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Preliminary Proposal

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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 come up with a design that would meet the criteria set.

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 House of Quality (HoQ)

The House of Quality shown below in **Figure 1** 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.

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

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 1: House of Quality (HOQ) for energy harvesting on an electric vehicle.

3 DESIGN SPACE RESEARCH

3.1 Literature Review

To better comprehend the scope of the project, different energy harvesting methods were thoroughly researched to garner a better understanding of what sort of conceptual designs our team could produce to effectively and efficiently harvest energy from an electrical vehicle. The main topics that were researched throughout the duration of this project are solar panels, regenerative shock absorbers, and alternators.

3.1.1 Solar Panels (Austin Engelbrect)

The portion of the project that this team member decided to focus on was energy harvesting from solar panels and how the team would implement the photovoltaic solar panel into the design of the vehicle in order to gather the most energy possible since this would no doubt be the largest energy harvesting source on the vehicle. The literature chosen mostly involves the implementation of PV solar panels in the most efficient way in order to gather as much energy as possible. The team was able to determine from the research that there is an optimal angle of tilt with respect to the sun in order to gather the most energy from the solar panel [1] [3]. Another interesting aspect of solar energy and possibly a future endeavor would be to decrease the size of the solar panel and increase the total number of panels each having a small motor on the side which would allow for the solar panels to rotate in order to optimize the amount of sun exposure thus increasing the amount of energy harvested [2]. Possibly the most important aspect of this particular literature review was to find a way for the team to effectively mount the solar panel in a fashion where the energy captured by the solar panel would allow for the power to be stored in a battery. Using an article from *Electrical Technology*'s website the team were able to see the most common way to set up a solar panel (12V and in parallel with the batteries) with batteries and a charge controller in order to see the most optimal charge storage and ease of use for the team as well as potential customers [4]. Finally, the last article that the team member read was more ways to implement a more efficient system in which the solar panel may operate. The article goes into detail about water immersion cooling of solar panels and how this can give up to a 17.8% increase at a water depth of about 1cm [5]. This along with other efficiency improving techniques would most likely not be implemented on the first iteration of the design so the team has the ability to get the basics down. However, these insights are very important in making sure that the design of the team has the ability to improve with time.

3.1.2 Regenerative Shock Absorber (Terrell Blackgoat)

This team member's focus was to research how regenerative shock absorbers could be used to extend the electric vehicle's battery life. Regenerative shock absorbers convert the constant vertical motion of the vehicle into electrical energy. Since suspensions are required on all vehicles, this device can replace common suspension systems [10]. Although this device is new, engineers are testing simulations and prototypes to figure out how much energy can be produced. One type of regenerative shock absorber that was tested contains a twin ball screws transmission and it generated approximately 3.701 W and had a peak and average efficiency of 51.1% and 36.4%, respectively [11]. This test was conducted on an electric vehicle traveling at 60 kilometers per hour. Another form of shock absorber contains an electromagnetic generator and a power converter system, a MPPT, attached. In simulation and experimental testing, this design generated a maximum and average power of 250 W and 100 W, respectively [12]. From the two articles, we can assume the shock absorber has enough potential to create enough energy to be stored. Not only will regenerative shock absorbers help extend the battery life of an electric vehicle, but it will also create a much smoother and comfortable ride [13]. This device will be one of the three types of energy harvesting system. To implement this device into the design, the team member must figure out what kind of material it should be made of. The shock absorber must withstand the entire weight of the vehicle and constant pressure, so the material must be strong such as high-strength steel [14]. Since regenerative shock absorbers are new, research will continue to make the device better than before.

3.1.3 Alternator (Miwa Dawidowicz)

Although alternators are used as a generator that turns mechanical energy into electrical energy, our team pondered whether it was possible to use an alternator as a way to harvest energy from a vehicle. Upon further research, one article mentioned that alternators could be disassembled and modified into a potential energy harvesting device [16]. Whereas another journal went into detail about magnetoelectric alternators being used to power smaller devices that required less than 4.28 μW of power [17]. Another way of using alternators as an energy harvesting device could be using the alternator as a way to improve the performance of a vehicle rather than saving lost energy. For instance, one peer reviewed article went into depth about how modified alternators could be used to improve the torque assist in a vehicle as well as the traction motor [18]. Finally, a newly designed energy harvesting device was proposed to test on high voltage, high kinetic areas in road tunnels based on linear alternators [19]. Although this newly proposed energy device is primarily meant for roads, this device has the potential to be used on vehicles by utilizing the wasted energy spent by the vehicle [19]. Even though alternators are considered low efficiency and limited, there is still room for improvement in modifying the performance of alternators to increase efficiency [20].

3.2 Benchmarking

The team were given the task of designing a system which harvests energy from outside sources and uses this energy to power a specific function of the vehicle. This has not been done before on a large-scale operation so benchmarking was limited to doing research on the regenerative braking systems of existing hybrid/electric vehicles. Other challenges that the team faced when attempting to benchmark the design is that although the main source of benchmarking had to be an existing system on a vehicle, most of this information on the systems are not readily available to the public which is a challenge the team had to overcome. This among other challenges forced the team's benchmarking process to be limited to the information that we were able to find online using the resources that we had available to us. The final benchmarking choices the team used were existing energy harvesting methods and regenerative braking systems.

3.2.1 System Level Benchmarking

The team had a limited range of total systems to benchmark against. The only full system that currently exists on the market is the regenerative braking system that is common amongst most hybrid and electric vehicles. Another system that is relatively related to the project at hand is the charging system for the gasoline power system. This system has three components, two of which work in tandem to decide when the battery of the vehicle needs to be recharged. The final system that the team used to benchmark was the solar charging systems that are becoming more popular in use. These are used to charge things stationary usually however the team has some interesting ideas on how to implement these into our design.

3.2.1.1 Existing Design #1: Regenerative Brakes

As stated previously the first design that the team looked into was regenerative brakes. This system is effective at gathering energy to be stored back into the battery pack of the vehicle which is obviously relevant to the project that we are working on. This system takes the DC motors that work to drive the wheels and when the brakes are applied the motors turn backwards acting as a generator to regain some lost electrical energy. There have been some newer models of vehicles reporting upwards of 70% of the kinetic energy that is wasted during braking can be turned into electrical energy [7].The complete system is the only direct comparison that we have for our project so it works well as a benchmark.

3.2.1.2 Existing Design #2: Internal Combustion Engine (ICE) Car Battery Charging System

This system is not directly related to the design that we have at hand but can give us some useful insight into how we can charge batteries using generators. This system uses its three components to charge the lead acid battery that is used to start an ICE vehicle. The battery expends some charge to turn the starter motor which then starts the engine. After this the alternator is run off of the rotating motion that comes from the motor which generates electricity. This then is fed through a voltage regulator which will decide how much voltage is allowed and also whether or not the battery of the vehicle needs to be charged [6]. Again though this is not a direct comparison to the system that the team was tasked with designing.

3.2.1.3 Existing Design #3: Solar Charging Systems

Another system that is relevant to the design that the team is working with is the use of solar charging. This is something that the team uses as a reference throughout the design process when looking at how to implement this into the main design. Photovoltaic solar panels work by using individual solar cells which absorb light. This excites electrons within the solar cell which is a current flow. This then can be taken and used in tandem with a charge controller which determines the amount of current that needs to be sent to/taken from the batteries that this solar panel is hooked up to[9] [8]. These are used anywhere from large buildings to parking lot coverings, and even on some individuals' homes. This is a good benchmark for the team to work against so that we may figure out how efficient these systems are and how we are going to implement them into our design.

3.2.2 Subsystem Level Benchmarking

The team broke their design into five subsystems: the photovoltaic solar panels, alternator, regenerative shock absorber, AC-DC converter, and a rechargeable battery. They were able to benchmark four of the five subsystems. Of the four subsystems, the photovoltaic solar panels and alternator were benchmarked by existing products in the market. The photovoltaic solar panels and alternator were benchmarked based on price, power generation, weight, and size. The AC-DC converter was also benchmarked with existing products in the market and the benchmarked characteristics were price, size, power input and output. The team did little benchmarking when it came to the battery. They chose to benchmark the battery’s cost, amps per hour, and volts. Since batteries are expensive the team had a limited range to choose from in order to stay under the given budget of $1500. The subsystem that could not be benchmarked was the regenerative shock absorber because this device is not mass produced due to it being a new product.

3.2.2.1 Subsystem #1: Photovoltaic Solar Panels

The function of the photovoltaic solar panels is to capture solar energy and transfer it to the AC-DC converter. This subsystem is important because the whole basis of the project is to use three types of renewable energy to help extend the life of a battery on an electric vehicle. Since the vehicle will always have direct exposure to sunlight, the photovoltaic solar panels have the potential to gather a large amount of energy for our design and store that energy into a rechargeable battery.

Photovoltaic Solar Panels			
Product Type	Monocrystalline Silicon	Monocrystalline	Polycrystalline
Cost Per Unit	$ 117.09	$ 167.19	$ 37.63
Volts (V)	18	12	5
Watts (W)	300	100	100
Size	670mm x 1129mm	48in x 21.5in	435mm x 200mm
Flexible? (Yes/No)	No	Yes	Yes
Purchase Site	Walmart.com	Renogy.com	Alexnld.com

Figure 2: Photovoltaic Solar Panel Benchmark

3.2.2.1.1 Existing Design #1: Monocrystalline Silicon

This product is a monocrystalline silicon solar panel that costs $117.09. It has the potential to generate 18 volts and 300 watts, which is enough power for our design. The main concern of this product is the size and flexibility. The team is looking for a product that is flexible enough to install on the roof of an electric vehicle. Since the roof of vehicles have a slight curvature and this product is not flexible, the team must design a platform that can hold this product, also the platform must be aesthetically pleasing.

3.2.2.1.2 Existing Design #2: Monocrystalline

This product is the monocrystalline solar panel. It costs $167.19. It has the potential to generate 12 volts and 100 watts of power. Unlike the monocrystalline silicon solar panel, this product is flexible and very thin. So installation on the roof of an electric vehicle will be easier and the team does not have to design a platform which will reduce the weight of the vehicle and save money, materials, and time. Although this product is not as powerful as the monocrystalline silicon solar panel, it still has the ability to produce a large amount of energy for our design and because of the thinness this product will be unnoticable.

3.2.2.1.3 Existing Design #3: Polycrystalline

This product is a polycrystalline solar panel. It costs $37.63 and it has the potential to generate 5 volts and 100 watts of power. This solar panel is not able to be combined with other solar panels due to the cable management. So this product will not be incorporated into the design. Also, this product has thickness that will increase the drag of the electric vehicle and the efficiency of a polycrystalline solar panel is much less than a monocrystalline.

3.2.2.2 Subsystem #2: Alternator

The team has decided to attach a belt from the axle to the alternator. Since the alternator works as a pulley, the axle will be rotating the belt to create rotational energy from the alternator. That energy will be transferred to the battery to be stored and power the headlights of the vehicle. The team chose alternators because it has an efficiency that ranges from 50% to 60%.

Alternator			
Product Type	Duralast Gold Alternator DLG1701-16-3	Duralast Alternator 13168	Duralast Alternator 14273
Condition	New	Remanufactured	Remanufactured
Cost Per Unit	$ 254.99	$ 79.99	$ 89.99
Volts (V)	12	12	12
Pulleys Included	1	1	1
Weight (lbs)	12.45	11.9	10.5
Purchase Site	autozone.com	autozone.com	autozone.com

Figure 3: Alternator Benchmark

3.2.2.2.1 Existing Design #1: Duralast Gold Alternator DLG1701-16-3

This alternator will not be used for the project due to the high cost. Although the alternator is in great condition, the team has decided to use remanufactured alternators due to the tight budget. Also, there are more alternators that provide the same amount of volts at a way cheaper price.

3.2.2.2.2 Existing Design #2: Duralast Alternator 13168

This alternator is the cheapest out of the three and provides the same amount of volts at a cheaper price. This alternator fits perfectly within the budget. The team must also purchase at least two alternators just in case of malfunction.

3.2.2.2.3 Existing Design #3: Duralast Alternator 14273

This alternator weighs the lightest of the three, but the team will not use this due to the cost alone.

3.2.2.3 Subsystem #3: Regenerative Shock Absorber

Regenerative shock absorbers are new to the market and only limited companies are manufacturing this product. The regenerative shock absorbers are either too expensive or the only way to get access to regenerative shock absorbers is to reverse engineer an electric vehicle. Also, limited research about regenerative shock absorbers are available to the public. According to the academic journal *Applied Energy*, this product has an efficiency ranging from an average of 44.24% to a high-efficiency of 54.98% and is able to produce an average power of 4.302 W at a vibrational input of 2.5 Hz and amplitude of 7.5 mm, in experimental testing [15].

3.2.2.4 Subsystem #5: Rechargeable Battery

The function of this subsystem is to collect the energy from the three harvesting systems, store the energy, and power the given components of the vehicle. For this subsystem, the team chose to use a deep cycle battery. The deep cycle batteries are designed to be recharged. The rechargeable battery was benchmarked by its cost, volts, and amps hours.

Rechargeable Battery			
Product Type	Deep Cycle AGM	ML35-12 GEL Mighty Max	ALSDC12-35J Duracell Ultra
Cost Per Unit	$ 217.61	$ 79.99	$ 109.99
Volts (V)	12	12	12
Amp Hours (AH)	100	35	35
Weight (kg)	29	10.5	11.23
Purchase Site	renogy.com	walmart.com	batteriesplus.com

Figure 4: Rechargeable Battery Benchmark

3.2.2.4.1 Existing Design #1: Deep Cycle AGM

The function of the deep cycle AGM battery is to discharge and recharge. The cost of one battery is $217.61, The team has decided this battery will not be added to the design due to the high cost and weight.. The team has a budget of $1500 and this battery will add a significant amount of weight to the car.

3.2.2.4.2 Existing Design #2: ML35-12 Gel Mighty Max

The ML35-12 GEL Mighty Max battery provides 12 volts and 100 amp hours for a cost of $79.99 per battery. The team has decided to use this battery because it is cheap and it provides enough volts and amp hours to power a component of the vehicle. Also, the battery is able to recharge and discharge and it only weighs 10.5 kg.

3.2.2.4.3 Existing Design #3: ALSDC12-35J Duracell Ultra

The ALSDC12-35J Duracell Ultra will not be used for the design of this project due to the cost. The team has found another battery with the same specifications for a much lower cost.

3.3 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.

3.3.1 Black Box Model

Figure 5 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.

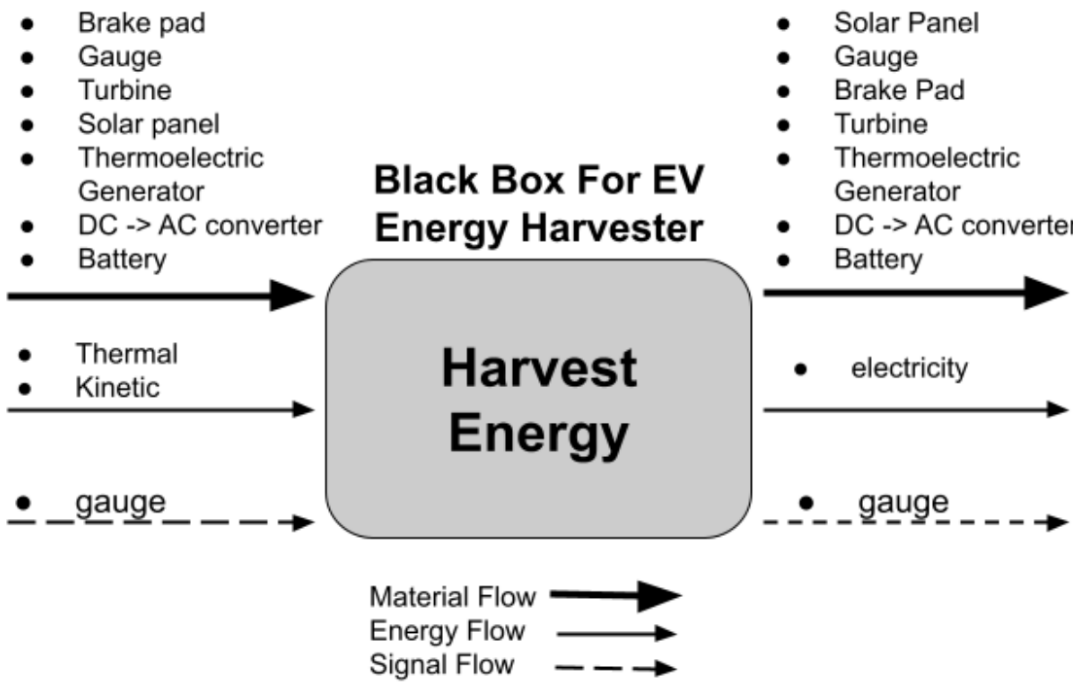

Figure 5: Black Box Model

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

Figure 6 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.

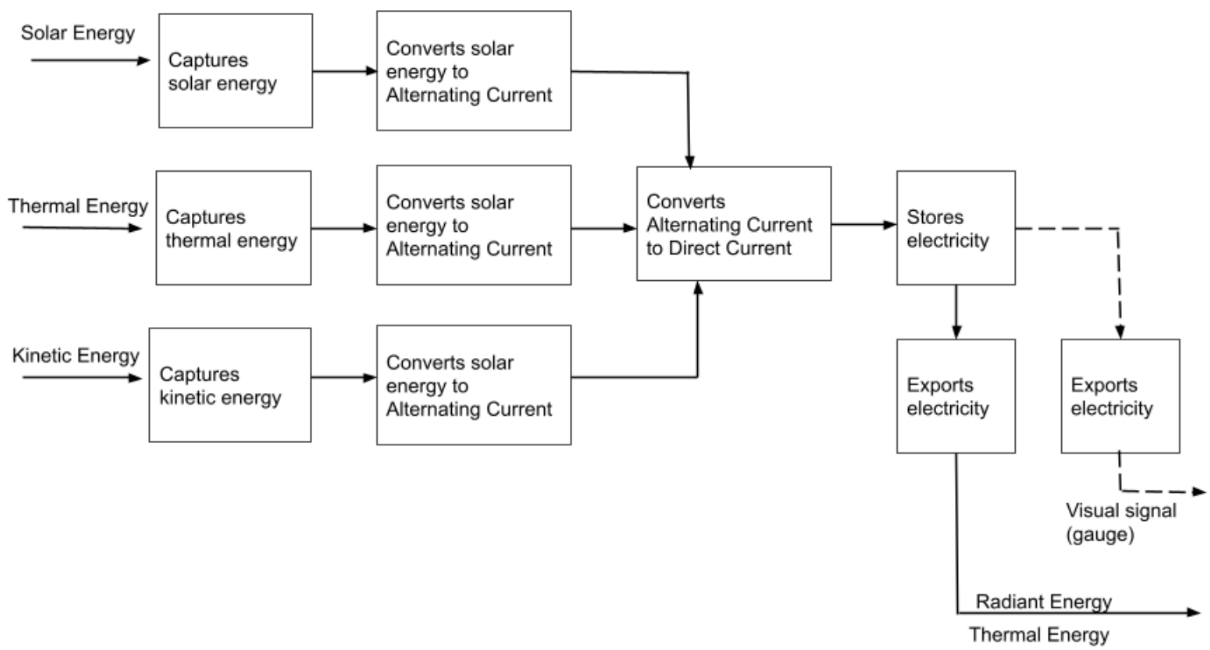

Figure 6: Preliminary Functional Model

4 CONCEPT GENERATION

4.1 Full System Concepts

Sub Function	Concept Variants								
Deploy/ Activate	Rotation of the axle	Sunlight hitting car	When car is on	Activates when outside temp reaches a certain temp	Activates when driving at certain speed	Activates when driving	Activates when driving by high frequency devices	Activates when the vehicle is at a high speed	Activation sensor
Capture/ Transfer	Alternator on axle converts electricity	Solar film captures energy	Thermoele ctric Generator	Shock absorbers	turbine	Piezoelectr ic harvester	Radio Frequency Energy harvester	Vortex induced vibrational piezoelectric device	Triboelectric
Convert Energy	Rectifier	Converter	converter	converter	generator	inverter	Inverter	Converter	Rectifier
Store Energy	Using small battery pack	Small capacitor to store energy	capacitor	Direct power to component	accumulat or	Supercapa citor	Small battery pack	Capacitor	Battery pack
Power Vehicle	Small computer used to direct power heat pump	Power goes directly to headlights	lights	Heat pump	Powers A/C	Powers radio	Powers Headlights	Radio	Powers interior car lights

Figure 7: Morphological Matrix

4.1.1 Full System Design #1: Design 1

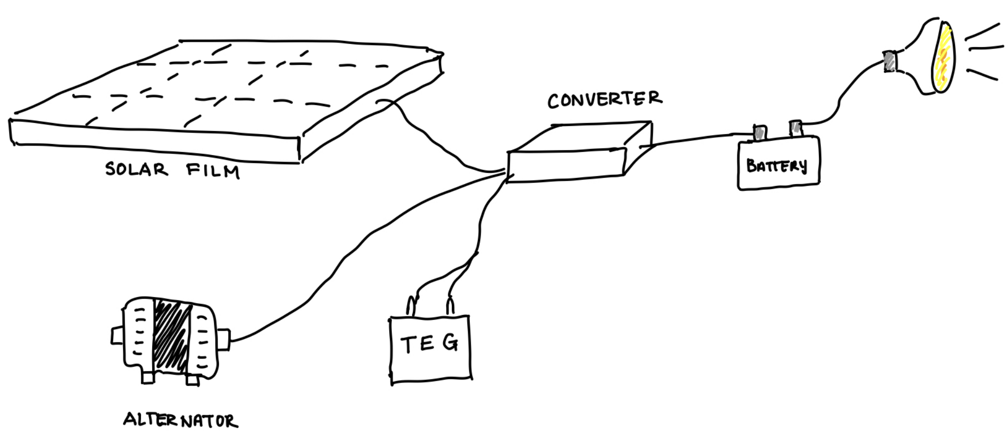

Figure 8: Design 1

This is the first design that the team had considered from the list of subsystems in the morphological matrix. The components include a solar panel, alternator, and thermoelectric generators all feeding into a converter to then feed a battery to be stored and then sent to power the headlights. This design was the favorite for the team although not without its flaws.

Pros:

- This design was relatively power dense when it came to the rest of the designs that the team was

working on
- The design has a simple set of components
- All of the components of the design could have readily been found by the team and would be easy to maintain
- Where the power is going for this design is simple enough to be implemented without running into the issue of having to work around other systems

Cons:

- The design has an alternator on it which is a mechanical component which is prone to failure at a higher rate than some of the other design components
- The converter for the design is expensive and does not serve too much of a purpose for the design
- The design has a very small amount of power generated from the TEG's that were implemented into the design

4.1.2 Full System Design #2: Design 2

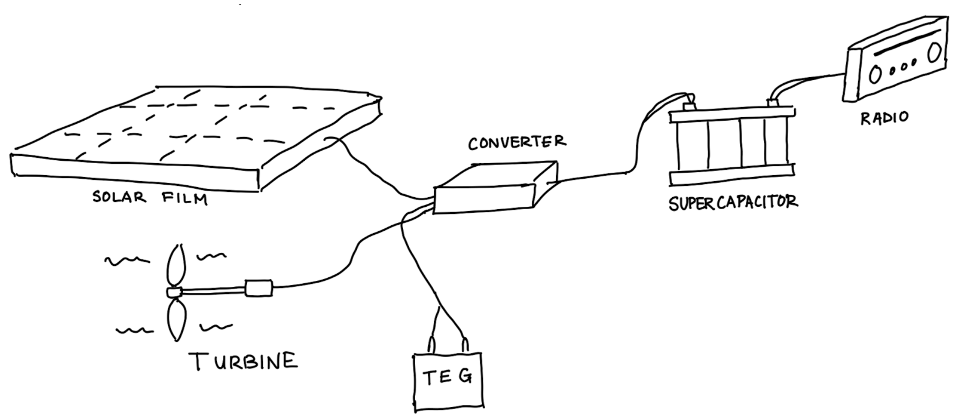

Figure 9: Design 2

This system is similar to design 1 in that it uses TEG's and a solar panel however the rest of the design is different in that it uses a turbine for a different energy harvesting source and a supercapacitor for the storage portion of the design.

Pros:

- Design gathers a large amount of energy that can be used
- The implementation of the design would be very easy
- The radio is not a power dense device so the energy needed is not a lot giving room for use of excess energy

Cons:

- This design would most likely ruin the design aesthetics of the vehicle that it would be put on
- Design using a supercapacitor is not really applicable to the design goal that the team was given
- The radio would be difficult to hook up to for most vehicles without actually causing any issues for the device
- A turbine is again a mechanical device and is prone to taking damage for on road conditions

4.1.3 Full System Design #3: Design 4

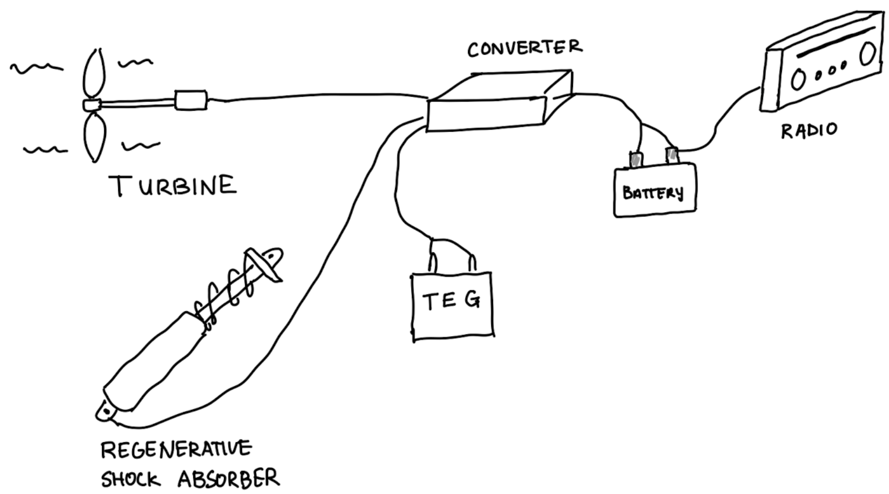

Figure 10: Design 4

This design was using similar parts to the previous two designs. The use of a turbine, regenerative shock absorber, and TEG's again. This design uses a battery for storage and then directs that power to the radio. The design was chosen based on the interesting use of new technology and the ability to be more subtle than a design that would have implemented a solar panel.

Pros:

- The device has an interesting use of a new technology
- The power that this device has the capability of generating is comparable to the other two main designs
- The battery storage is a good for the application that the team was going for

Cons:

- Design has mechanical components which are prone to braking
- The regenerative shocks are a very interesting idea just not easy to implement because of lack of product availability
- Radio, again, is a challenging thing for the team to hook the device up to

4.2 Subsystem Concepts

The subsystems that the team chose are largely based around the type of energy harvesting sources that the team had chosen to work with. These include solar, kinetic, and thermal energies. These were then sent to some sort of device that will take the energy harvested and convert it if necessary. This is then sent into the storage device where the energy will be kept. Following this the device will need to send the power to the source where it will be used.

4.1.4 Subsystem #1: Solar Energy Harvester

Solar panels are the only product that can harvest solar energy.

4.1.4.1 Design #1: Photovoltaic Solar Panel

Pros:

- Constant sunlight exposure if solar panels are installed on the roof of a vehicle.
- Easy to install on a vehicle.
- Solar panels do not weigh as much.
- Produces a large amount of power.

Cons:

- Solar panels are expensive.
- It may ruin the aesthetics of the vehicle if the solar panels are large.

4.1.5 Subsystem #2: Kinetic Energy Harvester

These are products that are able to harvest kinetic energy and the team can convert that energy into electricity for the electric vehicle. The three products chosen are a regenerative shock absorber, triboelectric generator, and alternator. Turbines are another product that can harvest kinetic energy, but it will not be used in our design due to its inefficiency if it was installed on a vehicle.

4.1.5.1 Design #1: Regenerative Shock Absorber

Pros:

- This device is highly efficient.
- It has the potential to create energy with the constant vibration of the vehicle.
- Installing this device in a vehicle will make no changes to the aesthetics.
- The device can increase the smoothness of the vehicle..

Cons:

- This device has a high cost per unit.
- This device is new to the market and limited research has been conducted.
- Not many companies are manufacturing this device.

4.1.5.2 Design #2: Triboelectric

Pros:

- It has the potential to create energy with the constant friction in the vehicle's rotating components.
- This device will not change the aesthetics of the vehicle.

Cons:

- This device is new to the market and limited research has been conducted.
- This device has a high cost per unit,
- Installing this device is inefficient and complex.

4.1.5.3 Design #3: Alternator

Pros:

- This device is moderately efficient.
- It has the potential to create energy with the constant rotation from the vehicle's moving parts.
- Large amounts of energy can be collected.
- Remanufactured alternators are inexpensive.

Cons:

- It needs a certain amount of revolutions per minute to activate.
- It will overheat at high revolutions per minute.
- Brand new alternators are expensive.

4.1.6 Subsystem #3: Thermal Energy Harvester

These are products that are able to harvest thermal energy and the team can convert that energy into electricity for the electric vehicle. The only available product that can harvest thermal energy is a thermoelectric generator.

4.1.6.1 Design #1: Thermoelectric Generator

Pros:

- Installing this device is simple because of the size.
- I can generate electricity from the temperature difference.
- Each thermoelectric generator is inexpensive.

Cons:

- This device does not gather that much energy.
- This device has a low efficiency.

4.2 Technical Selection Criteria

Although our team generated ten different design alternatives using the morphological matrix, we quickly were able to disregard four of the designs. These four designs were disregarded due to the composition of the design not being feasible or simply because the construction of the design would be out of our current budget. Therefore, our team was left with six design alternatives as shown in Appendix C. These six design alternatives were then put through a Pugh Chart as shown in Appendix A to qualitatively narrow down our choices by ranking each design based on our engineering requirements. By narrowing down our choices with the Pugh chart, we were left with 5 design alternatives to put into our Decision matrix shown in Appendix B. We chose to use the Decision Matrix as it helped to quantitatively choose our top two designs. Finally, after some comparison using existing data and our current budget we were able to decide that design 5 was our top choice. As a result, our team found out that our top concept design was Design 5. Design 5 included the implementation of adding regenerative shock absorbers, solar film, alternators, an inverter, and a battery in order to power the vehicle's headlights.

4.3 Rationale for Design Selection

After utilizing both the Pugh Chart and Decision Matrix, we were left with two top designs: Design 1 and Design 5. Although Design 1 consists of a solar panel, alternator, and thermoelectric generator, this design still had its flaws. Some of the flaws that prevented this design from being our top choice was due to the fact that the converter added into the system would be too expensive for our budget and did not aid in the purpose of the design. The reason that the converter did not aid in the design was because the alternator of Design 1 produced alternating current which the converter could not convert into direct current. Therefore, leaving our team with our top choice of using Design 5. Design 5 consists of the implementation of adding regenerative shock absorbers, solar film, alternators, and inverter. The advantage of this design was that it was more feasible as an inverter added our design to convert alternating current to direct current. In addition, Design 5 also implemented the use of our energy harvesting system to power the headlights of a vehicle which is less power dense than powering a radio such as in Design 1. As a result, because of the many benefits of using design 5, our team was able to fit more into our budget as it allowed us to have more of our budget spent on prototyping and contingency budget.

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5 APPENDICES

5.1 Appendix A: Pugh Chart

Datum: Regenerative Braking System for EV/Hybrid Vehicles

Engineering Characteristics	Weights		Design 1	Design 2	Design 3	Design 4	Design 5	Design 6
Design Weight (<150 lbs)	6	Datum	-	-	-	-	-	-
Price (≤ $1000)	5		S	-	-	+	+	+
Power (≥ 80 Watts)	9		+	+	+	+	+	-
Aesthetically Pleasing	5		+	-	+	+	+	-
Aftermarket Design	3		+	+	+	+	+	+
Three types of Energy Used	4		+	+	+	+	+	+
Withstand average road wear	3		+	S	S	S	+	-
Total +			5	3	4	5	6	3
Total -			1	3	2	1	1	4
Overall Score			4	0	2	4	5	-1
Weighted Total +			1.75	1.05	1.4	1.75	2.1	1.05
Weighted Total -			0.35	1.05	0.7	0.35	0.35	0
Weighted Overall Score			**1.40**	**0**	**0.7**	**1.40**	**1.75**	**1.05**

Figure 11: Pugh Chart

5.2 Appendix B: Decision Matrix

		Design 1		Design 3		Design 4		Design 5		Design 6	
Criteria (Customer Needs)	**Wei ghts (%)**	Score	Weight Score	Score	Weight Score	Score	Weight Score	Score	Weight Score	Score	Weigh Score
Lightweight	10	4	0.4	2	0.2	2	0.2	4	0.4	2	0.2
Inexpensive	20	3	0.6	1	0.2	2	0.4	3	0.6	2	0.4
Three Forms of Energy	5	5	0.25	5	0.25	5	0.25	5	0.25	5	0.25
Produce Power	30	5	1.5	3	0.9	3	0.9	5	1.5	3	0.9
Aesthetically Pleasing	25	3	0.75	2	0.5	2	0.5	4	1	2	0.5
Add on device	10	5	0.5	5	0.5	5	0.5	5	0.5	5	0.5
Total	**100**		**4.00**		**2.55**		**2.75**		**4.25**		**2.75**

Figure 12: Decision Matrix

5.3 Appendix C: List of Design Alternatives

Design 1: Thermoelectric generator, Alternator, Solar film, converter/rectifier, capacitor, headlights

Design 2: Shock absorbers, Piezoelectric harvester, Turbine, Converter, Battery, A/C

Design 3: Turbine, Piezoelectric harvester, Thermoelectric generator, Generator/converter, Supercapacitor, Radio

Design 4: Solar film, Turbine, Thermoelectric generator, Converter, Battery, Radio

Design 5: Shock absorber, solar film, alternator, inverter, battery, headlights

Design 6: Thermoelectric generator, shock absorber, solar film, inverter, battery, headlights

Design 7: Alternator, Piezoelectric harvester, turbine, converter, supercapacitor, headlights

Figure 13: A few selections of our team's alternative designs