EV Moghaddam

Final Proposal

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EXECUTIVE SUMMARY

The purpose of this project was to design and devise a method to implement a device onto an existing electric vehicle which will harvest electrical energy. The justification of this project is that the current climate crisis that is affecting the whole world requires effort from everyone in order to be resolved. The electric vehicle market is one which attempts to help aid the world by reducing emissions from vehicles. The client asked the team to design a device that would assist electric vehicles on their mission to make the world a cleaner place .The design is to use three different methods of gathering electrical energy and must be able to power at least one function of the vehicle i.e. headlights, radio, heat pump, etc. The device is also not to ruin the aesthetics of the current vehicle as it will be an aftermarket add-on product. Along with not ruining aesthetics of any given vehicle the device is not to add any significant amount of weight to the vehicle, along with this the device must not ruin the performance of the existing vehicle. Finally the device is not to cost a significant amount of money when compared to the price of the vehicle that it is being added on to. This led the team to design a device meeting all of the criteria listed by carefully exploring all of the paths which could be taken in order to achieve the desired outcome. First the team decided to look into various methods of harvesting electrical energy from sources outside of the vehicle. The three that were finally settled on after some brief analyses were; thermoelectric generators, solar panels, and a diffuser/generator combination. Each of these methods of energy harvesting were chosen based on their ability to meet the design specifications that the team needed to meet. For example the flexible solar panel was chosen due to its ability to gather large amounts of energy, it is a lightweight device, it is simple to implement and would not ruin the aesthetics of the vehicle. Once the team decided on these three forms of energy harvesting the next process was to choose all of the auxiliary components that would be needed to make the rest of the design function as intended. The components that the team settled on were a DC-DC inverter, a charge controller, wiring to connect all of the devices and a deep cycle battery to store the energy that is harvested. All of these components again have to meet the criteria that were set which made this portion of designing a little more challenging since these components are a little more challenging to store and also some of them are heavier than the sources of energy harvesting. These also went through much less analysis in order to make it into our design considering the less important roles they played in the design. Once the team decided which components were going to be implemented, prototyping began for the two energy harvesting sources that needed the most testing in order to answer questions the team had about the design. The team had the most questions about the diffuser and the thermoelectric generators. The testing for the diffuser would be done in order to help the team better understand how the flow through the device would affect a generator attached to a fan and how much energy the device would be able to generate. The thermoelectric generator prototype would answer the question of how the team plans on implementing the device in order to achieve the maximum amount of power generation. The finalized design has been chosen in order to derive the maximum amount of power from the surroundings in order to achieve the most efficient electric vehicle possible.

[Provide a one-page summary of your project, including description, design, and results.]

TABLE OF CONTENTS

1 BACKGROUND

1.1 Introduction

The team was tasked with designing a device that harvests energy from various sources so that it may be used to power some electric function of the vehicle. The team as well as the client that tasked the project feel that this is important in the industry because of the relevance to the current automotive industry. Society is rapidly moving towards having electric vehicles (EV's) as the main source of transportation, so the client believes that this is the perfect time and reason to start working on ways to make these vehicles more efficient. This will benefit the client in that they will see an improvement in the range of electric vehicles which will thus increase the mobility of such vehicles. This will also benefit the general public seeing as how the global warming crisis is only getting worse day by day. The more efficient an electric vehicle you have (which produces zero emissions) the less of an impact you have on the environment which will benefit everyone as a whole.

1.2 Project Description

The following is the initial project description given to the team by the client.

"The advent of electric vehicles (EV) in the past few years have revolutionized the car industry. While the history of modern electric vehicles goes back to the limited production of General Motors EV1 in 1996, we really know the first electric car to be the Tesla Roadster which was the first highway legal electric car to use lithium-ion battery in 2008. Recently, other car companies have started producing hybrid or fully electric cars. Electric cars can significantly help the environment by reducing pollution. However, there are still concerns regarding the effective range the car can travel on one-time charge.

The purpose of this project is to design an electromechanical device which can harvest electrical energy from on-road EVs. The team is required to first investigate for and identify potential electrical energy sources which can be harvested while the car is moving on the road. Then they should design a device which can harvest, store, and use this electrical energy to charge the car batteries or be used for operating other functions in the vehicle. The team is REQUIRED to investigate all possible sources of energy to be harvested and include at least three different areas where energy can be harvested."

2 REQUIREMENTS

This section will go into detail regarding the requirements that the team was given in order to begin work on the project and how these were turned into engineering requirements in order to successfully derive a design that would meet the criteria set by the client.

2.1 Customer Requirements (CRs)

The following are the customer requirements given to the team originally in the description of the project.

- The device should not add significant weight to the car.
- The device should not add significant cost to the overall car retail price. (Max: $1000 if justified)
- The device should harvest/generate enough electricity to do a proper electrical function in the car such as supplying electricity for headlights, stereo, etc.
- The device should not compromise the aesthetics of the car. If you plan to install it on the exterior of the car, it should improve the aesthetics.
- The device can be an add-on to the car so can be sold and installed separately. Great for current EVs in the market.
- The device must be durable enough to withstand road conditions
- Design must be reliable enough to be used in market application
- The design must be safe enough for average person to operate

This list of customer requirements is short and to the point. However, it does highlight some of the more important characteristics of this project. The most important and heavily weighed being the energy harvesting capability of the design as well as the aesthetic improvement of the vehicle design. These two, when the team was discussing with the client, seemed to be the most pertinent. For obvious reasons the team must design a device that harvests electricity. The aesthetic improvement is one that the client seemed to emphasize a lot since they have an understanding of the amount of time and money that is put into ensuring the design of electric vehicles is performance improving and pleasing to look at. The other customer requirements the team was tasked with were that the device must be an add on to existing vehicles in the market. This was not too much of a challenge since that is by nature how the project would work. The price requirement was given to the team in order to provide a reasonable price point to sell the product at and to keep the cost for the potential customers down relative to the vehicle itself. Finally the last of the original customer requirements that were given to the team was to not add significant weight to the vehicle. This again is important so as to not make the whole design pointless by wasting more energy carrying the extra weight of the product than the product itself generates. The other requirements are general requirements that the team was tasked with in order to ensure that the design would be safe for the customer to use and that the product would last long enough to be worthwhile in the industry. All three of these requirements are very important in our design ideas and were ranked relatively high.

2.2 Engineering Requirements (ERs)

The following are the engineering requirements that the team has developed based upon the customers needs as well as some ideas that the team felt were very important to the success of this project.

- Lightweight Design (< 150 lbs)
- Price relative to vehicle ($\leq \$1500$)
- Power produced (≥ 80 Watts)
- Aesthetically pleasing (Y/N)
- Aftermarket design (Y/N)
- Three methods of energy harvesting (Y/N)
- Withstand average road wear (Y/N)
- Safety of use (Y/N)

The engineering requirements chosen were based upon the customer's needs and desires for the project. The weight of the design was chosen to be less than 150 lbs in order to ensure that the performance of the vehicle would not be inhibited by the product. If the weight were too heavy the gains seen by the device would be negatively affected. The price of the device is one of the most important (and also challenging to abide by) requirements that the team has. The point being that the potential customer of this device does not want to spend a large sum of money on an aftermarket device after they have already spent a large sum of money on the vehicle itself. Power being produced by the device was a requirement that was set in order to give an overestimate of the power that the device will actually need to produce in order to power a function of the vehicle. The customer was very adamant about the device not ruining the aesthetics of the vehicle so the team made this one of our engineering requirements. Although it is not exactly objective via a number the team plans to design around the vehicle in a hidden fashion that allows for the device to still function properly without compromising the vehicle's looks. The aftermarket nature of the device comes from the customer's desire to have the product be an add on to an existing vehicle. This implies that the customer wants this design to work for most electric vehicles on the market which helps the team choose a design that will work for the average vehicle. The customer wanted the team to investigate all of the possible sources of energy harvesting and find a minimum of three to integrate into the design. The device being able to withstand average road wear is something that is also very important to the design as the team wants the device to be able to last generally as long as the vehicle can last. Finally, the team has made it a requirement that the design be able to be safely operated by the user. The metric we are working off of here is to hopefully require almost no user input from the device in order for it to function, meaning that the user will simply have to get into the vehicle, turn it on, and drive with the device functioning.

2.3 Functional Decomposition

The team has generated a Black Box Model and a Functional Model for the design of the project. Since the team is purchasing the subsystems, the benchmarks are required to determine which products are better for the final design. The Black Box Model helps the team visualize the inputs and outputs of the whole design. As for the Functional Model, the purpose is to visualize the input's process at every subsystem until it leaves the function

2.3.1 Black Box Model

Figure 1 is a depiction of a Black Box Model. The purpose of a Black Box Model is to visualize the overall design as a function and create a relationship between the inputs and outputs of the system. Everything on the left side is the inputs and everything on the right side are the outputs. Each input and outputs are categorized into three flows: material flow, energy flow and signal flow. The material flows are materials needed to make the function, in this case harvest energy, work properly. The energy flows are types of energy that will pass through the function. The signal flow is how the energy will be measured. Using this model, the team is able to get an idea of what is needed to design their project. Once the Black Box Model is complete the team will have a better understanding of what is needed to make their design function properly.

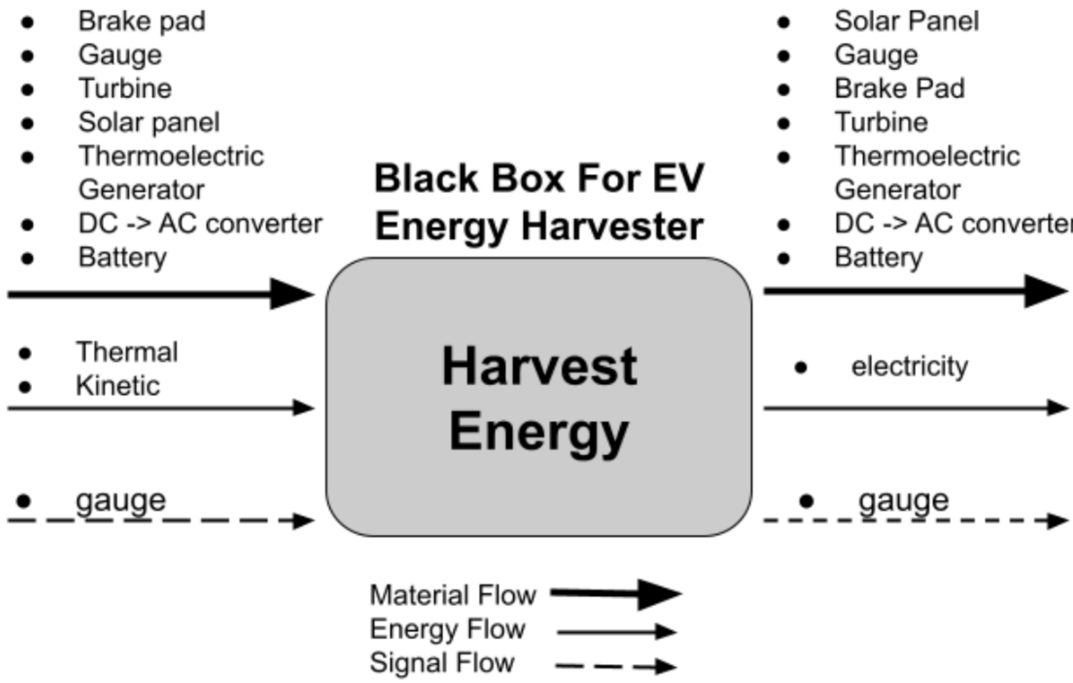

Figure 1: Black Box Model

2.3.2 Functional Model/Work-Process Diagram/Hierarchical Task Analysis

Figure 2 is a depiction of a Functional Model. The purpose of a Functional Model is to visualize each input from the Black Box Model and its process as it flows through the design. This helps the team determine what is needed to make the design work effectively. The team must follow each input individually until it leaves the system. In the figure below, the three types of energy will be evaluated at each subsystem. The purpose of the design is to harvest energy and convert that energy into electricity and power a component of the vehicle. In the Functional Model the component that will be powered is the headlights. So the inputs will leave the function as radiant energy and thermal energy from the headlights.

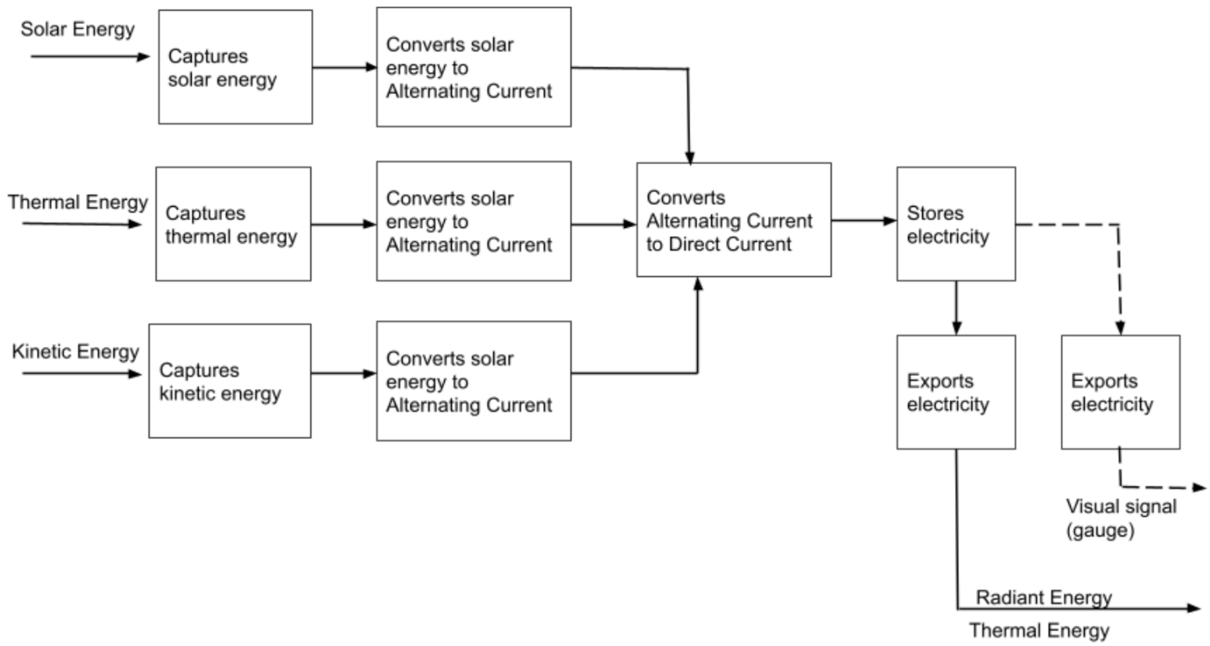

Figure 2: Preliminary Functional Model

2.4 House of Quality (HoQ)

The House of Quality shown below in **Appendix A** weighs the customer needs on a scale from one to ten to show their level of importance with respect to the engineering requirements. By ranking the customer needs by their respective engineering requirements, our team was able to determine which heavily weighted requirement should be implemented in the concept generation stage. The results showed that the most weighted engineering requirement was to ensure that no additional weight was added on to the vehicle. While the second most weighted engineering requirement was to make sure that the aesthetics of the electric vehicle would not be compromised. This helped the team to choose a design that was lightweight and aesthetically pleasing. Some of the requirements that we had are subjective and have less of a measurable impact on the design, however, the two most heavily weighted customer requirements were still taken into consideration with our design. For instance the diffuser is going to be hidden underneath the car and also made out of plastic which will allow for the lightweight and visually pleasing characteristics of the design to come out. The type of solar panel that we chose also was affected by the House of Quality. We chose to use a lightweight thin solar panel that allows for the device to conform to the top of the vehicle. The procedures for testing our device against the customer requirements were again more subjective. The team have however chosen to prototype two design components that we weren't entirely sure about in order to see if they would help power the device. The two components that were prototyped were the nozzle and the thermoelectric generator. We simulated the uses of either of them in order to determine the charging capabilities they would have for our design. These both turned out to be rather effective although the solar panel remains the main source of energy harvesting capabilities.

2.5 Standards, Codes, and Regulations

In order to comply with the safety regulations, EV Moghaddam has looked into several different standards and codes of practice that will help aid in the design of the energy harvesting devices. These standards will help ensure that the team and our consumers will be safe when using the energy harvesting devices as shown in Table 1.

Table 1: Standards of Practice as Applied to this Project

Standard Number or Code	**Title of Standard**	**How it applies to Project**
ASME Y14.5M 2004	ASME National Standard Engineering Drawing and Related Documentation Practices	This standard requires that all engineering drawings will have a uniform layout for stating and interpreting dimensioning, tolerancing, and related requirements.
IEC 62548:2016	IEC standard that sets out design requirements for photovoltaic arrays including DC writing, electrical protection devices, switching and earthing provisions.	This standard requires that photovoltaic panels should come with the respective design layout of the DC wiring and the electrical components that will be used.
SAE J-2344	SAE standard guidelines for electric vehicle safety.	This standard regulates how safety and abuse testing will be conducted for the electric vehicle.
SAE J-2464	SAE standard for electric vehicles with rechargeable energy storage system safety and abuse testing.	This standard regulates how safety and abuse testing will be conducted for an electric vehicle that has a rechargeable energy storage system.

3 Testing Procedures (TPs)

The testing procedures used in order to ensure that the design that we have met were chosen in a manner that allowed for the team to come up with the most accurate results which would lead the team to best optimize our design. Some of the tests had to be subjective by nature of how our customer had laid out their vision of the project. The rest of the tests however discussed in the following sections will give the team a good insight into how well our design works well.

[Use this section to discuss the testing procedure developed by the team for each Engineering Requirement. Number each testing procedure for reference in House of Quality. Testing procedures MUST be detailed enough to completely describe how each Engineering Requirement will be tested to prove it has been satisfied (including what the testing equipment is, where the team will acquire the equipment, how the test will be performed, etc.). Each team must include testing procedures that verify the system in reliable and robust (i.e. can withstand numerous tests, withstand external forces such as drops or impacts, etc.).]

[Include a brief introduction to this section here before moving on to Section 3.1.]

3.1 Testing Procedure 1: Weighing Device

This test is designed to inform the team of the weight of the design that we have chosen and give us an idea of the overall size of the design. We will weigh the device as well as get its overall dimensions to see how well off we are in our design thus far.

3.1.1 Testing Procedure 1: Objective

The test at hand will basically be us weighing each of the individual components of the design as well as taking measurements on their dimensions in order to determine overall size and weight of the design. We are testing this part of the design in order to get an accurate reading on if we chose our components in a manner that allows the overall design to come under our target weight.

3.1.2 Testing Procedure 1: Resources Required

The resources required for this test will be a scale of some sort and a measuring device such as a tape measure. The location will most likely just be one of the group members' homes. We will also need a group member to take the measurements and one to record the data. Then we will need to compile all of this information into a spreadsheet using Excel to get the total values.

3.1.3 Testing Procedure 1: Schedule

This test should take approximately one hour to complete assuming the team is not rushing to get this done. The team plans on completing this test over the winter break that is upcoming in order to work slightly ahead of schedule. Things that need to be done before this test can be run is gathering all of the materials. This means ordering the solar panel, battery, thermoelectric generators, printing our diffuser, and ordering a small generator that has a fan attached to it.

3.2 Testing Procedure 2: Thermoelectric Generator Voltage Test

This test is designed to measure the amount of power generated from the thermoelectric generators. This helps the team determine the overall power of the design to verify it produces enough power to the headlights of the vehicle or to be stored in the battery.

3.2.1 Testing Procedure 2: Objective

By testing the thermoelectric generators, the team will be using the seebeck effect to determine how much power can be produced. The team decided to use a multimeter to measure the volts and amps at different temperatures. This will help the team get an accurate measurement of the design.

3.2.2 Testing Procedure 2: Resources Required

The resources required for this test are a thermoelectric generator, a led light, resistors, breadboard, an iron to produce heat, a bag of ice, and a heat sink. This test will be conducted in the Engineering building where the team has access to a multimeter, a breadboard, and resistors.

3.2.3 Testing Procedure 2: Schedule

This test will take no more than an hour to complete. The team will be conducting this test on November 30th, 2021 in the Engineering building. The team has all the required materials to conduct this test, so testing should run smoothly considering everything works the way it should and every member of the team will be in attendance. This test will determine how much power can be generated from the thermoelectric generators, so next semester the team will get an idea of the overall power production from the design.

3.3 Testing Procedure 3: Nozzle and DC Generator Voltage Test

This test is designed to measure the amount of power generated from the nozzle and DC generator.

3.2.1 Testing Procedure 3: Objective

The objective of this test is to determine how much power can be produced at different velocities. The team will be using a nozzle for this test because the airflow velocity at the exit will be larger than the airflow velocity at the inlet. The increased velocity will help power the DC generator which then will produce kinetic energy from the fan into electricity.

3.2.2 Testing Procedure 3: Resources Required

To complete this test the team will need a vehicle, a nozzle, a DC generator, a multimeter, a breadboard, and resistors. All members of the team will be required to attend to help set up the test and take measurements. The data and graphs will be recorded in Excel. The team has all the required equipment to perform this test.

3.2.3 Testing Procedure 3: Schedule

This test will take approximately one hour to complete. The team will be conducting this test on November 29th, 2021 at one of the group member's houses. By conducting this test, the team will get an idea of how much power the nozzle and DC generator can produce in order to achieve a total power of 50 watts. The team will then use this data to help determine if the design needs to be iterated for next semester.

4 Risk Analysis and Mitigation

This section will go into details about the risks that are involved in analyzing and utilizing the energy harvesting device. By recognizing the potential failures in the device, our team will be able to mitigate future failures that may occur.

4.1 Critical Failures

As of date, the team has considered five subcomponents where critical failures may occur as shown in Table 2. These five subcomponents include the: solar panel, thermoelectric generators, nozzle/generator, charge controller, and battery.

Table 2: Showcasing the FMEA of the energy harvesting device.

Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Potential Causes and Mechanisms of Failure	RPN	Recommended Action
1 - Solar Panel	Weather damage, Overheating	Loss of power to device	poor implentation of device	30	implementing device properly
2 - Thermoelectric Generators	thermal fatigue, adhesive wear	Loss of power to device	poor implentation of device	20	implementing device properly
3 - Nozzle/Generator	impact deformation, impact wear	Loss of power to device, road hazard	poor implentation of device	45	implementing device properly
4 - Charge Controller	overflow of current, electrical shortage	Loss of power to device	Device overuse/unregulated use of the device	10	Keep device updated and check regularly
5 - Battery	high-cycle fatigue, overcharged, too many charge cycles	Loss of power to device	Device overuse/unregulated use of the device	40	Add component to regulate incoming volts and currents

4.1.1 Potential Critical Failure 1: Solar Panel

The solar panels will be mounted to the top of the vehicle. The main potential failures are weather damage and overheating. Weather damage can be caused by many things such as hail, snow, corrosion from humidity and the list goes on. The solar panels can also overheat causing thermal stress from long exposures to UV rays and high temperatures. The effects of these failures are not severe. If the solar panel fails it would just stop working or a decrease in efficiency. To prevent these failures, the solar panel must be up to date on maintenance and checked for signs of potential failures.

4.1.2 Potential Critical Failure 2: Thermoelectric Generators

The thermoelectric generators will be mounted to the motor of the electric vehicle. The main failures are thermal fatigue and adhesive wear. Thermal fatigue can be caused by long exposures to heat or sporadic temperature changes. Adhesive wear can be caused by rubbing of the thermoelectric generator and the motor. The effects of the failures are minimal. If the failures were to occur, the thermoelectric generators would stop working. To prevent these failures, the thermoelectric generators must be regularly checked for signs of thermal fatigue and adhesive wear.

4.1.3 Potential Critical Failure 3: Nozzle/Generator

The diffuser and DC generator will be attached to the bottom of the electric vehicle. The main failures are impact deformation and impact wear. Impact deformation and impact wear can be caused by the vehicle driving over large objects and damaging the subsystem. The effects of these failures are moderate. Since the diffuser and generator are large components, it could be a road hazard if it were to fall off the vehicle. To prevent these failures, the driver must not drive over large objects and check on the diffuser regularly.

4.1.4 Potential Critical Failure 4: Charge Controller

The charge controller will be mounted inside the vehicle. The main failures are overflow of current and electrical shortages. To prevent these failures the charge controller must be updated and checked regularly. After a couple years the efficiency of the charge controller tends to decrease.

4.1.5 Potential Critical Failure 5: Battery

The battery will be mounted inside the vehicle under the seats. The main failures are high-cycle fatigue, the battery being overcharged, and too many charge cycles. These failures will cause the battery to lose its efficiency, the charge cycle will decrease, and will not store as much energy. To prevent these failures the battery must be checked regularly and adding a charge controller will help extend the life of the battery.

4.2 Risks and Trade-offs Analysis

Although there are several risks that are involved in this project, there are also some trade-offs as well. These trade-offs essentially balance out the risks by mitigating these risks from occurring. The risks that were previously mentioned above such as the solar panel losing connection or the thermoelectric generator falling off the brake pads can easily be avoided if installed properly and having the proper adhesive attached to the device. The main take away from all the potential risks is that these failures can all be avoided by taking precautions and properly installing each device.

5 DESIGN SELECTED – First Semester

This section will go into more detail about the team's most recent choice for the final design of the energy harvesting device. The design mainly consists of a solar panel, thermoelectric generator, and nozzle that will all be wired and connected to a charge controller that will then control a component of the electric vehicle.

5.1 Design Description

The energy harvesting device will consist of three subsystems which are the solar panels, nozzle and thermoelectric generator. Beginning with the nozzle design as shown in figure 3, several analyses were made by using previous knowledge garnered from fluids 1 and fluids 2. These analyses include making several reasonable assumptions so that the Navier Stokes equation can be utilized to calculate the flow happening within the nozzle. Next, the exit velocity and pressure difference with and how much energy this could theoretically generate. By conducting this analysis, we were able to determine if the design was feasible.

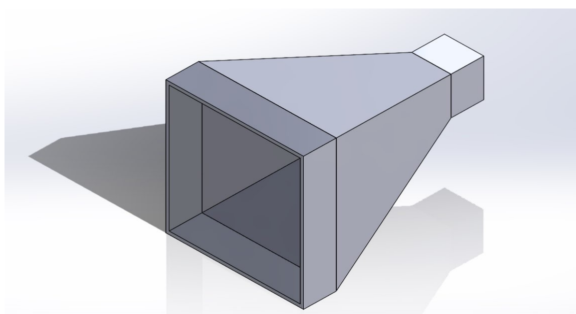

Figure 3: CAD model of the nozzle.

In addition to the nozzle component, our team will also utilize a solar panel as shown in figure 4. In order to figure out how much power can be generated within a year, our team plans to place a solar panel on top of the roof of the electric vehicle and conduct an analysis on the amount of sunlight that is gathered yearly. This analysis was done by taking into consideration the location of where we are located, figuring out how much average sunlight occurs yearly. This can then help determine the theoretical values of energy output and compare them to real results once our team has tested out the solar panel in the second semester. This will help our team gain a better understanding of just how much solar energy is being generated to power a component of the car.

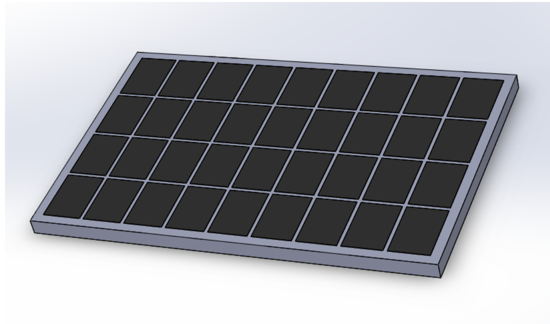

Figure 4: CAD model of the solar panel.

Finally, our team also looked into analyzing thermoelectric generators as shown in figure 5. The analysis that was done looked more into the theoretical performance of the thermoelectric device. The first thing that had to be done was calculating the theoretical of the thermoelectric device by using the Figure of Merit equation. In addition to the theoretical performance, the theoretical efficiency of the thermoelectric device was also calculated. This helped our team determine just how efficient the thermoelectric devices were in respect to our energy generating needs.

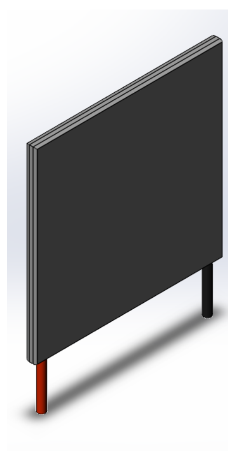

Figure 5: CAD model of the thermoelectric device.

5.2 Implementation Plan

The team plans on redesigning the current CAD model in order to fit more exactly to our needs. This redesign will include a more comprehensive wiring schematic diagram, more detailed views of the components that will be utilized and finalizing which components will be purchased in order to further the process of the project. Our current CAD model is shown below in Figure 6.

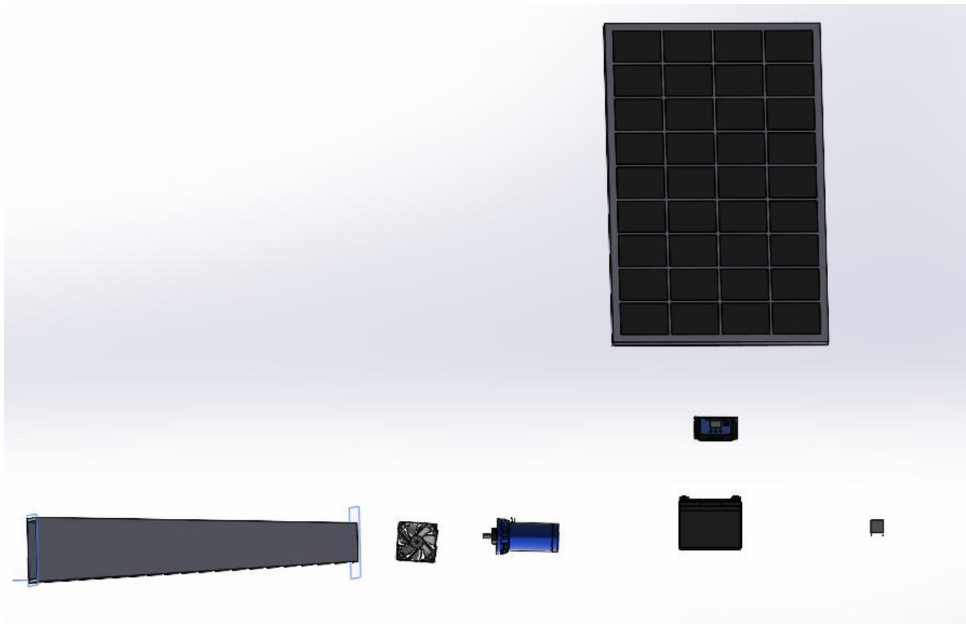

Figure 6: Current exploded view of energy harvesting device.

Next, the prototype will be put through more rigorous testing to ensure that the device will function as required. Once testing of the prototype is completed, the Bill of Materials can be finalized along with the finalized CAD package. The team plans on working during the winter break in order to keep on track with second semester deadlines. A rough schedule for the second semester of capstone is shown in below:

Tasks for Second Semester	Team Goals for Second Semester
● Post Mortem ● Finalize CAD package and begin building the finalized prototype. ● Finalize the finished prototype ● Midpoint presentation ● Hardware Review ● Testing procedures revised. ● Test Device to ensure the validity of the calculations. ● Draft Poster ● Present final product, operation/assembly manual.	● Finalize wiring schematic of current design. ● Functional Thermoelectric generator that produces enough power to power a component of the car. ● Functional way to mount the nozzle onto the car without ruining the aesthetics of the car.

6 CONCLUSIONS

All in all, this report shows the progress that was taken throughout the first semester of capstone. The main goal of this project was to come up with three different ways of harvesting wasted energy from an electric vehicle that will not exceed the $1500 allowed budget. This report essentially goes into detail on how the team met various requirements such as having three different ways of gathering energy, deciding the specific size, weight and cost each item should be for the energy harvesting device. In addition, this report explains the testing procedures that were done in order to ensure that the design could theoretically work with the respective calculations done as proof. Even though the team encountered many challenges, the team was still able to overcome these challenges and work together to come up with a solution. It is believed that with the calculations that were done this semester that our team will be able to complete and build the final project product for next semester.

7 APPENDICES

7.1 Appendix A: House of Quality

Legend	
A	TEG1-12611-8.0
B	Monocrystalline Silicon Solar Panel

	Weight (lbs)	Price ($)	Power (W)	Aesthetically Pleasing (Y/N)	Aftermarket Device (Y/N)	3 types of energy used (Y/N)
Weight (lbs)						
Price ($)	+					
Power (W)	0	+				
Aesthetically Pleasing (Y/N)	0	0	0			
Aftermarket Device (Y/N)	0	-	0	0		
3 types of energy used (Y/N)	+	+	++	0	0	
Able to withstand avg roadwear (Y/N)	-	+	0	+	+	0

Customer Requirements / Design Requirements	Importance	Weight*	Price*	Power*	Aesthetically Pleasing*	Aftermarket Device*	3 types of energy used*	Able to withstand avg roadwear*	Customer Competitive Assessment: 1 Worst	2	3	4	5 Best
1) Not add significant weight	6	9	2	2	2	2	2	4				AB	
2) Must not be too epensive relative to the vehicle	5	1	9	4			3	3			B		A
3) Must supply enough power to perform at least one vehicle function	9		4	9		4	7			A		B	
4) Does not compromise the vehicles aesthetics	5	3			9	5		4		B			A
5) Is an add on to the vehicle	3				6	9	3	2					AB
6) Device captures at least 3 different forms of energy	4		3	7	2	3	9			A		B	
7) Device must be durable enough to withstand road wear	3	2			5			9					
Technical Requirement Units		lbs	$	Watts	N/A	N/A	N/A	N/A					
Technical Requirement Targets		150	1000	80	N/A	N/A	N/A	N/A					
Technical Importance: Absolute		80	105	141	98	112	135	92					
Technical Importance: Relative		7	4	1	5	3	2	6					

Figure 7: House of Quality