the Energy Harvesting Platform.
- Schematics for major subsystems

5.1 Hardware Design

This section describes the hardware components and how each subsystem work in the overall hardware design. The hardware design consists of the microcontroller, power supply, lighting, and structure of the Platform.

5.1.1 Hardware Block Diagram

This section describes the overall flow and necessary components needed to complete this project. Since our project relies on converting mechanical energy to electrical energy, one of our biggest focuses is on creating/choosing the most efficient piezoelectric sensor.

Component Requirements:

- Input: Vertical depression of less than 5mm
- Piezoelectric Sensor: Generation of AC Voltage of more than 6V
- Battery: Should be rechargeable, Minimum capacitance of 2000 mAh
- LCD Display: Should display how much power is being generated, total power capacitance and power consumption
- Charging Station: Should be able to output at least 5W

As shown in Figure 25, the piezoelectric transducer produces a current and voltage, that power directs to the voltage divider to be split into parts so the microcontroller can read the voltage produced by the piezoelectric transducer without damaging the processor. The same power is wired into the rectifier, allowing all AC current to flow through to the voltage regulator. The voltage regulator regulates the voltage to 5 volts, allowing the microcontroller to read and be powered by the energy source. As the standard microprocessor can only take between five to twelve volts, the regulator prevents the microprocessor from frying due to high voltage. The regulated voltage then goes to the LEDs.

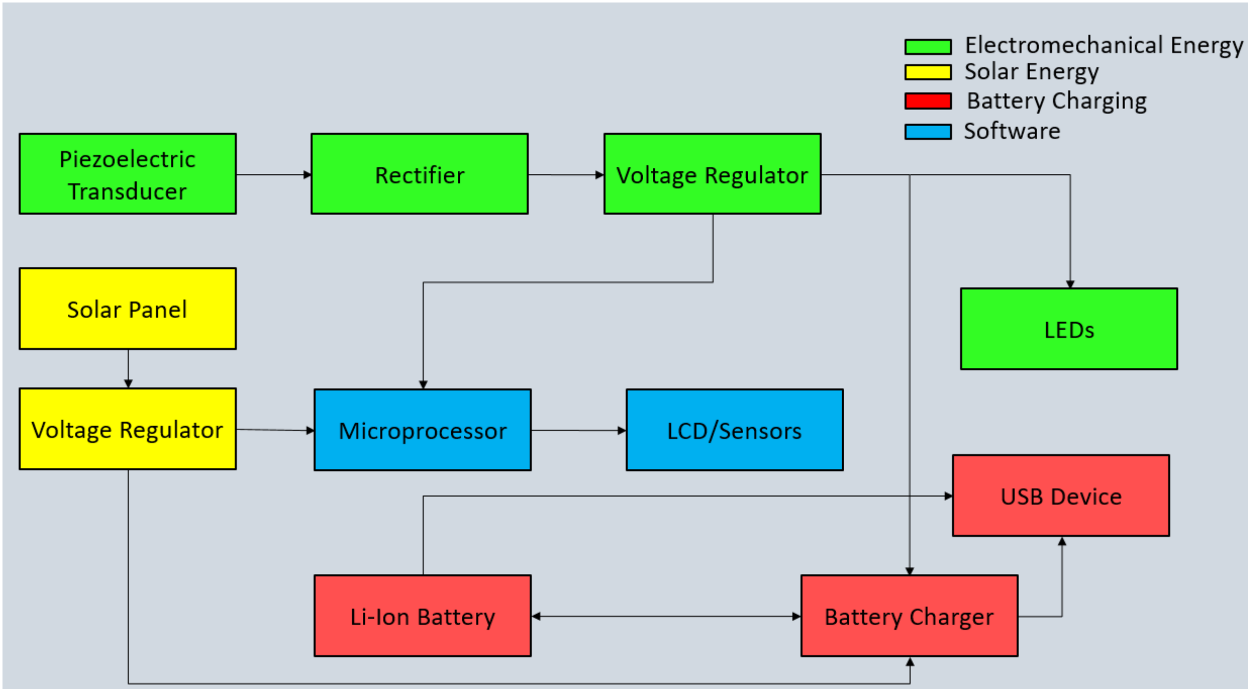

Figure 36. Hardware Block Diagram

The solar panel is a secondary power source used in the Energy Harvesting Platform. As the solar panel is a premade and tested power source, the power harvested from the solar panel is connected directly to the battery charger and USB power device. The solar panel is also connected to a voltage regulator then to the microprocessor for the microprocessor to determine and prove the solar panel is harvesting a constant power while the sun is out.

5.1.2 Piezoelectric Transducers

The piezoelectric discs are the main source of voltage for the project design and therefore, have a very specific configuration in order to have an output result of what is required for the rest of the system to function accurately and efficiently. The two main aspects of connecting piezo discs is that in series, they produce more voltage, and in parallel, they produce more current.

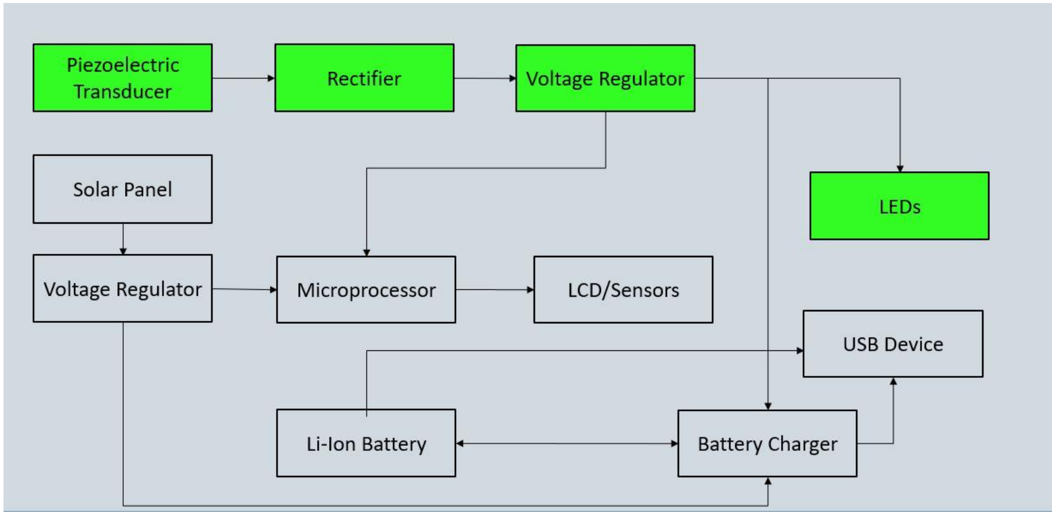

Figure 37. Piezoelectric Circuit

After testing the piezo discs in both configuration, we found that connecting them all in parallel will provide the current necessary to charge the battery since we only need 5 volts and a single piezo disc can generate between 8 to 10 volts. The configuration shown in Figure #2 is how the piezo discs will be connected to the rest of the system to meet the current requirement necessary to successfully provide efficient power to the LEDs.

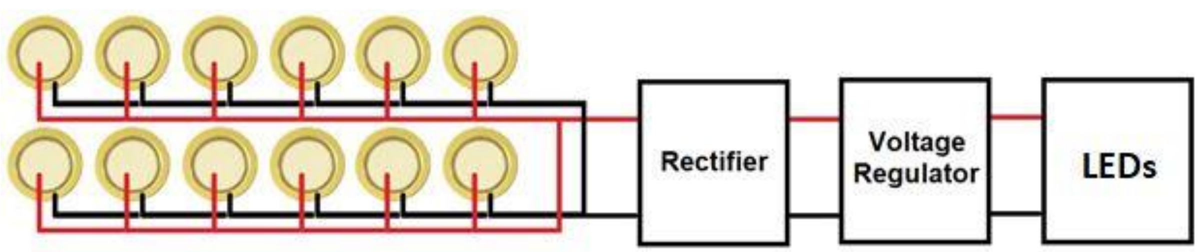

Figure 38. Piezoelectric Transducer Configuration

5.1.3 Rectifier/Voltage Regulator

After the piezoelectric input, we need to convert the AC power into DC power. The component chosen was the LTC3588. This IC is a surface mount device and in order to test this chip, we need to solder it to a breakout board. The breakout board then allows us to use a breadboard to add external components as necessary in the application. Below shows our initial breadboard testing of rectifier and regulator combination. All of these components are through hole, so in the worst case scenario, we have backup components and we know how the circuit works.

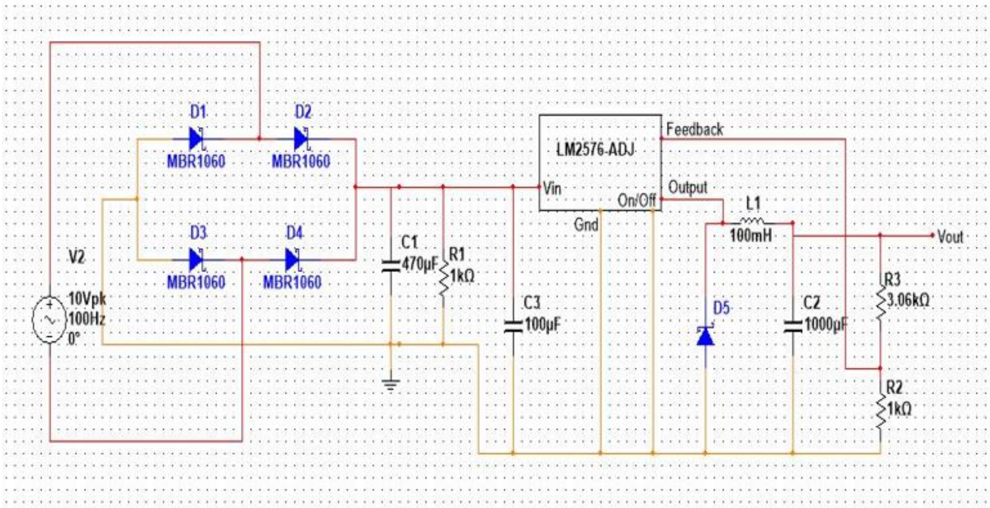

Figure 39. Rectifier Connected to Regulator

5.1.4 LEDs

The piezoelectric circuit ends in flashing LEDs. These LED's will be placed underneath the tile and will flash when the platform is stepped on. As described in our design specifications, we would like the platform to light up within 5 steps on the platform. Our initial design was to use LED strips, but that proved to consume too much power. We decided to go with 4-5 DIP LEDs around each side of the tile, all placed in parallel with each so that when the threshold voltage is met, all LEDs will turn on.

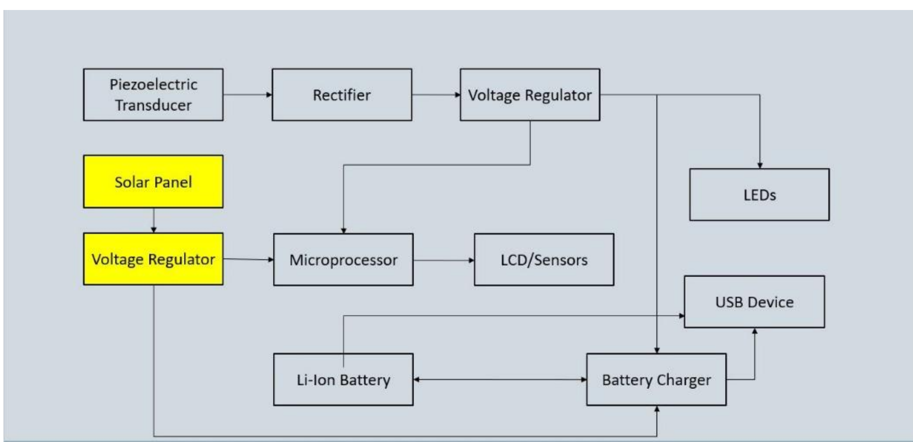

Figure 40. Solar Energy Circuit

5.1.5 Solar Input

The next hardware design aspect involves the solar panel inside the tile. The power ratings for panels of the size are very low, so ensuring that all the components inside of the tile are low power/power efficient is a big part of our design. The current output for the solar panel that is being used in this design is 660mA so that is able to be sent to the battery directly. However, most solar panels are rated for 12V or higher and that will definitely fry the microcontroller pins if not regulated. A voltage regulator may be introduced or perhaps a voltage divider to help keep the voltage in an acceptable range for the microcontroller.

5.1.6 Voltage Regulator

The switching regulator that was chosen is the LTC 3115-1. Again, as with the regulator in the piezoelectric circuit, this component is a surface mount device. In order to test this component, a breakout board was purchased and from there we were able to use a breadboard and external components to achieve the designed input and output specifications. The LTC 3115-1 provides constant 5V output which is perfect for the microcontroller pins, LCD display, external battery and the USB charging cables.

5.1.7 Microcontroller Circuit Design

This section provides an overview of the connections and components necessary to successfully implement the design. Along with the final circuit designs, several considerations are mentioned as well as possible modifications. The final schematic design for the microcontroller will be seen in the PCB schematic for the whole project shown in a later section.

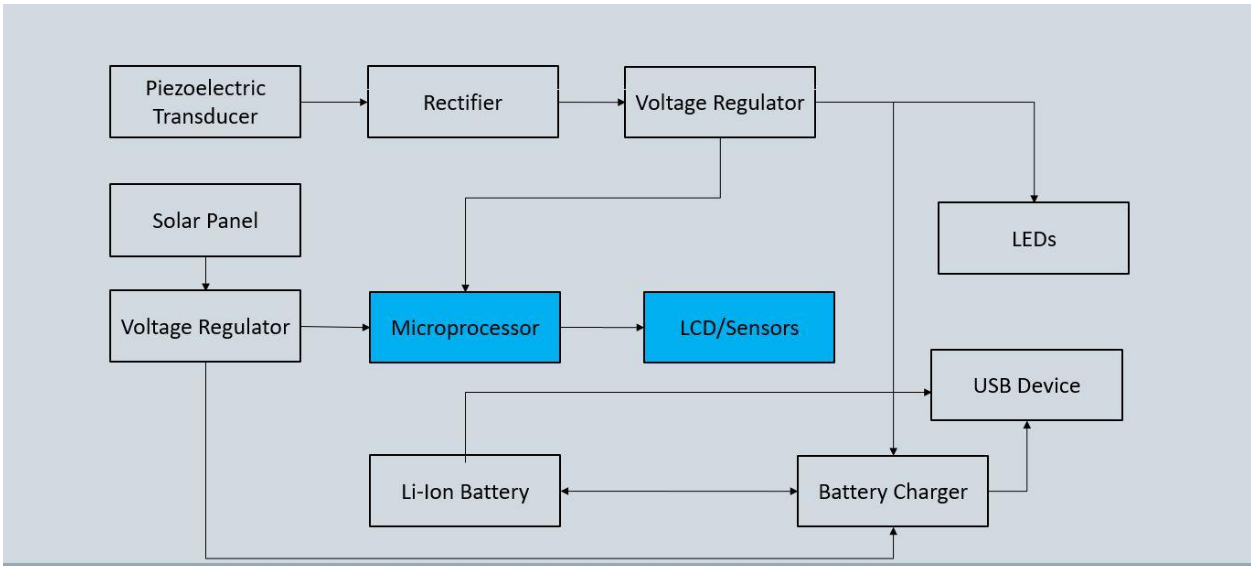

Figure 41. Microcontroller Circuit

5.1.7.1Stand-Alone ATMEGA328P

For most of the initial breadboard testing, the Arduino Uno was used to run the codes and test the circuitry, but for the final design only the ATMEGA328P chip will be placed in the PCB with the necessary components and connections to get the microcontroller running.

For breadboard testing, the ATMEGA328P-PU chip is used as it can be placed on a breadboard, but the surface mounted packaging will be used on the final design to offer a more professional and space saving design. After the bootloader program is burned on the chip, a process which will be briefly explained in the software design section, the microcontroller chip on the Arduino will be removed as this will only act as programmer board which can be removed after all the programming is done.

Several things need to be kept into consideration when building the circuit to constitute a running microcontroller chip. First, connections need to be made to the power source to power the device, as well as connections to ground. Another important set up is to establish an external oscillator. The oscillator circuit is done by connecting an oscillating crystal between the pins PB6 which pertains to XTAL1 and PB7 which pertains to XTAL2. This is followed by two equal capacitors which are placed in series and connect to ground. These capacitors are known as the load capacitance and are used to decrease the oscillating frequency of the crystal. This needed capacitance can be calculated using the following equation which is provided in the ATMEGA328P datasheet.

$$C = 2C_L - C_s$$

Here, the pin stray capacitance and crystal vendor load capacitance are used to complete the calculations. But, a capacitance range can also be obtained by the Low Power Crystal Oscillator set up in the datasheet which has a capacitance range for the C1 and C2 capacitors at 12 – 16 pF for a frequency of 16 MHz. Finally, the capacitors are set to 22 pF each.

Forming proper connections for the reset pin is also important as it provides for a reset signal when power is applied to the system and sets the device to operate at a recognized state. This feature is very important as there might be a need to manually reset the system in any case where there are issues with the program or connections. This circuit is built with the use of an RC circuit and a physical button which will act as a switch to control the flow of current. The capacitance will be set at 10 μF and the pull-down resistor at 10 KΩ. A bigger button will be placed so that it is exposed and accessible from the outside of the casing, for fast and easy resetting. The capacitor is connected to the input voltage or V_{CC} and connected in series with the resistor which will be connected at the other end to ground. The button will be connected in parallel to the capacitor, shorting it whenever it is pressed and driving the current through the pin and causing the reset. Finally, the pin will be connected in between the capacitor and resistor. This provides for a working reset button, ideal for troubleshooting.

Finally, there is the serial communication pins necessary to program the device. Since the device is to be programed through the Arduino Uno, which has its own microcontroller removed and only the FTDI chip is used, there needs to be connections made between the pins pertaining to RX and TX on both the microcontroller and the Arduino Uno respectively. These connections are simply done with wires. What is important is to leave the mentioned pins accessible in the PCB circuit as they will provide for all the programming needed for the project.

5.1.7.2 LCD Interfacing

The LCD used in this project provides for the parallel type of interfacing where either 4 or 8 data lines are connected to transfer the desired information to the display. Even though the selected LCD display for this project is of dimensions of 20x4, for testing a 16x2 display will be used. This LCD has the same pin connections to be able to carry the final design to the final product. The different interfaces are explained in the LCD section in our research, along with the choice selected.

For this project, a 4-bit parallel interface will be sufficient which will only use the minimum number of pins to create the connections. A rundown of the interface connections includes the power supply connections, the microcontroller connections and the LED backlight power supply connections. The power supply connections encompass V_{SS} which is connected to the common ground, V_{DD} connected to the power supply to power the display and V_0 which controls the contrast of the LCD display and is connected to a PWM input. This will be briefly explained in the software design section.

The first part of the microcontroller connections is done using the pins RS, RW and E which are command pins a and will be described in a later section. For this project, RS an E are to be connected to the pins PB0 and PB1. These are automatically set by the included functions in the LiquidCrystal library in the used IDE and can go to any digital pins other than RX and TX. The RW will only be used in write mode, hence it will be connected to ground.

The second part of the microcontroller connections is establishing the data lines. Here, the lines D0 – D3 remain unused for a 4-bit parallel interface as only the last 4 high order bi-directional three-state data bus lines are needed. These lines are D4 – D7. Again, these connections can go to any digital pins other than RX and TX, and here they are set in the ATMEGA328P pins PD4 – PD7. The last connections to mention are the LED backlight power supply, and it is these that light up the LCD panel. As LEDs are diodes, the have an anode and cathode pin. The anode pin is to be connected to the power source through a voltage divider to provide 3.4 Volts throughout, and the cathode is to be connected to the common ground. This ensures the LCD is properly lit, which greatly helps visibility and readability.

5.1.8 Reading Analog Signals

The platform on this project will create power from both a solar panel and piezoelectric transducers that will take the force of a step and convert it into energy. The created energy will be presented through an LCD to observe how much power is being created by the platform, as well as well as observing the voltage, current and power ratings of the battery pack connected to the system, a power reservoir for later charging a device. Since power can’t directly be measured with the microcontroller using the A/D converter, voltage can. This will be the basis for designing a voltmeter and ammeter. And these measurements will afterwards be converted and properly calculated to power through the software. A final schematic will be seen at the end of the Hardware Design section. Late in the section, issues and final circuit designs are discussed and solutions presented.

5.1.8.1 Voltmeter Circuit Design

The microcontroller used in this project has a built-in A/D converter that converts an analog signal to a digital one. Theoretically, the voltage source can be connected straight to the pin and the necessary reading will be done. The issue in most cases is the amount of voltage the pin can handle without the microcontroller suffering any damages in the process. As mentioned before when comparing microcontrollers, the maximum voltage it can sustain is 6 V, but for our design the maximum amount of voltage to be seen is 5 V. to achieve this, a voltage divider will be used to drop down the voltage. A voltage divider consists of 2 resistors, one in series with the output voltage and one in parallel. This output is what is connected to the A/D converter. The voltage can be measured by the following equation:

$$V_O = \left(\frac{R_2}{R_1 + R_2}\right) V_{IN}$$

To measure values up to 50 V, the resistors chosen are R_1 = 91 kΩ and R_2 = 10 kΩ which produce a voltage ratio of 0.1. To read values up to 100 V, the resistors to use can be R_1 = 21.5 kΩ and R_2 = 1.13 kΩ which provide a voltage ratio of 0.05. The group design will not see very large voltages flowing at once, so the second configuration is not needed and the used the values for R_1 and R_2 will be the first pair mentioned. The circuit will be implemented for thee sources, to accommodate the outputs of the piezoelectric sensor, the solar panel and the battery pack to constantly monitor values. These will be connected to the first three A/D converter pins, A0 – A2.

5.1.8.2 Ammeter Circuit Design

Measuring current of a source with a microcontroller is not as straight forward as measuring voltage as the A/D converter pins can only measure voltage signals. To measure current one must measure the voltage coming across a resistor and in the software, convert the value to current using the measured value and the known resistor value. This is done using Ohm's Law seen below:

$$V = IR$$

To measure current two resistors will be used, one will be the load resistor which will be of small resistance, but still significant and a shunt resistor. A shunt resistor is a high precision very small resistor of usually less than one ohm and it is used to measure the voltage drop across the resistor which can in turn be used to calculate the current, ideal for measuring current. The typical topology of the circuit is the source, load resistor and shunt resistor all connected in series. This is the ideal circuit as there is very little effect in voltage drop form the shunt resistor and the current can be measured correctly from the load. The output will be connected between the load and the shunt resistor. Here the measured voltage drop will be the product of voltage division and the final measured current will be the voltage divided over the shunt resistor value. For the project, 10 Ω will be used for the load and 0.47 Ω will be used for the shunt. To achieve the very small resistance of the shunt resistor, ten 4.7 Ω resistors were placed in parallel and measured to be 0.47 ohms. This is only done in testing as a surface mount resistor with the specified value will be placed in the PCB. A 100 Ω is also placed right before the A/D pin to ensure that enough resistance is there to protect the device from damage as the pin may provide lower resistance than the resistors having all the current flow through. This circuit will be connected to the input from the sensor, solar panels and the battery where the current will be measured and used to calculate the power.

There are other ways to measure current through a microcontroller using other components. One of these components is a Hall Effect Sensor. This component is a transducer that responds to a magnetic field by varying output voltage. In DC current, this sensor works by using the hall effect to measure the magnetic field produced by current flow around a current-carrying conductor. When the sensor is energized through constant current and exposed to the concentrated conductor's magnetic field, it produces a potential difference that can be measured for calculating current and amplified for larger current signals. This provides for a very precise current sensing device with repeatable measurements, which is worth mentioning. But, these devices tend to be more expensive than shunt resistors with a limited rangeability. For this reason, as well as not needing large amplified currents, is why the shunt resistor is implemented as mentioned already. Regardless, it can still be implemented if need be.

5.1.8.3 Design Constraints and Modifications

As mentioned earlier in this section, the original design implemented a voltmeter and ammeter with voltage dividers created with shunt resistors. This utilized the A/D converter provided by the microcontroller in the system to measure voltage and current created by the platform sources to be able to calculate and display power outputs. As this was implemented and tested in later stages, issues arose where power dissipations in form of heat made this design inefficient. Many different shunt resistor values were tested to find the most optimized design, but ultimately the result did not provide the accuracy that was desired. After testing hall effect sensors and power monitors, the design arrived at the implementation of the high-side I^2C Out Current/Power Monitor, the INA219 for Texas Instruments. This integrated circuit provides for very accurate analog readings as well as power monitoring, ideal for monitoring battery states, current draws and power outputs to keep battery life in check. The INA219 circuit design is thoroughly explained in the following subsection. Buttons are also implemented, a forward and backward cycling button, to cycle through displayed data in the LCD and thus maximizing the LCD screen space and display data for all sources measured.

5.1.8.3.1 INA219 Implementation

To measure voltage and current, the INA219 high-side current and power monitor is implemented with the recommended setup, but with some modifications to tailor to the need of the system. The module receive analog input through IN+ and IN-. To measure shunt voltage, a 0.1Ω 1% 3W is placed in between these pins. A 200Ω 5W resistor is placed between pin IN- and ground to measure bus voltage. Current measurements are also done here. A bypass capacitor is placed between the power supply and ground to filter any noise that may be seen. 10KΩ resistors are placed on the serial clock line (SCL) and another on the serial bus data line (SDA). These resistors are tied to V_{cc} to limit current seen through these bus lines.

The final design aspect sees the address pins A_0 and A_1, which are wired differently through the circuit. Given there are multiple power sources in the platform, three modules of the same are needed to measure analog signals for each source and battery. These need to be wired in a manner that establishes different slave addresses per module while maintaining the use of the same serial lines. The first module address pins are wired A_0 and A_1 to ground for a slave address of 0x40, the second module address pins are wired A_0 to ground and A_1 to V_{cc} for a slave address of 0x41, and the third module address pins are wired A_0 to ground and A_1 to SDA for a slave address of 0x42. This setup allows for the I^2C serial bus to receive measurements from different integrated circuit modules, ideal for our design. All three implemented INA219 IC's are wired equally, minus their address pins.

5.2 Software Design

This section will cover the software design that will be implemented into the ATMEGA328P microcontroller selected for this project. An overview of the block diagram will be presented to give an understanding of the functionality and direction of the program. The section will be divided into subsections to present the different physical interactions with the microcontroller, which require software. A final section is placed to discuss software modifications to suit other modifications to the system, as well as any encountered issues.

5.2.1 Software Functionality

The software has several main functions, but its main function resides in reading the voltage and current created by the platform and displaying the power related to those values through an LCD display. Secondary functions include controlling LED's to turn on/off when the platform is pressed/depressed and to read the current stored power in the battery. These functionalities will provide the user for a real-time update on the performance of the platform as well as the current power reservoir, which can be used for charging a small device.

5.2.2 Software Block Diagram

In this project, the software will use configurations to the analog and serial modules to be able to interface each part of the program and connect it together for a complete project.

When designing this project, several considerations are considered as several analog values are read through the A/D converter, and external devices are also controlled to perform under certain circumstances.

The figure below shows the software flow chart, which roughly demonstrates how the program will perform.

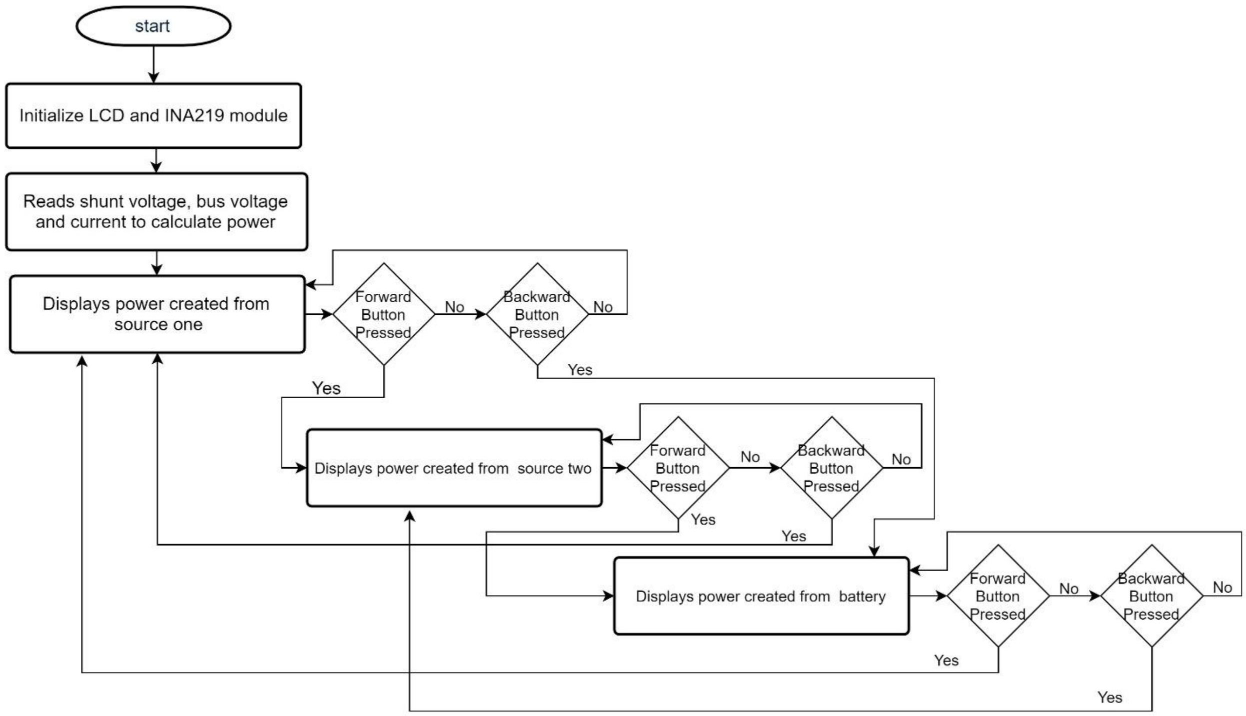

Figure 42. Software Block Diagram

5.2.3 Bootloader

To make this microcontroller run more efficiently, a bootloader is installed to enrich the capabilities of the device and thus ease the programming. A bootloader is a program that initializes the system and allows the device to load programs into it. This program will be run every time the system is reset and will replace each application code at the memory location with a new one each time it is reprogramed as well as starting said application.

Given the group already possesses an Arduino Uno Developmental board, it can be used to both burn the bootloader and program the microcontroller without the need to incur further costs in external development tools.

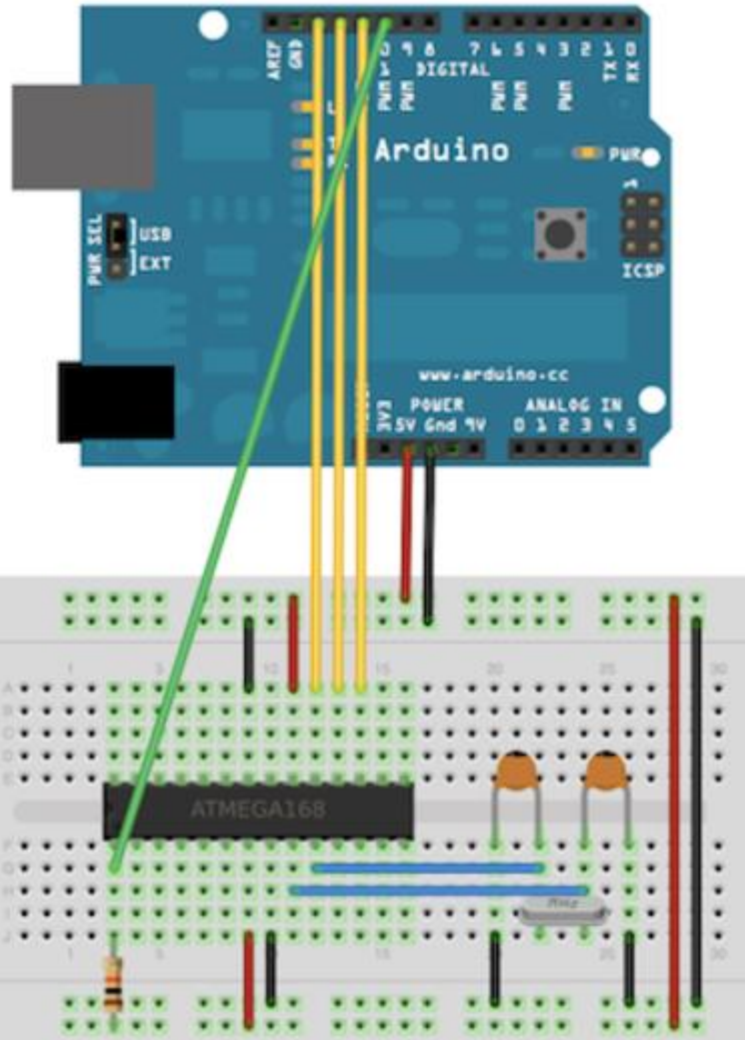

Figure 43. Breadboard connection for standalone ATMEGA328P (Courtesy of Arduino)

From the Arduino Company website, a tutorial is done on how to connect the standalone microcontroller and the development board for burning the programs, along with the necessary external components. This will be useful to set up the microcontroller that will be used in the PCB as well as programming once it's in the board. Here, the serial connections are used to connect to the USB-to-Serial connection, where all the programming will take place. And the program burning will take place by simply uploading a code. This provides for a easier programming environment.

Although in the image a tube type packaging is seen for the microcontroller, a dip socket or a breakout board is ultimately used to program the tray packaged ATMEGA328P microcontroller, which given its smaller size, saves space in the application.

5.2.4 Development Tools

What makes programming possible is the use of an Integrated Development Environment (IDE) that is compatible with the microcontrollers architecture, in this case AVR. An IDE is a software application that provides tools to programmers for developing software and thus improving productivity. For this project, several IDE softwares are compatible and useful, but we will mostly focus on the Arduino Software IDE as most of the testing is done using the Arduino Uno Development Board. The Arduino Software IDE is an open-source software that contains basic necessary tools for writing code, compiling and uploading the code to the microcontroller. This IDE also includes a list of libraries which give the program added functionalities which in turn simplify the code. Being an open-source software, it is constantly being enhanced by the programming community to better suit people's needs which provides more support, many resources for troubleshooting and optimization. This is ideal for the programmer who still lacks some experience with bigger implementations.

Another important aspect is it gives the option to easily install the bootloader, which is mentioned in the previous section and greatly helps the programmer to easily implement code. Lastly it makes for easier serial monitoring as serial communication is done by set functions which can be easily incorporated in the code, and automatically display the data.

The Atmel Studio 7 is another useful IDE to use for programming microcontrollers. Created by the same manufacturer as the ATMEGA328P, Atmel. This IDE is ideal for large projects as it gives enhanced performance with increase editor productivity. Apart from up-to date information on devices, it also allows for low power application designs, software libraries, collaborative workspaces that give access to many other works and optimized code, device specific support and data analyzer. Compilers and debuggers are available within the software or to buy.

The key feature of this software is the ability to transfer Arduino environment created projects directly to this environment with a full transfer of code and libraries. This can prove useful when an issue is present in the code, or when finer tuning needs to be done to optimize. The project in this case will be mostly implemented in the Arduino Software IDE, with the Atmel Studio as a resource, and perhaps the final implementation.

5.2.5 LCD Interface

As mentioned before in the research section, the LCD module comes with different interfaces which vary depending on the programmer's preference and needs. For this project, a parallel interface will be used as it is faster and simpler to implement. The parallel interface in this case will be done using 8 bits. The chosen LCD module, which is a 20x4 character count has 16 pins, each pertaining to a specific function. Here, the data and commands are sent through the data lines D0-D7.

When programing the LCD, there are three main registers to program, the command register RS, the data register RW and the enable E. These registers control how the display runs and displays data, allowing for different displaying configurations per preference. As the name suggests, the RS sends a command to the LCD to perform a given function and the RW reads and writes data to the LCD. While data is being sent to the LCD, the RW register must be set to low to signify to the LCD that data is being written, else it is set to high when data is being read. The other important register is the enable register E which enables the pin form high to low, depending on when the data is sent. Ideally, the enable pin is to be set as low before the data is sent, and then high along with the RS to be able to successfully transfer data to the LCD. To send a command, the enable pin remains high while the RS pin is set to low.

For further configuration of how the data will be displayed, there are several instructions that can be implemented which are established by creating a set of void functions that take the set instructions and configure the display. Some of these instructions control when the screen clears, returns to the home screen, cursor increments/decrements, etc.

Another way to control the LDC is by using the Liquid Crystal library included in the Arduino Software IDE. There are specific set functions that work to display, and modify the data presentation. Following are some of the main functions included in the library.

Functions	**Description**
begin()	Sets the LCD dimensions.
LiquidCrystal()	Enables the pins to be used in the interface to display data.
clear()	Clears the LCD screen and cursor position in upper-left corner.
display()	Turns LCD display after being turned off for a while.
write()	Write character to LCD.
scrollDisplayLeft()/scrollDisplayRight()	Scroll contents one space to the left/right.
serial.begin	Initializes serial communications.
serial.available	Reads all available characters.
serial.begin	Displays the characters read to the LCD.

Table 21. Several Liquid Crystal library functions in Arduino IDE

Here the LCD can be set by the character size, pins used initialized and the data displayed and modified. These present functions facilitate the flow of data to the LCD as well as setting the desired display configurations. Given the data to be presented is more than what can be displayed at a single time in the screen, a function to scroll left is set in place along with auto scroll to automatically scroll left.

Another thing to consider when displaying to the LCD, is to allow sufficient time between the data so as to be able to read anything in a timely manner given the text will be scrolling left. For the delays, these will be implemented in millisecond.

One last thing to mention towards the LCD is the use of the pulse width modulation for setting the display's contrast. In most designs a potentiometer is used to regulate the contrast with the provided dial, but we desire to eliminate this bulk component. A PWM pin is then used to control the contrast pin in the LCD. This is set using the function analogWrite() where an analog PWM wave value is written to the pin. The value used regulated the duty cycle of a steady square wave created by the pin. This value to be written was modified several times to arrive at the number which gives a desired contrast.

The one selected for the project is 130. This gave the perfect contrast for viewing. And the LCD is also initialized with the character dimensions.

5.2.6 LED Interface

For this project, the LEDs selected for the project are an RGB LED strip. Here, an LED strip will be placed inside the platform casing to light up when the platform is stepped on. Some configurations regularly go with the implementation of LEDs such as brightness modulation, how the lights will behave in terms of light-up patterns, any needed delay, and when they need to be on or off, depending on the design. Usually a connection and control to LEDs is done with MOSFETs which help sink them to ground as well as control brightness of each individual color in the strip. This is done with configuring the pulse width modulation (PWM) module, which each pin is connected to the PWM pins available in the microcontroller. In terms of code done to configure the and control the LEDs, the pins are set as outputs, the analog input used to control the fadeout form colors and a delay set to control the blinking of each.

For this project, due to monetary and space constraints the LEDs will be simply turned on and off when the platform is either pressed or depressed. Brightness modulation will not be done as it requires more components. And given all the LEDs will turn on simultaneously only when needed, delays will not be needed. The function to turn on and off will be controlled simply by a button that will act as a switch allowing power flowing through only when the button is active low, and cut current flow when the button is active high.

5.2.7 ADC Configurations

This project will produce AC and DC voltages which will be measured by the microcontroller to calculate voltage and current and thus power to inform the user of the power created by the platform. The AC voltage, created by the piezoelectric sensors will be converted into DC voltage to arrive at a uniform DC power reading. Since the ATMEGA328P can’t sustain voltages larger than 6 V without suffering hardware damage, the incoming voltage is divided with a voltage divider. Inside the program, this read voltage will be converted back to the expected measured value through computation to provide for an accurate reading. To achieve all these readings, the built-in A/D converter will be configured to receive analog these signals and properly convert it do digital values that can be transferred to the LCD.

An A/D converter is an analog module which converts an analog signal, usually a voltage on a pin, to a digital value. There exist different A/D converters that provide different parameters of accuracy. Some of these are Flash ADC, successive approximation and sigma-delta. The flash ADC user a single comparator per voltage step and a string of resistors making it the fastest type. The comparators used are 2 times to the ADC bit, and these are very power consuming. The second ADC is the successive approximation converter which uses a counting logic and comparator to perform the necessary conversion, but takes a toll on clock cycles. The last ADC is the sigma-delta which uses 1-bit DAC, filtering, and oversampling to achieve extremely accurate conversions controlled by the input reference and the input clock rate.

Different resolutions are also seen with the ADC, which in turn affect the precision and efficiency of the module where they vary from 1, 4, 8, 10, 12-bit etc. What this means is that higher bits allot more space for value digits which increase the readings precision. The ATMEGA328P's built-in ADC includes 10-bits.

To utilize the A/D converter, several calculations need to be made to arrive at an accurate digital representation of the readings based on the 10-bits provided for the conversion. This 10-bit ADC can detect 2^{10} = 1024 discrete analog values making this the module's resolution. Sample and hold is also built in to help obtain more accurate readings.

It is important to remember that for measuring the analog signal, a voltage divider is present to regulate the input voltage to at least 6V, the maximum allowed to the pin. This is further explained in the hardware design section. To calculate the resolution for this project, the following equations apply:

$$ACD = \frac{V_{IN} * 1024}{V_{REF}}$$

$$Resolution = \frac{V_{REF} - V_{REF-}}{1024}$$

This equation determines the amount of voltage seen per every one increment of the ADC value, and thus the voltage steps between each digital value. For the project, a V_{REF} = 5V and V_{REF-} = 0. In this case the resolution yielded would be in the order of 4.9 mV per each digital voltage.

The Arduino IDE that is used caries the analogRead() function that reads the value for the specified analog pin. This function uses the analog resolution to calculate the input analog voltage to show it in the LCD.

5.2.8 Digital Voltmeter

To measure the voltage created by the piezoelectric sensors and the solar panel, a circuit consisting of a voltage divider is done to cut down the seen voltage by the pin. This is seen in the hardware design section. When it comes down to obtain the digital signal of this voltage, as mentioned in the previous section, the A/D converter is used to convert the signal which can be used to display the value obtained from the measurements. From the ADC section, the resolution calculated is used to calculate an accurate reading of voltage that is represented by the 10 ADC bits. The voltage is first obtained from the ADC reading and then the digital voltage value is calculated by the following equations:

$$Voltage_O = Analog\ Voltage * Resolution$$

$$Digital\ Voltage = \frac{Voltage_O}{\left(\frac{R_2}{R_1 + R_2}\right)}$$

Lastly, the value is turned into a string that can be read through the LCD. This is done using the serial functions for the Arduino.

5.2.9 Digital Ammeter

Measuring the created current from the platform can be quite tricky as the microcontroller only read voltage values. A circuit using resistors, and a shunt resistor, a very small precise resistor, the current can be measured as the voltage drop in said shunt resistor. The circuit design is seen in the hardware design section. Very similarly, the voltage is collected through the ADC read function from the pin and converted to a digital value as seen in the previous section. It is important that the measured voltage value used to calculate current is the one through the shunt resistor as it provides the most accurate value. The value of said resistor is considered as it is used to revert the voltage to current through the following Ohm's Law equation:

$$I = \frac{V_{shunt} * Resolution}{R_{shunt}}$$

This equation will ensure that the correct value is calculated with the best precision possible.

5.2.10 Power Calculations

This part of the program is essential to the project as it provides the user with a specific output of the power made by their step and the solar energy collected by the panel. Once voltage and current have been converted to digital values and calculated, these values can be used to calculate power. The equation of power is given by:

$$Power = V * I$$

A very simple calculation is done to obtain the final result, which will be outputted through the serial function within the library. Another important factor is establishing an endless loop which can be accomplished by a while loop that is always true. Inside this loop is where the ADC readings, the calculations and the LCD printings will reside. Any other initializations of pins, LCD, ACD and variable declarations can be done outside of this loop. The purpose of this loop is to provide constant endless update to the information presented as ideally the platform will be constantly creating energy, be it by step or solar harvesting. Delays may also be necessary to provide for timely displaying of the information.

5.2.11 Battery Interface

An added feature to this project is the ability to measure how much power is stored into the battery. This is useful when charging a hand-held device, as well as monitoring the health of the battery through its performance. The interface will be done the same way as how the current and voltage was measured for the platform. This will also reside within the while loop to constantly provide updated values.

5.2.12 User Interface

What constitutes the user interface for this design is the option to view the data collected through the A/D converter and outputted to the display. The display in its self in not interactive other than providing for an automatic scroll to view the data, as well as delays to manage data with a manageable pace. The real interaction lies with the platform itself and the ability for the user to see real-time energy logs that come from their energy generated step. As well as providing visual interaction with the LED lights, an invite to continue stepping on the platform.

5.2.13 Software Design Modifications

Given the original design to implement voltage dividers and use the built-in A/D converters provided by the microcontroller was not entirely successful in producing optimized results, the INA219 is implemented successfully into the circuit as mentioned in the Hardware Design section. At this point A/D resolution configurations are not needed and discarded, along with any previous measurements done. To incorporate the power monitoring module, a library from Adafruit is used to better access the inputs, but calibration registers are modified to achieve the highest A/D resolution the module can provide. Since three different modules are used, they are assign different hexadecimal slave addresses per their hardware setup to be able to access the data collected from all modules through the same I^2C serial lines. To make power calculations, current, bus voltage and shunt voltage are measured. Bus voltage and shunt voltage are added to obtain the load voltage noting that shunt voltage is in mV, bus voltage in V and current in mA respectively. Conversions must be made to avoid calculation errors. These measurements of current and load voltage are used to calculate the power. This is done for all three modules where voltage, current and power outputs are displayed for each measured source to observe all this data two buttons are programmed into the software, one forward and another one backwards to cycle through the displayed data. Lastly, different delays are set for measurement sampling and button response when screen cycling. Note that an initial project title appears every time the system is turned on for approximately 2 seconds.

5.2.14 Design Summary

The software described will mostly employ Arduino Software IDE libraries to facilitate and optimize the code. The main goal for this software is to convert analog signals into digital and have those values displayed in an LCD module for easy viewing as well as to keep track of the productivity and overall health of the product. As well as maintaining the interaction that takes place with its individual subparts. As mentioned before, the software utilizes the INA219 as a power monitoring system with its built-in A/D to measure analog signals and calculate power outputs all for observing product efficiency and performance as well as the battery’s health and power draws. Overall, it performs a series of simple yet necessary calculations as well as the manipulation and configuration of LCD ad cycling buttons to display such data. Within this design, space and monetary constrains were considered and helped shape the path taken to achieve the explained design.

5.3 PCB Design

The PCB design for this project was created using all the above mentioned steps. As stated before, the ability to complete all these steps was possible due to one of the group members having access to all the necessary machines and resources from their internship and receiving permission to use all the required machines and software.

5.3.1 Layout

The software design of the PCB was accomplished using KiCAD which, mentioned before, is a free open-source community program. The method of using a two layer board with vias is shown in Figure # to prove that it was absolutely necessary due to the complexity of the connections based on pinouts of the microcontroller unit and the other components on the board that were all connected to it. The red is the top copper layer and the green is the bottom copper layer.

One of the main issues was being able to route all the traces from the voltage regulator and the microcontroller unit to the other components which was only possible due to making the right decision of a two layer board. The component footprint placement was carefully decided and shown to be the most efficient location on the board to make the board as small as possible while still making sure there was enough room between each component to avoid any capacitive or short circuit failures.

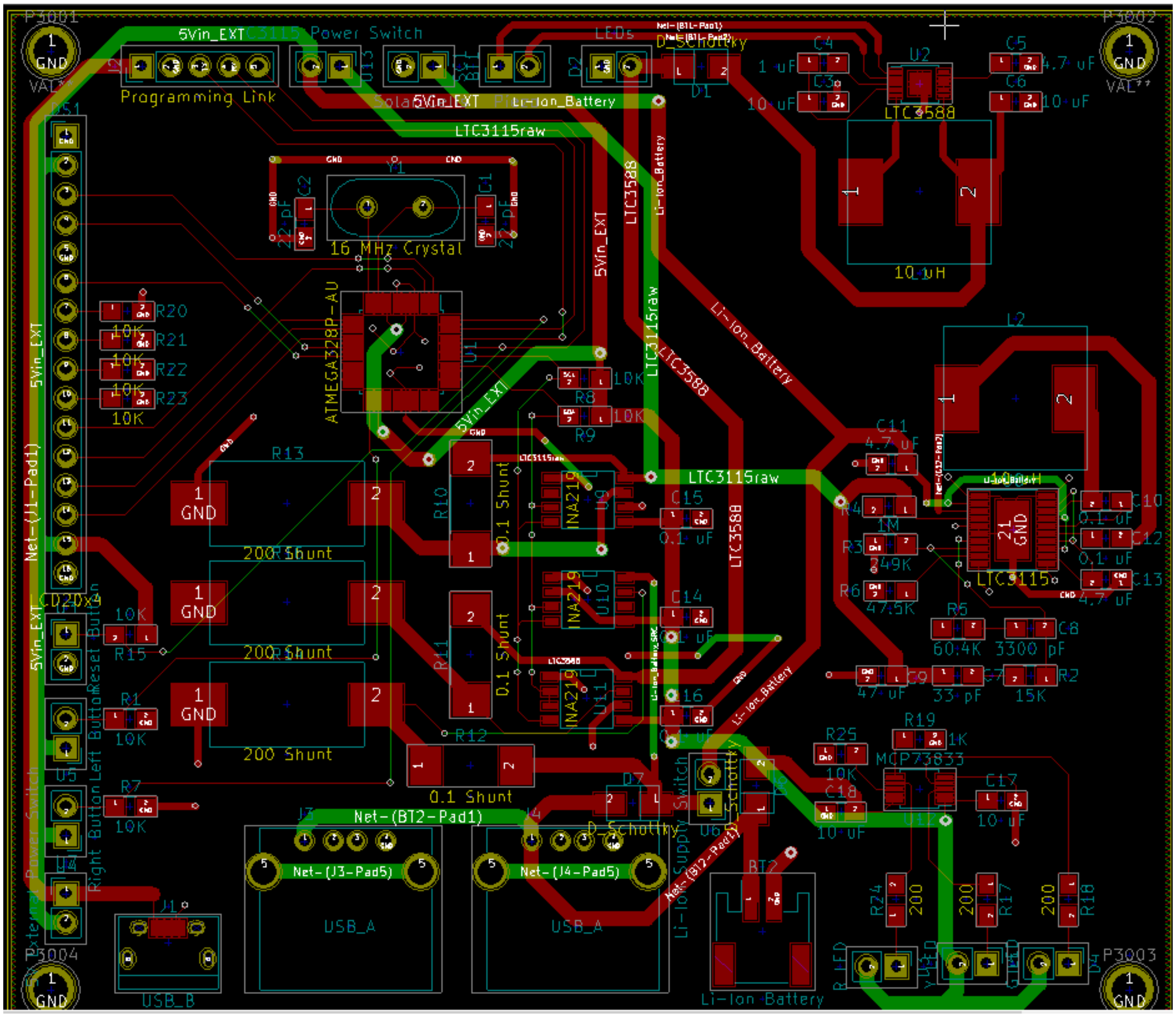

Figure 44. PCB Layout

5.3.2 Zones

One of the important aspects of designing the PCB was making sure that all connections are secure. This means that every connection to each component is isolated and that every other connection, such as ground, can be the common plane. This application is shown in the figure below, where the yellow part is the ground layer. This zone was created so to prevent any short circuit failure.

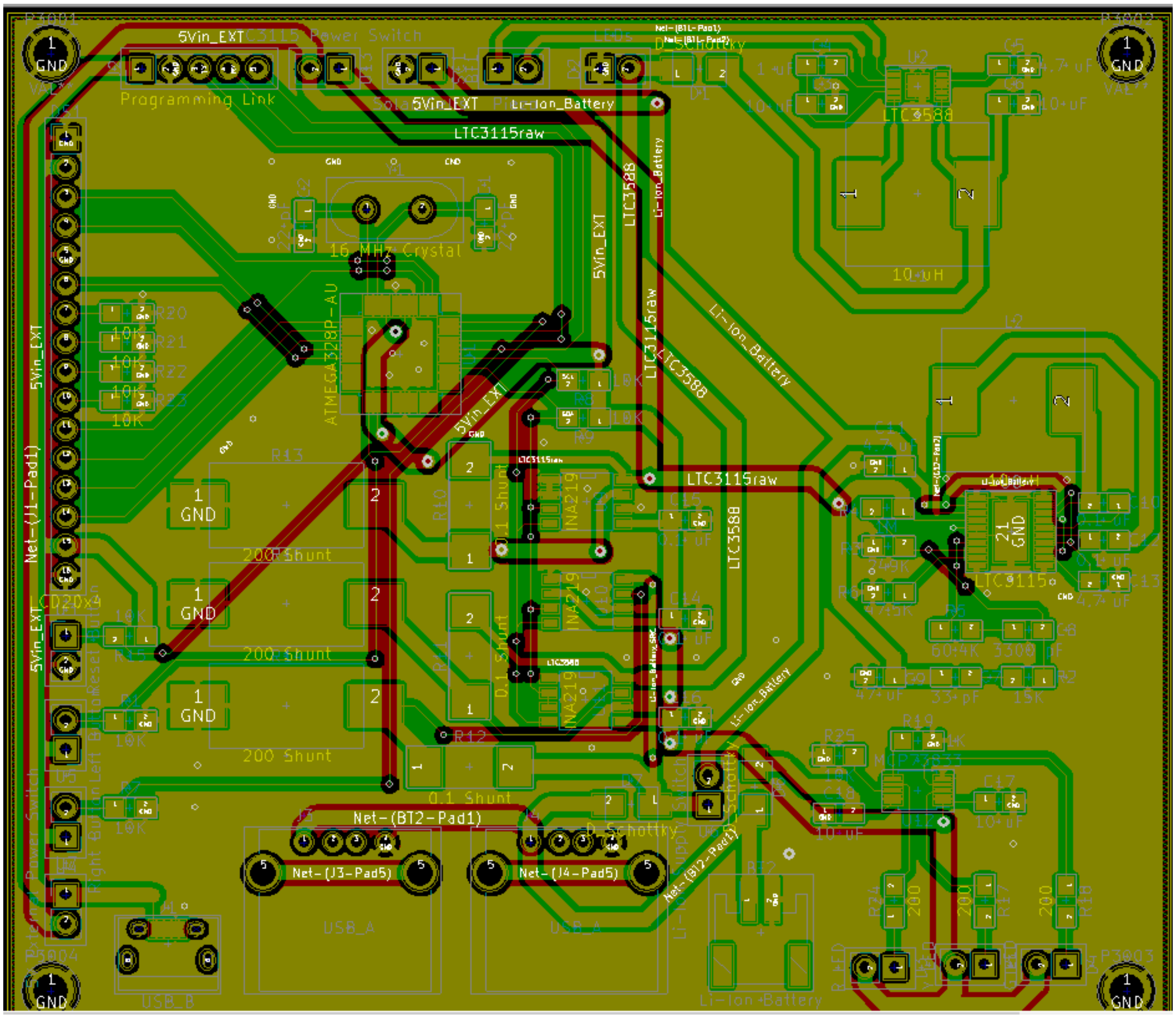

Figure 45. PCB Zones

The 3D view of the PCB design has been provided for educational purposes. This gives an insight to how the final PCB product should look like after completing all the steps in the PCB design and assembly. It is a realistic representation of the PCB and is to-scale of how all the components will look so that whoever follows the design of this project, knows that the PCB should end up looking like figure below.

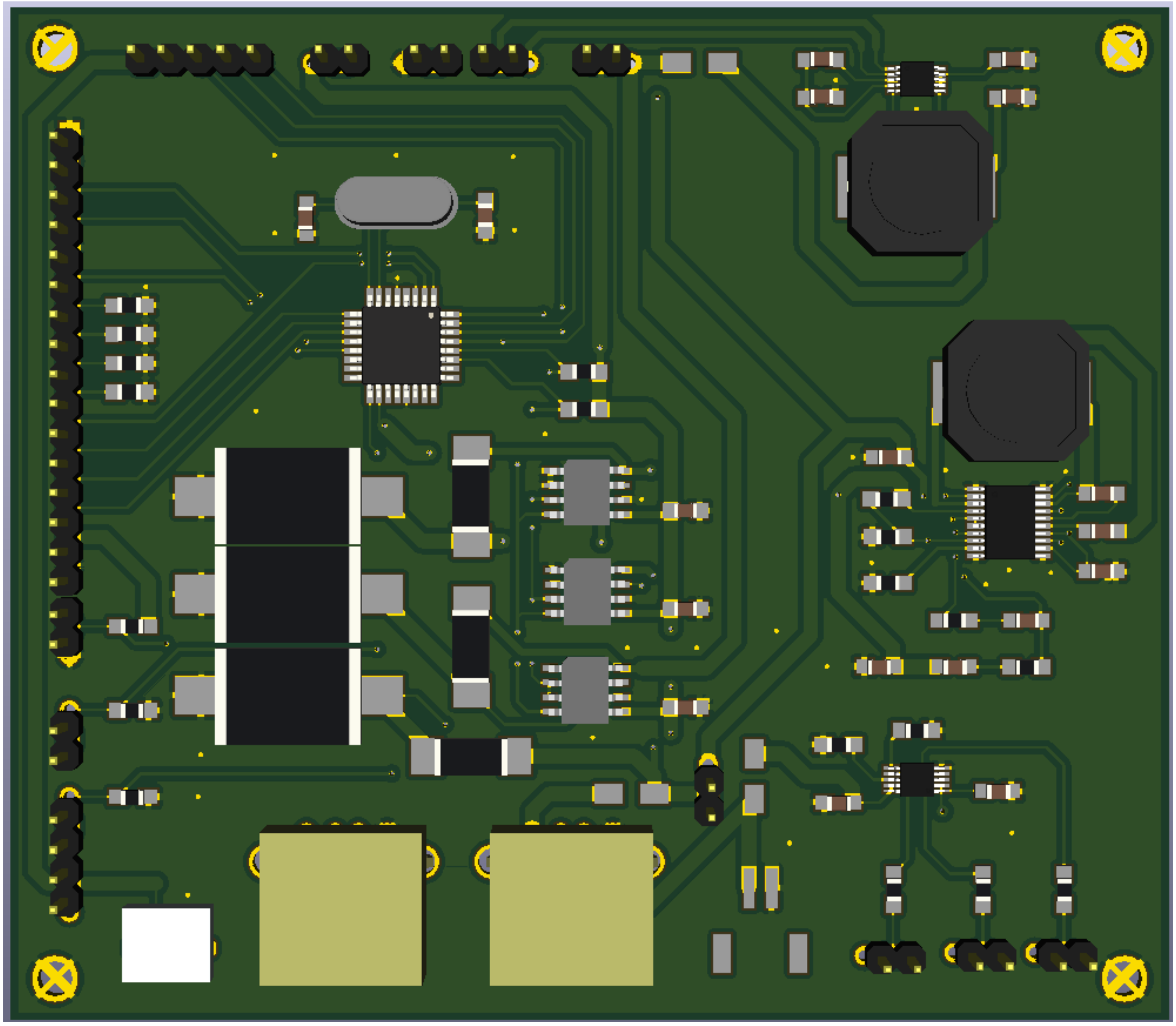

Figure 46. PCB 3D View

5.3.3 PCB Schematic

The figure depicted above shows our PCB layout of our final hardware design choices. This schematic will ultimately be transformed to create our PCB design. Tracing the design of our PCB, we can see our piezoelectric input will be connected the LTC 3588 Piezoelectric Energy Harvesting Unit. The output of the rectifier passes through a capacitor and a resistive load that will help smooth out the AC voltage into a DC voltage. The output is also connected to our chosen voltage regulator, the LTC3115-1. The LTC 3115-1 can take a wide input voltage range and output a constant 5V, 2A, once connected to all of the external electrical components and given the input voltage is above 6V. Also connected to the input of this voltage regulator is the solar panel. The voltage will be stepped down as well to output 5V, 2A just like the piezoelectric input. The output of the regulator is then sent to the MCP73833, our lithium-ion charger, which is then connected to the battery and the cell phone. The MCP73833 will prevent overcharging and well as block reverse current from the output.

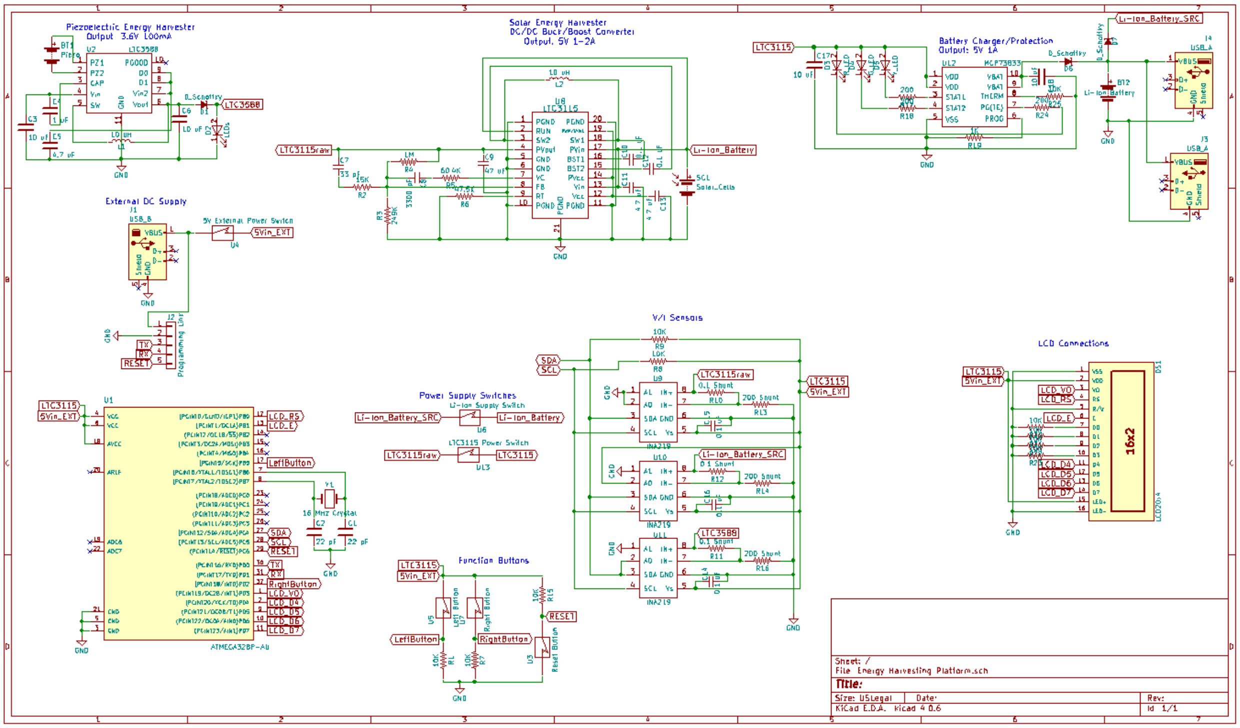

Figure 47. PCB Schematic

To verify how much power is being generated from each input source, a microcontroller connected to an LCD display is utilized. Input from the piezoelectric discs are sent through the INA219 to the microcontroller to ensure the voltage is low enough to be handled by the microcontroller. The pins are then read, calculations will be performed by the microcontroller to solve for the input voltage and that value will be sent to the LCD display. Input from the solar panels will also go through a voltage divider, be read by the ADC pins on the microcontroller, the actual input voltage will be calculated, and will be sent to the LCD display. To read the battery values, the same process will occur and will be displayed on the LCD.

5.3.4 Breadboard Design

As seen in the below figures, these are the final hardware decisions for the breadboard layout. In the bottom breadboard, we have the piezoelectric discs connected to the full wave bridge rectifier, which then connected to the regulator. For the solar panel, we have the leads plugged directly into the input of the voltage regulator. In the top breadboard, we have the microcontroller connected to the LED display. Connected to the LED display is the output of the voltage regulator from the bottom breadboard. Also connected to the voltage regulator is the input of the MCP73833, whose two outputs are the lithium-ion battery and a cellular device. Visible in the figures as well, is the battery icon on the cell phone which indicates that phone is charging, and that all the components in this circuit design is functioning.

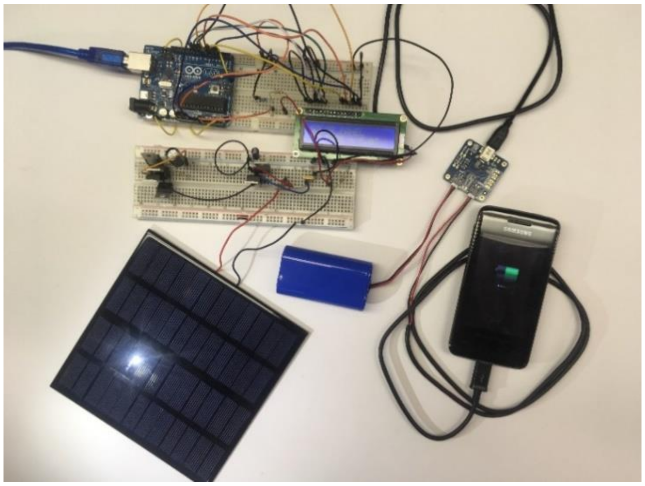

Figure 48. Solar Panel Breadboard Design

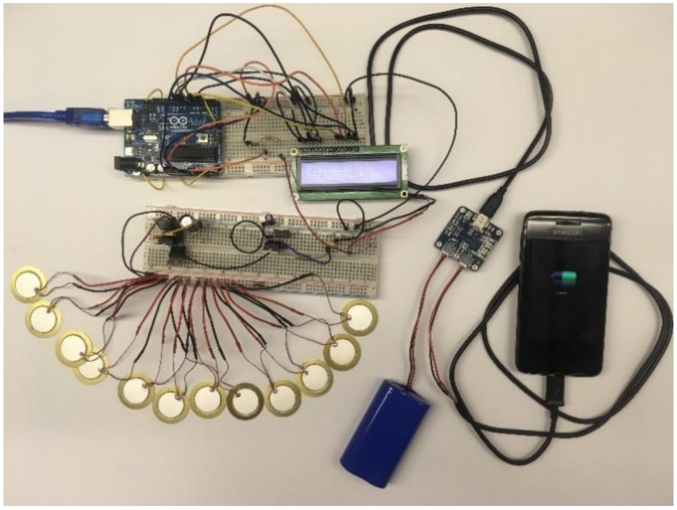

Figure 49. Piezoelectric Breadboard Design

6. System Housing

This section describes the casing and chassis for the project. As the platform will be placed at places with human traffic and could be placed out on the road, the design of the housing needs to be able to withstand constant pressure as well as the weather. As it is placed in the ground, the housing must be able to prevent water from leaking in and damaging the electronics inside.

6.1 Chassis Design

The platform is designed to be a square for ease of installation. Four springs will be placed at each corner to provide stability and compression. Each of the springs will have its own casing. The spring casing will also act as a mechanical stop to stop the top half of the casing from over compressing and damaging the piezoelectric transducers. In the center of the Platform, twelve rods will be placed. These rods will be what presses on the piezoelectric transducers to generate the voltage and current. There will be a total of twelve transducers placed and all of them will be wired in parallel configuration as stated in previous sections.

A separate casing will be made for all the electrical components for the tile. Spacing for the components and wires will be added as needed. The two platforms will be connected together through the spring and spring casing with a wire for the solar panel to charge the battery. The entire dimensions of the tile will be 12.5 inches in width by 12.5 inches in length and four inches in height.

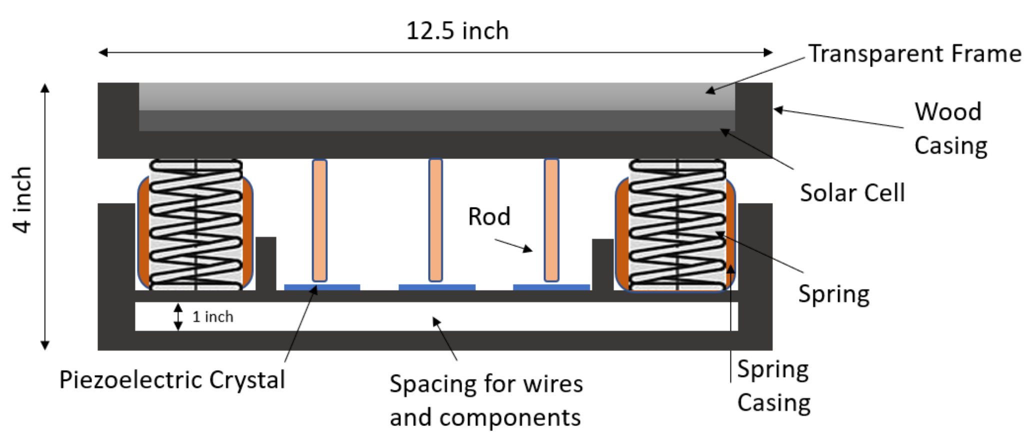

Figure 50. Chassis Internal View

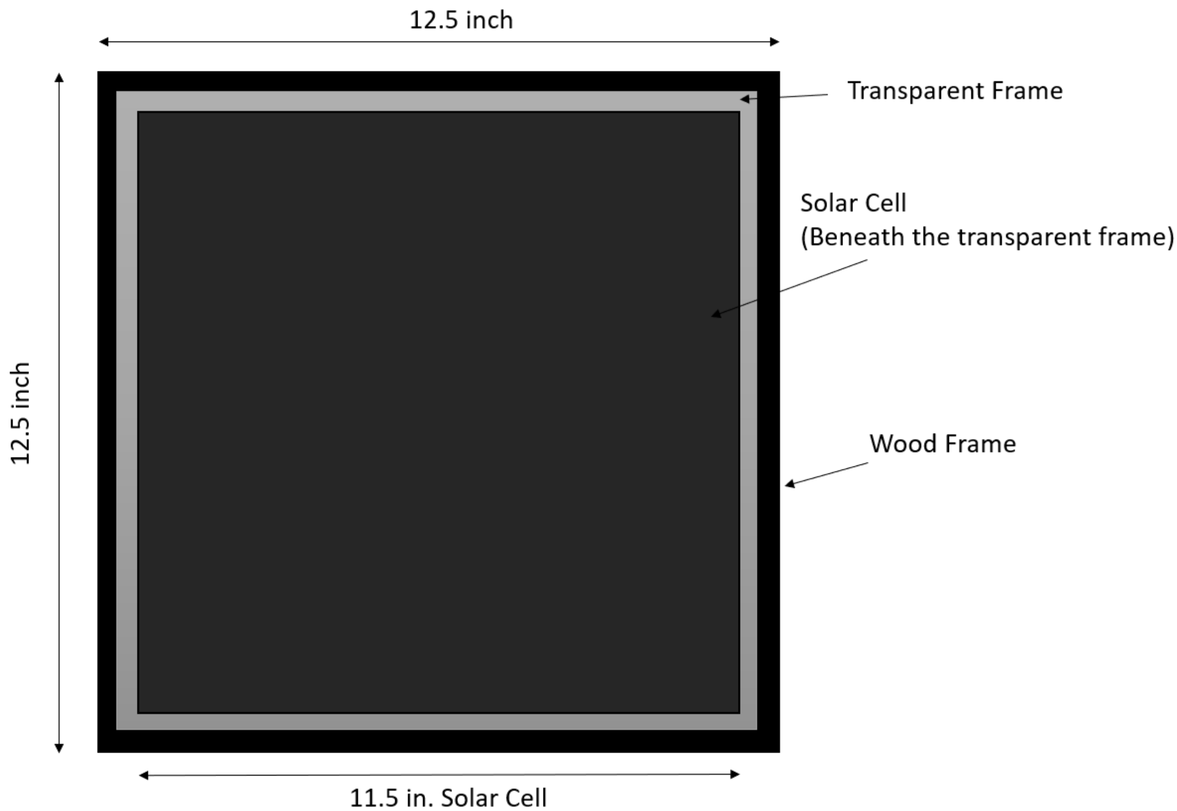

Figure 51. Top View of Chassis

As shown in the figure above, solar panel is 11.5 inches by 11.5 inches. The acrylic top will be twelve inches by twelve inches. This leaves enough space for the entire solar panel to be exposed to the sun when left outside. The acrylic will be surrounded by wood to prevent it from moving. The acrylic will also be glued to the wood using epoxy glue. This will prevent the acrylic from falling when the Platform is flipped. The epoxy glue will also prevent water, dirt, or other elements from seeping into the Platform and causing damages to the solar panel and LED light strip.

As shown in the figure below, the casing of the Energy Harvesting Platform will be a rectangular prism made out of wood. In the final process of staining the wood for preservation and protection, the group will also be painting the exterior casing black. The black section shown in the figure indicates the solar panel. Although it does not show clearly, two transparent acrylic sheets will be placed in the indent between the wood and above the solar panel. LED strips will be placed in the space along with and surrounding the solar panel. Each section of the Platform will be secured with nails screwed in at the four corners.

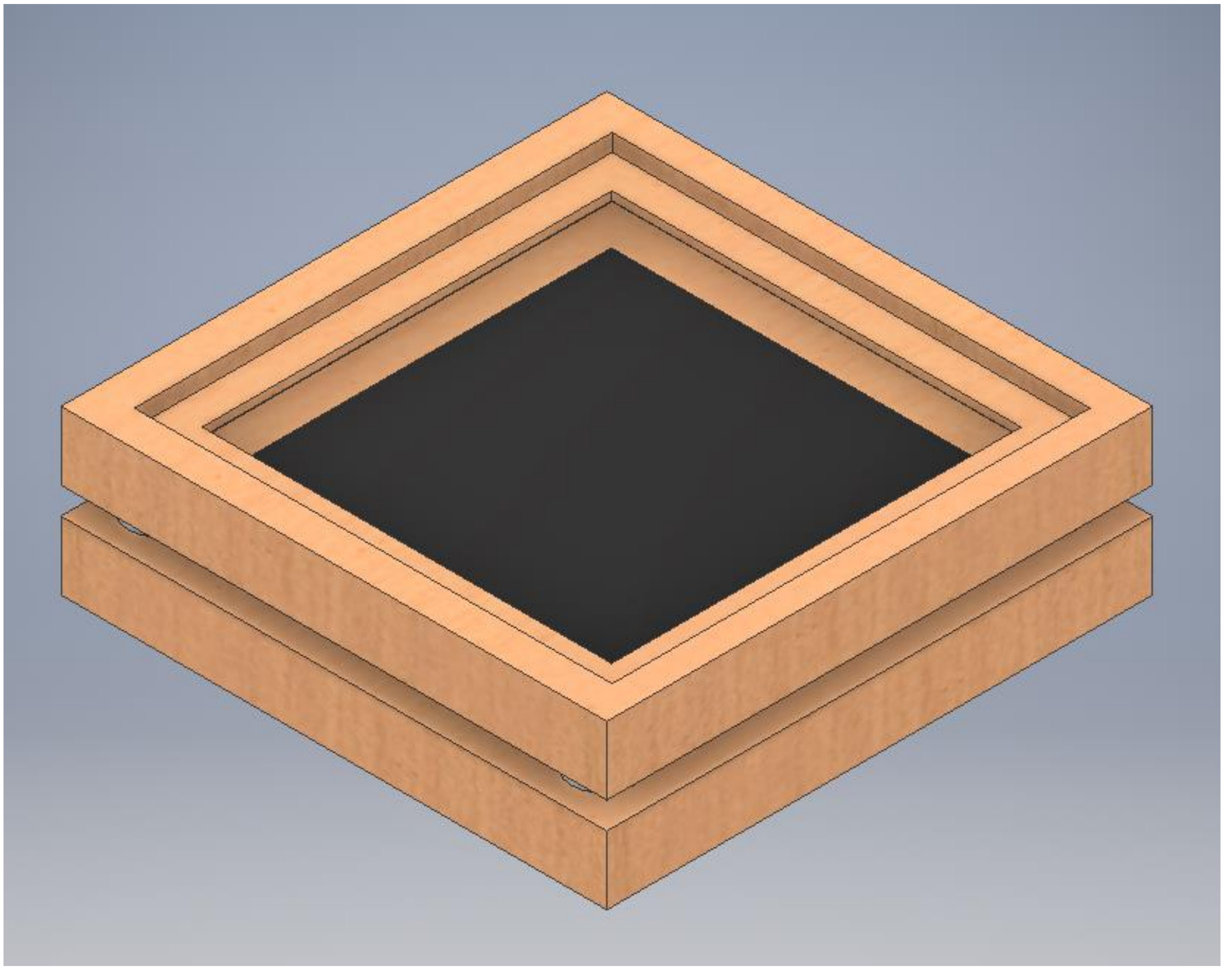

Figure 52. 3D Modeling of Casing

The space between the two parts of the Platform is the height necessary for the compression to apply enough pressure on the piezoelectric transducer to generate the power needed. We have found that the piezoelectric transducer can generate fifty volts if the rods presses the transducer down about one to two millimeters. Pressing down more than two millimeters does not increase the amount of voltages or current generated and could also damage or crack the transducers. With that calculation in mind, the spring casings are set to the height in which the rods will press down on the transducers exactly at two millimeters.

From the top of the panel, we will only be able to see the casing and the solar panel underneath as well as the LED light strip surrounding the solar panel. From any of the side views, the person will only be able to see the casing, part of the rods and the spring casings. An updated version of the Platform will be made to cover up the open space to prevent water or dirt damages.

6.2 Weatherproofing

During the lifespan of the platform, they will most likely be exposed to all elements of weather, most commonly the rain. In order to prevent the rain from damaging the electronics within, the casing of the tile will be completely sealed. During rainstorms, debris may fall on top of the Platform. The Platform must be sturdy enough to prevent cracking or breaking from said fallen debris. If the Platform is implemented in the states or other countries, the Platform are subject to be exposed to snow, hail, sand, and extreme heat or cold. In order to save time in the future from having to design different casing for different locations, the design for the Platform during the development and planning phase will have to include these conditions as potential hazards.

As the rain or other elements may also damage the casing itself and cause corrosion or insect damages, the casing itself will need to be protected and covered in preservative materials. During the research phase, we have found that marine use epoxy glue is best for the intended use of this project, as the epoxy glue can be applied as extra coating, and once it hardens, it will be weather resistant as well as insect resistant. However, due to our limited budget, we decided to go with using wood stains and spray paint used on ports and docks. Although this material is not ideal for the project, it provides enough protection for the Platform to be used during testing and use in Orlando Florida. If this project is to be mass produced and sold commercially, then the group will be swapping out all the casing components into the ideal parts for maximum efficiency as well as looks and durability.

As the Platform will be placed in the ground, there may be possible dirt damages. Dirt may fall onto and inside the platform whenever the platform is pressed. If the dirt stacks up and condenses, it may prevent the Platform from being compressed. The group also had to consider the spaces between the individual Platforms. If too much dirt or rain water gets in, it may damage the Platform casing or create other problems with compression.

6.3 LCD and Charging Port

The LCD and charging port for external devices will be connected up and out of the ground for people to access. A smaller, separate casing will be made for the LCD and the charging port. This small port will be connected through the bottom of the casing and covered by heat shrinks to prevent external damages. This external housing will be self-designed and made out of wood so it can be laser cut easily. This can also ensure a perfect fit for all of the components.

6.4 Considerations and Cost

One option for the chassis would be to buy pre-existing casing such as photo frames and swap out the glass with sturdy, transparent acrylic sheets cut down to size. By doing this, we could save time and use it for endurance testing. This option will be cheaper than buying materials and creating a frame by ourselves. However, by using photo frames, we will only be able to create half of the chassis, which only covers the surface where people step on, and the solar panel below it. The chassis for the other electrical components, the springs, and the piezoelectric crystals will still need to be self-designed and implemented in. With the dent of the photo frame, the Platform will not be a flat surface. When stepping on the frame, the user's step will sink down before the Platform compression, and may cause a misstep, leading to injuries.

The ideal design for the casing of the Energy Harvesting Platform cannot be bought locally or online, the casing will have to be self-designed and manufactured. Although choosing to do this, it will be slightly more time consuming and more expensive, this can allow us to make sure the chassis is durable, long lasting, and fits all the components correctly.

The group decided to design and manufacture our own Platform casing. This will prevent unnecessary complication and we will be able to edit the design as needed until it is satisfactory.

6.5 Material

Out of the wide selection of materials, the group decided on using wood, acrylic, 3D printed PLA plastic, springs, and machine screws because these materials fit into our budget and the materials are accessible to us. These parts are also easy to work with, allowing us to save time and difficulty. If any parts end up not fitting, we can make changing quickly by simply buying or printing new parts.

For the wood exterior casing, the group decided to go with using Birch wood. This type of wood is common for crafting and small project and can be bought in craft supply stores and home improvement stores. This type of wood is not really the ideal wood for our project, as the wood can be subject to corrosion and insect damages. The ideal wood for this project would have been the White Cedar wood as described in the Research section of the report. White Cedar is mainly used for outdoor projects such as canoes and fences. It has some natural abilities to prevent weathering and insect damages. However, due to budgeting and ease of crafting reasons, the group decided to use birch wood. The group will be able to cut and process birch wood using laser cutters for speed and accuracy. With proper preservation materials, birch wood can be protected from weathering and insects as well.

The wood preservation material the group decided on is wood stain. This wood stain is used on porches and ports. This wood stain wood preservative is also not the ideal preservative for out project. The ideal preservative would be Epoxy resin. As epoxy resin cures, it will harden and add additional protection to the casing. However, as epoxy resin is more commonly made by mixing two solutions, the resin and the hardener, epoxy resin is usually expensive. The reason we chose to use common wood stain is also because of budgeting reasons. As before, if the Energy Harvesting Platform will become sold commercially, the casing materials will be swapped out for better ones. The most ideal casing will be made out of stainless steel or ceramic, as it prevents weathering and insect damages and also increase in durability and life span. Once again, if the Energy Harvesting Platform will be sold commercially, then it would be best to use Epoxy resin. However, if the group decides to use some type of metal or ceramic, then epoxy preservation is not necessary.

The group is using 3D printed plastic for the spring casing and as the rods that pushes down the piezoelectric transducers to produce the current and voltages. We originally thought that we would be able to find materials that could be used as replacements, such as PVC for the spring casing. However, with the springs that we found, we were unable to find a PVC tubing that fits the springs perfectly. By 3D printing the parts we will be able to set all the pieces perfectly and adjust as necessary. The PLA plastic is the more commonly used plastic for 3D printing, although there are times the print does not come out perfectly, PLA is easier to heat up and produces less problems than ABS plastic. The PLA plastic 3D printed parts are sturdy enough to press down on the piezoelectric transducers and also prevent the Platform from being over compressed.

For the springs, the group decided on using normal springs instead of rubber springs. Although rubber springs are weather proof, normal wire springs are easier to obtain and the sizes are smaller. As we need to add in a mechanical stop to prevent the springs from over compressing either way, it was easier and cheaper to buy and use normal springs instead of rubber springs.

For gluing and connecting the casing, the group chose to use sheet metal screws and epoxy glue. No matter which screws the group decides to use, the end results will be similar. The group chose the sheet metal screws based on the screw sizes and no other particular reasons. In terms of glue, there were multiple choices. The group ultimately decided on using epoxy glue because once the glue cures, it will be transparent. Wood glue is good for bonding wood, super glue is strong but could weaken depending on the type of material it is bonding. Compared to other glue, epoxy glue is a lot stronger when combining two different types of materials. In our case, as we are bonding wood and acrylic, epoxy glue would best fit our needs.

7. Testing

All products need to be tested for safety and functionality before it can be sold. To ensure successful creation and implantation of the Energy Harvesting Platform, all the parts, software and hardware, will need to be tested and made certain functionality and performance.

This section describes and outlines the software, hardware, simulation, and product testing procedures for the Platform.

7.1 Software Testing

Each software component must be fully functional in order for the project to work. If any component fails, the Platform will not work properly. In contrast with hardware testing, software testing can be performed much easier, as the tests can be done on the computer without any hardware components. If there are any errors in the code, the code can be broken down into sections for individual testing to find the error.

For the Energy Harvesting Platform, it will consist of a few major software programs:

- Controlling LCD Display
- A mode to switch between displaying different information
- A switch to turn off LCD after a moment of not being used
- Reading voltage and current input for:
    - Piezoelectric sensor
    - Solar Panel
    - Battery
- Calculating power from collected data

7.1.1 LCD Testing

After the microcontroller and the LCD have been connected, the testing begins with a simple code to print a message to the display. Once the program was uploaded to the microcontroller and ran, it displayed the message string. Here, there is testing with printing different characters, as well as where the cursor will be placed in the LCD by column and row when the program first starts. Another function is used to scroll the string to the left when there is too much data to display at a time. This addition to the code is tested to verify scrolling is done properly as well as verifying that the added delay is adequate to still read the data before and after it scrolls. Another method to switch between display is with the use of a button or a timer to change the display to the next set of data. This last method is quickly tested with the use of a delay, and if statements to maintain the information current until it needs to be updated, all residing inside the loop function.

Lastly, there are two functions that deal with turning on and off the display without losing the data. This is useful for conserving energy and elongating the life of the LCD, as there is no need to have the display on when not in use. Here the display() and nodisplay() functions are used along with a check to the analog pins to make sure that no data is being recorded. If so then the display turns off, and inversely the display turns on when data is being measured. A delay is set as well. Here, some time is waited without analog input until the display is turned off. Data is then inputted once the display is off and it is observed that commencing activity turns the display on.

7.1.2 Voltage and Amp Meter

This part of the program was initially the most crucial as it processed the created values to data we can read. First the ADC resolution is calculated with a reverence voltage of 5 V. this is used throughout the calculations. An analog value for voltage is received from the voltmeter through the A/D pin. As well as a voltage from the shunt resistor in the ammeter circuit. These values were used to calculate digital values for current and voltage. Once the calculations are placed, the program is run to verify the accuracy of what is outputted, showing the final values on the screen. If nothing is inputted to the microcontroller, then the values are zero. After encountering issues with the voltage and amp meter, the INA219 is implemented. This is tested with a DC supply to observe all the voltage and current values are correctly outputted. Afterwards, power calculations are done as mentioned in the next section. Testing is also done for voltage and current measurements for multiple modules at once this proves successful with high accuracy.

7.1.3 Power Calculations

Power calculations are done quite easily as the calculated current and voltage will just be multiplied together. At this point, the power from the piezoelectric sensor, the solar panel and the battery are to be displayed. The testing first started with DC source input values where verification of the correct power value was obtained. This required some trouble shooting with calculations to obtain the optimal result. Once this was done, then the implementation of several power calculations is done and outputted to the screen. This is tested as well and with some minor error percentages, the desired result is obtained.

7.2 Hardware Testing

This section covers the hardware testing to ensure each component works properly. This section also includes the testing of each subsystems included in the Energy Harvesting Platform.

7.2.1 Chassis Testing

The chassis will be tested for durability by being placed on the ground and stepped on. To test weather proofing, we will be sprinkling water on the chassis to make sure the water does not seep through. The transparent frame will be tested to ensure the solar panel receives enough light to harvest solar energy. The performance of the chassis will be tested by having all members step and put all their weight on the Platform. The springs will provide enough tension to prevent the Platform from sinking too fast, and the spring casing will prevent the Platform from compressing more than 5 millimeters. Once the weight is off, the Platform will decompress and return to its normal height. Given that there is no continuous weight on the Platform, the spring should work for a few years. When stepping on the Platform, the user should barely feel the effect of the Platform compression.

During the stress testing, we would also like to know how much weight the Platform can handle. We will be adding as much weight as we can on top of the Platform until the acrylic breaks. If we somehow are able to put up more than three hundred pounds of weight on top of the Platform without the acrylic breaking or cracking, then we should have no problem handling the weight of anyone that walks on the Platform.

As the products shown in the Research section. Some companies have already created a dance floor version of the Energy Harvesting Platform. If their tile can handle the weight of tens of people jumping on top of the tile without the tiles being damaged, we believe our Platform will be able to handle the same amount of stress.

7.2.2 Solar Panel Testing

The solar panel test will be conducted by exposing the panel to sunlight, then connect the panel to a multi-meter and test for voltages and currents. The panel should produce a constant voltage and current.

Another test will be performed during the prototype phase while the panel is connected to the battery for charging. The LCD display should show the charge rate of the battery as it charges using solar power.

As solar charging takes long periods of time, during the midterm demonstration and the final presentation, there will be a time-lapsed video showing the different battery levels after a few hours of time left out in the sun. As the solar panel is placed within the Platform with a few layers of acrylic covering the panel, the group needs to ensure that the solar panel will still be exposed to enough sunlight to function.

The table below shows the basic requirements to be met by testing the solar panel without any components or load connected to it.

Measurement	Expected Value	Actual Value
V_{OC}	12V	14V
I_{SC}	830 mA	863 mA

Table 22. Solar Panel Testing Specs

7.2.3 Microcontroller Testing

The microcontroller will be controlling the displays and reading of the Energy Harvesting Platform. The microcontroller tests will be similar to software testing, which includes:

- Running initial basic code
- Verifying the stand-alone microcontroller circuit
- Battery level reading and display
- Reading and displaying voltage level
- Reading and displaying current level
- Testing final circuit setup for accurate performance

The LCD display testing will be conducted while testing the microcontroller as the two components are needed to produce the necessary results.

7.2.3.1 Microcontroller Circuit

This section demonstrates the different testing done to verify accurate circuit design, as well as the performance seen from the voltmeter and ammeter, which make an important part of the project as it provides the efficiency and operational performance of the main product, the energy harvesting platform. A picture of the final breadboard testing will show successful testing of the mentioned features.

7.2.4 LCD Interface

The LCD is a crucial part in the project as it presents all the data. For breadboard testing a 16x2 LCD is used as it was readily available and still has the same connection pins as the chosen 20x4 at the parallel interface. The 4-bit interface was first done with the Arduino Uno, as some research was done with the development board and the desired connections found. Some trial and error was done an eventually the desired pins where chosen. This was later transferred to the standalone microcontroller with the help of the pin-out diagram for the microcontroller given in the datasheet.

Originally, a potentiometer was set to control the contrast of the LCD. This worked perfectly as the dial modulated the opacity of the text and allowed to tailor it to any intensity. Later, the potentiometer was removed to conserve space and replaced with a connection to a pulse width modulation pin. A play with values led to the correct constant contrast. More on this testing is given in the software testing section. Finally, a test code was run to simply print out code and thus testing the accuracy of the connections. The connections worked perfectly as the message was visibly displayed and a 4-bit interface allowed for free pins which can be used to add extra features later if desired. Later in the design, buttons were implemented and tested to cycle the data the LCD displays. This is tested successfully as the forward and backward button performed as desired.

7.2.5 Stand-Alone ATMEGA328P

Once the circuit is built and the bootloader burned into the blank chip, several test codes were programmed into the device that just print out a string to LCD. At this instance, the LCD is also connected to the microcontroller device. After programming, the device was disconnected from the development board to verify the microcontroller could run on its own. This was successful as the string was displayed and the program continued running, even when it was reset.

7.2.6 Voltmeter

When designing the voltmeter, we realized the need for a voltage divider due to max voltage to pin constraints. Since the incoming voltage will be under 50 volts, we needed a resistance ratio of 0.1 and chose resistors accordingly, with the available selection. After successfully testing the voltage divider with a DC supply the correct voltage drop was achieved. When ready it implemented into the microcontroller circuit and run. First it was connected to a DC voltage and the LCD output tested, then it was connected the rest of the project circuit and the voltages tested for the piezoelectric sensors, the solar panel and battery. With a small percentage error to the expected value, the circuit outcome was successful.

7.2.7 Ammeter

Testing the ammeter required a similar approach to the voltmeter circuit. Before testing the voltage divider that makes up the ammeter, the parallel resistor circuit used to create the shunt value is measured to make sure the 0.47 Ω resistance is achieved. The voltage divider in the circuit is tested to verify that the correct amperage is measured by dividing the obtained divided voltage by the shunt resistor value. Once the correct value is obtained, which was achieved with some resistor value manipulation, it was connected to the microcontroller. A check was done at the max read voltage for this design, 50 V, that the input would not exceed 5 V of input into the pin.

When both voltage and amp meters were successfully running, the resulting values were used to calculate power. Unfortunately, the results provided were not as accurate as needed, which lead to the use of theINA219 power and current monitor.

7.2.8 INA219 Testing

INA219 is first tested with a development board purchased by Adafruit and DC source. This allowed for an understanding of the integrated circuit and how it would perform in the project design. After the final circuit implementation as mentioned in the Hardware Design section, the modules where individually and as a whole tested with a DC source. After verifying proper function of the built circuit, they were tested with the platform and the sources it provides to observe how accurate the measurements resulted. This final testing resulted successful, with a few minor improvements which were done in the software. Only when the circuit worked as intended was it then transferred to the PCB.

7.2.9 Piezoelectric Transducer Testing

The piezoelectric transducers are providing the main input voltage to charging the Li-Ion battery. To test this component, it will be connected to only a multimeter and have pressure applied to it to produce a voltage and have the value read by the multimeter. The current that is produced from the piezoelectric transducers will be test after connecting them in parallel configuration. As a series configuration increases the voltages produced and parallel configuration increases the current produced, we will be setting the piezoelectric transducers in all parallel configuration. In order to provide enough power to the other electrical devices, the piezoelectric transducers need to harvest enough current as well as voltage. As each piezoelectric transducer disk provides an average of six to eight volts, the team needs more current than voltages. By having all the transducers in a parallel configuration, we will be able to harvest as much current as we can from the piezoelectric transducers. The table below shows the basic requirements to be met by testing the piezoelectric transducer without any components or load connected to it. Buttons used to cycle data were also tested successfully to verify circuit building accuracy.

Measurement	Expected Value	Actual Value
V_{OC}	6-8 V	6.6-8.2 V
I_{SC}	1 A	100 mA

Table 23. Piezoelectric Transducer Testing Specs

The piezoelectric transducer will also be tested using the chassis. This will allow us to test whether the chassis is of the correct design or not. If the chassis test passes but fails with the piezoelectric transducers included, the chassis will have to be partially redesigned.

7.2.10 Li-Ion Battery Testing

The Li-Ion battery is the only power source for the USB charging device and the microcontroller. The battery will be tested by using a multimeter to read the voltage when the battery is fully charged and fully discharged. The readings should match the table below.

Measurement	Expected Value	Actual Value
Fully Charged	4.2 V	4.21 V
Fully Discharged	3.0 V	3.02 V

Table 24. Li-Ion Testing Specs

7.2.11 Li-Ion Battery Charger Testing

The Li-Ion battery charger is designed specific to the Li-Ion battery and therefore, all requirements are met. They are both manufactured by the same brand and are sold with the other as a recommended purchase because they were designed to work with each other. A test can still be performed by attaching the Li-Ion battery to the JST connector on the charger and using the multimeter to measure the output from the load terminals. The same can also be performed for the input voltage from the USB mini b port.

7.2.12 LED Testing

The LED is an addition that the team would like to add to the Energy Harvesting Platform. Although the component itself is not necessary, the added effects makes the Platform more interesting. The LED will be powered by the solar panel, as that is the only power source that is able to produce 12V in the system. The LED will only light up when the Platform is compressed by being stepped on. This setup will only require a button to allow current flow to turn on the LED. We can easily test the LEDs by connecting the LED to the solar panel out of the Platform and press the button to see if the connection and current flow is stable. Assuming nothing goes wrong, the LED will light up as soon as the button is pressed. When the button is released, the lights will turn off.

7.2.13 LCD Testing

The LCD will be displaying the information read by the microcontroller. It will be displaying:

- Voltage and current input from
  - Solar panel
  - Piezoelectric transducer
- Power
- Battery Ratings

This information will allow the user to see how much voltage and current is produced from the power sources. The LCD can be tested by displaying random information. The test will consist of displaying characters. Since the numbers will be based on the programming of the microcontroller, we will know if the LCD is functioning properly or not based on whether it can display the correct or incorrect characters.

8. Administrative Contents

All engineering related design and production requires delegated planning and administration if the project is to end in success. All members will act as the administrator and keep other in track and focused.

This section contains:

- Budgeting and finances that will be required to create the Energy Harvesting Platform
- Semi-detailed milestones and deadlines for each part of the project to ensure the project will be finished on time
- Task delegation for each member to be assigned a responsibility

8.1 Estimated Budgeting and Finances

The following table displays the estimated budgets and finances for the project. Each item needed is listed with cost per item and quantity needed. Multiple parts are purchased in case one malfunctions.

Item(s)	Cost/ Item	Quantity	Sub Total
12 pcs 27mm Piezo Discs	$19.99	2	$39.98
ACO Power 10 W Solar Panel	$29.90	1	$29.90
Casing Materials	$49.98	1	$49.98
Lithium Ion Battery Pack 3.7V 4400 mAh	$19.95	1	$19.95
ATMega328P-AU	$2.07	1	$2.07
INA219BIDR	$2.38	3	$7.14
LTC3115	$7.93	1	$7.93
LCD Screen	$13.98	1	$13.98
LTC3588	$4.96	1	$4.96
MCP73833	$0.85	1	$0.85
PCB	$59.99	1	$59.99
Miscellaneous			$40
Total: $276.73			

Table 25. Estimated Budgeting

8.2 Milestone Discussion

This section describes the milestones, tasks, and deadlines throughout the project for each member to focus and complete to ensure the project will be completed. The table includes the tasks for both Senior Design 1 and Senior Design 2. The milestones will be updated as the project becomes more finalized and more information is obtained.

Number	Task	Start Date	End Date	Status
Senior Design 1				
1	Project Selection	5/16/2017	6/2/2017	Completed
2	Initial Project Documentation	5/23/2017	6/2/2017	Completed
3	Initial Documentation Update	6/2/2017	6/9/2017	Completed
4	Develop Table of Contents	6/2/2017	6/12/2017	Completed
5	Parts List	6/2/2017	6/30/2017	Completed
6	Draft Document	6/2/2017	7/30/2017	Completed
7	Component Test	7/10/2017	8/1/2017	Completed
8	Final Document	6/2/2017	8/1/2017	Completed
9	Design Overview	6/2/2017	7/1/2017	Completed
Senior Design 2				
10	1st Prototype with Breadboard	8/1/2017	8/17/2017	Completed
11	PCB Design	7/1/2017	9/1/2017	Completed
12	Housing Design	7/1/2017	9/1/2017	Completed
13	CDR Presentation	7/1/2017	9/29/2017	Completed
14	Peer Review	8/1/2017	9/29/2017	Completed
15	Conference Paper (8 page)	11/1/2017	11/17/2017	Completed
16	2nd Prototype	8/1/2017	11/5/2017	Completed
17	Mid-term Demo	9/1/2017	11/1/2017	Completed
18	Final Presentation	11/27/2017	11/27/2017	Completed
19	Web Exit Interview	12/5/2017	12/5/2017	Planned

Table 26. Milestones

8.3 Task Delegation

The task delegation table describes which team member is responsible for which part of the design. The design choices will ultimately be reviewed by the entire team and will then be chosen and/or bought. The component choices that are made should complement the overall design of the system and should flow seamlessly together with one another.

Sanjay	Primary tasks: Responsible for the power generation of the tile. Researches the performance, cost-effectiveness, layout, and types of piezoelectric transducers as well as the energy-efficiency, size and types of solar panels available for purchase. Secondary tasks: Responsible for the design of the printed circuit board (PCB) and the soldering of electrical components. Researches different PCB design software as well as PCB manufacturers
Travis	Primary tasks: Responsible for researching electrical components, designing and testing the circuit using simulation software and breadboard testing, respectively. Ensures that the power generated by the piezoelectric discs and the solar panel can be harvested effectively and efficiently. Secondary tasks: Creates and updates group meeting plans. Creates the PCB schematics and assists in the layout of the PCB design.
Michael	Primary tasks: Focuses of the housing and material selection of the tile. Utilizes a 3D modeling software as well as a laser cutter to design and build prototypes of the tile. Ensures the tile is weather resistant, durable and effective. Secondary tasks: Proofreads the project report constantly to ensure continuity, while also fixing any spelling and grammatical errors. Verifies every section, table and figure is labeled and numbered correctly.
Kiara	Primary tasks: Responsible for microcontroller selection and learning the programming language and software to program the microchip. Focuses on the output stage of the design including programming/interfacing an LCD display, programming a button to toggle LEDs inside the tile, and implementing a charging station. Secondary tasks: Requests progress updates from each team member to ensure that every section is done in a timely manner. Ensures that chosen components are bought and delivered prior to breadboard testing

Table 27. Task Delegation Table

Tasks were delegated between CAD design, PCB design, components, and software systems. The tasks are color coded for visibility. The delegations are non-binding. Each group member agreed to assist in the overall project design and development when needed.

8.4 Stretch Goals

Technology similar to the Energy Harvesting Platform have already been implemented elsewhere in the world. Although piezoelectricity was discovered in the 1880s, the technology is not widely used as the energy production is small compared to other energy sources. There is a wide variety of improvements that can be implemented to upgrade the Energy Harvesting Platform.

8.4.1 Portability

One of the main idea behind the Energy Harvesting Platform is that it will be placed on the ground as a part of normal sidewalks it has a high possibility of being constantly used depending on the location. An upgrade for the Tile could be portability. If the piezoelectric crystals can be placed at the bottom of a person's shoes, they will be constantly generating energy as they walk. If an additional energy harvesting system, such as vibrational energy, could be included, the amount of energy stored will also increase. Vibrational energy are a type of piezoelectricity such that it generates energy when vibrating at a high frequency. However, energy harvesting using vibration and piezoelectricity systems needs to be improved before this upgrade can be implemented. As of today, the energy harvested from piezoelectricity is insignificant compared to energy harvested from other sources.

By making the system compact, portable, and can be brought around by a person, they will feel more benefit using the system because the energy the harvest and store will only be used by themselves, unlike the Platform where the energy stored can be used by the public.

8.4.2 Wireless Charging

Another system that can be implemented as an upgrade to the Energy Harvesting Platform is wireless charging. Currently, wireless charging for phones are already being sold on the market. This allows the user to charge their phone or other devices without the need to carry around a charging cord that has the possibility of being tangled or damaged. By implementing this system, any user passing the Energy Harvesting Platform could charge their phone without worrying about the USB being of a different type than the ones they use.

By eliminating the need for USB cords, it will be one less component that may be damaged when using the Platform. Unlike the USB cords, the wireless charging component does not necessary need to be directly in contact with the device. A layer of casing can be placed in between to prevent water damage and protection against other elements.

9. Conclusion

The Energy Harvesting Platform project involves existing technology that has a future with clean energy in mind and therefore, is beneficial to the success of self-sustainable technology. The environment is constantly in danger of human-produced pollution and solutions must be developed to alter the path in which the Earth's atmosphere is being directed. This project focuses on using natural resources to create energy, thus removing unfavorable methods such as using coal and other fossil fuels to produce energy for the world.

The completion of the Energy Harvesting Platform project will be a culmination of years of learning for each of the group members and applying all of the combined knowledge to successfully produce a dual-source self-sustainable energy-harvesting platform. Regarding the completion of this project, we are on point with our project timeline and ahead of time with a prototype PCB design.

During this semester, an abundance of research was conducted and used to determine whether or not this project was actually possible. With perseverance from each group member, it has been concluded from much research and testing, that this project has a definitive completion date. Our goal of completing this project by the end of the next semester is guaranteed with a successful, working final product.

Several challenges during the conceptual design stage were encountered and with proper team leadership and management, along with teamwork amongst the group members, the challenges were overcome and solutions to every problem were obtained. While this group is made up of only electrical engineers, the project required software programming knowledge which, with great effort, was achieved by all group members working together to evenly distribute the workload of what is considered to be the weakness of electrical engineers, software programming. Once this project is complete, each group member will be proficient in software programming, basic hardware design involving AC and DC power sources, and schematic and PCB software design and assembly.

The most significant accomplishment of this project is applying the knowledge of what each group member has learned in recent years about circuit design and learning new concepts within a limited amount of time. Several aspects of this project were unknown to all group members, and through determination and teamwork, a product that is being designed to improve the Earth's environment with advanced technology, was brought to initial preparation. In the years to come, the Energy Harvesting Platform will be the iconic self-sustainable method to produce energy for the world.

10. Appendices

This section consists of the appendices in which references, copyright materials, and additional documentations are kept.

10.1 Works Cited

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10.2 Copyright Permission Requests

This section contains the copyright permission requested from companies to use their images and other resources.

10.2.1 Energy Floors

Sylvia Meijer - Villafane <Sylvia@energy-floors.com> Jun 27
to me

Hi Vena,

Thanks for supporting us! We really appreciate it.

I've just sent you some documents via WeTransfer.

Regarding costs, the following price estimation is what I can provide you with:
SDF (75x75cm) purchase: between 2000€ and 2750€ per tile (depending on order quantity)
SEF (75x75 cm) purchase: between 500€ and 750€ per tile (depending on interactivity and order quantity)
SDF / SEF rental: 60€ – 75€ per tile per day
[Incl. all necessary hardware (cables, controller, laptop) and installation costs; Excl. transportation costs for equipment and crew.]

For further questions please check our website where you can find many details like our company history and mission; descriptions of our products; a portfolio and list of clients we work for and the best of our photos and videos. If you want to use photos or videos for your own presentation, please credit them with: *Photo/Video by Energy Floors*.

Please also check out our **videos on Vimeo** to see our Energy Floor in action. Ofcourse you can use them in your presentation.

Good luck with your project!

Met vriendelijke groet / kind regards,

Sylvia Meijer-Villafane

Marketing & Communication

ENERGY FLOORS

Directiekade 12 | 3089 JA Rotterdam | The Netherlands | +31 10 276 22 13 | www.energy-floors.com

WATCH OUR SHOWREEL

10.2.2 OnyxSolar

Diego Cuevas Jun 28
to me

Good afternoon Jay,

Thank you for your email. We offer a wide range of designs and options for the PV pavers. Would you be able to provide us with more detail information regarding your project? We would ideally need information on the total sqft of project - so to better assess you in terms of technology choices, project location, and basic drawings, to be able to run some calculations on energy output.

Please, take a look at some pictures attached with different PV floor systems.

I look forward to hearing back from you.

Regards,

Diego Cuevas
Onyx Solar Group

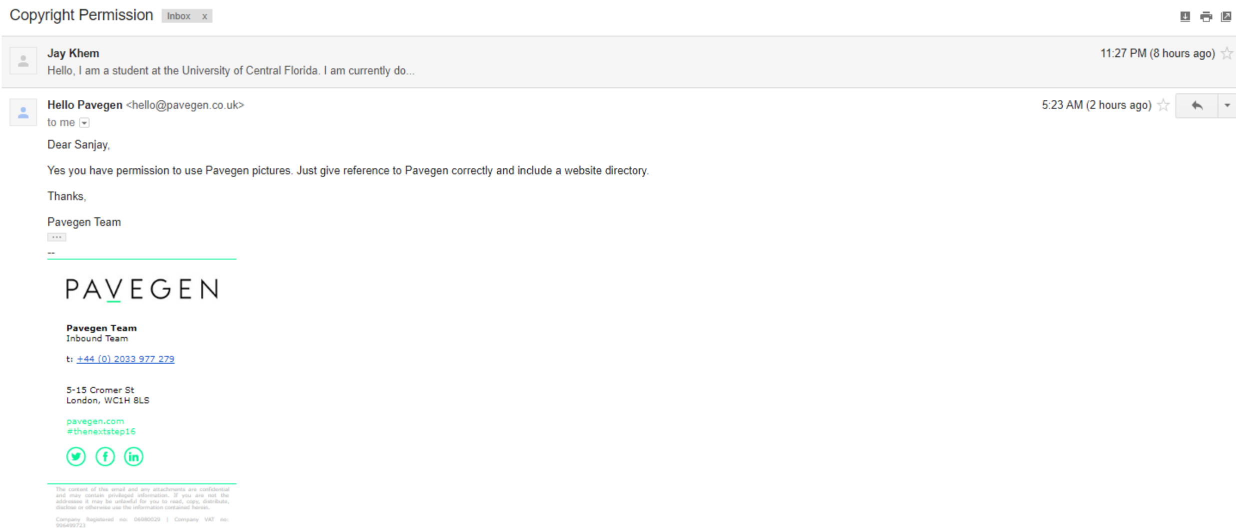
Don't miss the **webinars** we are offering this week here.

Over a hundred projects on five continents prove our global leadership.
Check out the outstanding ROI of our PV Glass here!

Diego Cuevas
Vice President
Business Development USA
usa@onyxsolar.com
www.onyxsolar.com
Tel.: (+1) 917 261 4783
Fax: (+1) 646 571 2001

ARCHITECTS NEWSPAPER 2015 GAME CHANGER
glass magazine award winner 2015 MOST INNOVATIVE GLASS
2016 GLOBAL LEADER for Building Integrated Photovoltaic Glass
2016 BEST GLOBAL Photovoltaic Glass Provider
POPULAR SCIENCE BEST TECHNOLOGY OF 2015

10.2.3 PaveGen



Copyright Permission Inbox x

Jay Khem 11:27 PM (8 hours ago)
Hello, I am a student at the University of Central Florida. I am currently do...

Hello Pavegen <hello@pavegen.co.uk> 5:23 AM (2 hours ago)
to me

Dear Sanjay,

Yes you have permission to use Pavegen pictures. Just give reference to Pavegen correctly and include a website directory.

Thanks,

Pavegen Team

--

PAVEGEN

Pavegen Team
Inbound Team

t: +44 (0) 2033 977 279

5-15 Cromer St
London, WC1H 8LS

pavegen.com
#thenextstep16

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10.2.4 Texas Instruments

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10.2.5 HK RE Net

轉寄: EEO/17/0225轉寄: Fwd: Permission to Use Picture - Google Chrome

Microsoft Corporation [US] | https://outlook.office.com/owa/projection.aspx

Reply all | Delete Junk | ...

轉寄: EEO/17/0225轉寄: Fwd: Permission to Use Picture

W wlyu@emsd.gov.hk
Wed 8/2, 10:32 PM
Travis Badall

Reply all

Inbox

Dear Travis,

Thanks for your enquiry.

Please note that we have no adverse comment on your use of the figure.

Regards,
Willy Yu
Tel: 2808 3396

-------- Forwarded Message --------

Subject: Permission to Use Picture
Date: Sun, 30 Jul 2017 02:46:40 +0000
From: Travis Badall <travisbadall@knights.ucf.edu>
To:eepublic@emsd.gov.hk <eepublic@emsd.gov.hk>

Hello, my name is Travis Badall, I am a student at the University of Central Florida. I am doing a research project for one of my classes, I was wondering if I obtain permission to use a figure on one of your pages. I would like to use the figure for the shunt charge controller on the following page:
http://re.emsd.gov.hk/english/solar/solar_ph/solar_ph_to.html

Thanks,

Travis Badall

Solar Solar Photovoltaic Technology Outline - EMSD HK RE Net

10.2.6 Home Power Inc

BR Ben Root <ben.root@homepower.com>
Yesterday, 12:19 PM
Travis Badall; mailbox@homepower.com

Reply all

Action Items

Hi Tavis,

Sure! feel free to us it. Please credit it to "homepower.com".

Or just redraw the thing yourself, and give yourself credit. It's pretty darn simple, conceptually.

Peace,
Ben

Benjamin M. Root
Art Director, Home Power Magazine
ben.root@homepower.com
541-531-3377
www.homepower.com

On Jul 29, 2017, at 9:04 PM, Home Power Magazine <web@homepower.com> wrote:

Sent: Saturday, July 29, 2017 - 21:04
Website user:

From: Travis Badall
Email: travisbadall@knights.ucf.edu
Topic: Article Comment/Question
Subject: Permission Request to Use Picture

Hello, my name is Travis Badall, I am a student at the University of Central Florida. I'm currently doing a design project and I would like to request permission to use the PWM duty cycle figure in my paper. The image is found on this page:
https://www.homepower.com/articles/solar-electricity/equipment-products/2012-charge-controller-buyers-guide

Thanks,

Travis Badall

10.2.7 Arduino

Permissions of Use of Arduino Tutorials

Kiara R <kiaramr97@gmail.com> 4:08 PM (10 hours ago)
to trademark

Good afternoon,

I am a senior student in the Engineering Department at the University of Central Florida, currently enrolled in Senior Design 1. I am asking for permission to include part of the tutorial named "From Arduino to a Microcontroller on a Breadboard" into my research paper. The tutorial will be summarized, but referenced as part of a tutorial that the group followed to burn the bootloader program into the microcontroller ATMEGA328P as we need to use it on our own PCB and program it. It is referenced in the text in our paper that the tutorial is provided by Arduino's Website.ml appreciate your time taken to briefly assess this matter.

Cordially,
Kiara M Rodriguez

10.2.8 Electronic Design

usercare 7:53 AM (17 minutes ago)
to me

Jay,

Your request has been sent to our editorial department for review.

Thank you,

Diane Mason
Business intelligence | informa

T: 001 913-967-1877
usercare@penton.com
www.informa.com
Agribusiness intelligence | **Financial intelligence** | **Industry & Infrastructure intelligence** | **Pharma intelligence** | **TMT intelligence** | **Transportation intelligence**

From: Jay Khem [mailto:venaserax@gmail.com]
Sent: Tuesday, August 01, 2017 1:55 AM
To: usercare
Subject: Copyright Permission

10.2.9 International Energy Agency

Rights@iea.org <Rights@iea.org> Aug 11
to me

Dear Jay,

Thanks for confirming. Unfortunately this is not an IEA figure as per the source mentioned. Could you please check with EPIA whether they agree with your intended use?

Many thanks in advance

Kind regards

Bérengère

10.2.10 Barcelona Tech

Copyright Permission

Jay Khem <venaserax@gmail.com> 3:04 AM (0 minutes ago)
to francesc.j.rob.

Hello,

I am a student at the University of Central Florida. I am currently doing my Senior Design Capstone Project and my research is in regards to microcontrollers. I was hoping I could obtain permission to use certain pictures in my research paper where I mention the existing technology of the microcontrollers. Please let me know if I have permission to use this picture.

http://digsys.upc.es/ed/CSD/ap/CSDap.html

Regards,

Sanjay Khemlani

10.2.11 The Conversation

Jonathan Gang <jonathan.gang@theconversation.com> Aug 1

to me

Hi Sanjay,

Most articles on our site feature photos published with a creative commons license, which allows them to be shared and used without permission. Unfortunately, it appears this is an older article, and the source and license of the images isn't listed. I wish I had a clear answer for you, but I'm not sure who owns the rights to these images.

This article is from our Australian edition, so you might have better luck emailing their science and technology editor Michael Lund at michael.lund@theconversation.edu.au. You could also try contacting the author. You can find their contact info here: https://theconversation.com/profiles/cameron-shearer-169456

Sorry I couldn't be more helpful, and good luck!

Best,
Jonathan

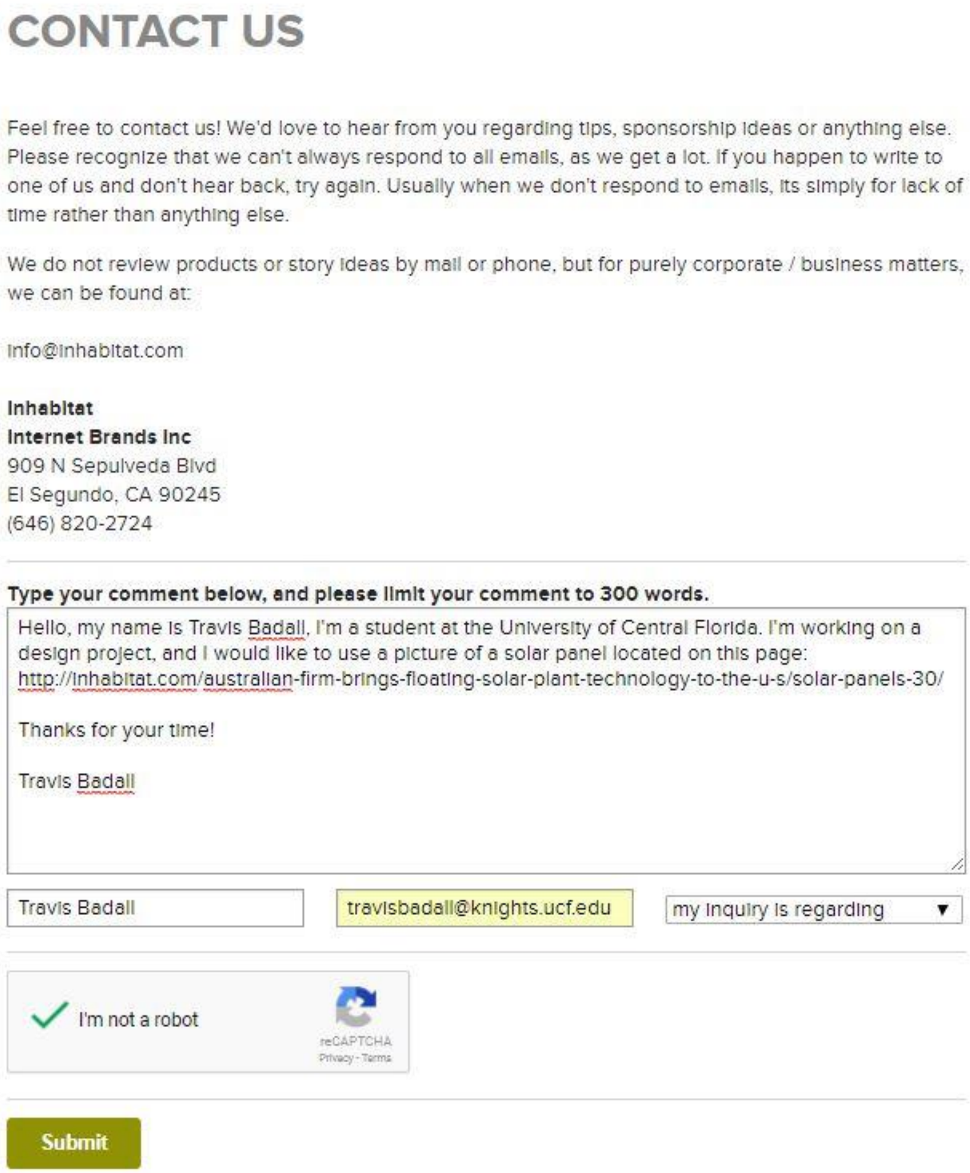
--

Jonathan Gang
Editorial Researcher, The Conversation US
413-896-3496
@JonathanSGang
625 Massachusetts Ave., Cambridge, MA 02139

THE CONVERSATION

Twitter: **@ConversationUS**
Facebook: **facebook.com/theconversationUS**
Sign up: **theconversation.com/us/newsletter**

10.2.12 Inhabitat Internet Brands Inc



CONTACT US

Feel free to contact us! We'd love to hear from you regarding tips, sponsorship ideas or anything else. Please recognize that we can't always respond to all emails, as we get a lot. If you happen to write to one of us and don't hear back, try again. Usually when we don't respond to emails, its simply for lack of time rather than anything else.

We do not review products or story ideas by mail or phone, but for purely corporate / business matters, we can be found at:

info@inhabitat.com

Inhabitat
Internet Brands Inc
909 N Sepulveda Blvd
El Segundo, CA 90245
(646) 820-2724

Type your comment below, and please limit your comment to 300 words.

Hello, my name is Travis Badall, I'm a student at the University of Central Florida. I'm working on a design project, and I would like to use a picture of a solar panel located on this page: http://inhabitat.com/australian-firm-brings-floating-solar-plant-technology-to-the-u-s/solar-panels-30/

Thanks for your time!

Travis Badall

Travis Badall | travisbadall@knights.ucf.edu | my inquiry is regarding ▼

I'm not a robot | reCAPTCHA | Privacy - Terms

Submit

10.2.13 Sherwin Williams

BRAND NAME	SHERWINWILLIAMS
TO	SWTechinfo@sherwin.com
VERSION	v1.00
FROM	michaellin91@knights.ucf.edu
SUBJECT	Other
FIRST NAME	Michael
LAST NAME	Lin
ZIP CODE	32826
MESSAGE	Homeowner or Professional: I am a Homeowner Hello, I am a student at the University of Central Florida. I am currently doing my Senior Design Capstone Project and require using Epoxy Coating in my project. I am hoping to acquire permission to use your Epoxy Comparison Chart in my research paper as screenshots. The comparison chart is linked: http://protective.sherwin-williams.com/pdf/epoxy_coating_comparison_chart.pdf Regards, Michael Lin