Power Generation through Recycled Materials

Senior Design Final Report – April 2012

By

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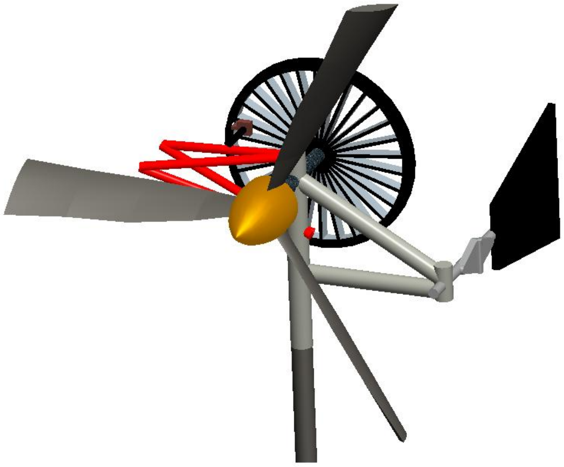

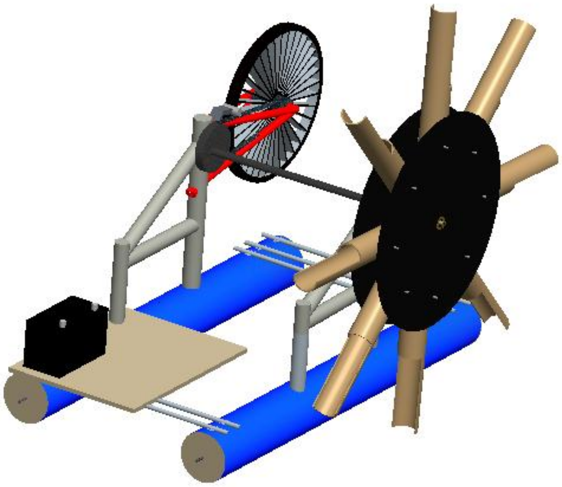

Project Sponsor

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I. Abstract

The goal of this project was to take readily available parts from the trash of the “developed world” and create an electrical power generator that runs off renewable resources (wind power, solar power, hydropower, geothermal). The project also needed be very cost-efficient as many people in third world countries do not have the financial resources to purchase new systems for green energy production.

Cummins laid out specific objectives that needed to be met by the final design. The power generation device needed to produce 100 W•h/day, and store a minimum of 300 W•h. In addition, they placed constraints on the cost of the device and the locations where the device would be operational. The total cost to the user for the power generation device could not exceed US $50.00. The locations selected needed to be in third world countries that were 500 km away from each other and 100 km away from an ocean coastline.

It was determined that the renewable resources that were most adequate, due to the cost constraint, were wind energy and water energy. During the concept generation phase it was decided that each concept would follow a similar infrastructure that would contain four main components. The first is a rotational component that changes the potential of the renewable energy source into rotational mechanical energy. The second component is one that will increase the rotational velocity from the rotational component. The next component is an energy conversion component that changes the rotational mechanical energy into electricity, and finally a power storage component that will store that electricity. Four designs were initially generated to solve this problem, though only two were selected for carrying out the construction process. The two were a horizontal axis wind turbine (HAWT), and a micro hydroelectric generator (MHET).

The designs that were eliminated were the Tesla Turbine and the Vertical-axis wind turbine (VAWT) due to lack of adequate available construction materials at the scrap yards and high complexity. The ones available were not robust enough to support a VAWT structure in high

wind velocities. The Tesla turbine proved to be highly complex and expensive for the required scaling to meet the objectives.

The three designs were analyzed based on a power production standard of 10 W. This standard was selected to take into account wind energy not being available throughout the 24 hours of the day, and to account for losses in power generation while still meeting the objective of 100 W•h/day. The scale was deemed very important because the size would directly impact the cost of the system. The pricing was obtained from Marpan Recycling to be US \$0.02/lb of plastic and US \$0.15/lb of metals. Next the wind and water speeds were estimated from the chosen locations. Wind speed was selected to be an average of 4 m/s, and an average water speed of 6 ft/s.

The necessary sizes of the turbines were calculated using reduced efficiencies as well as inconsistencies in wind flow and water flow. This was necessary to develop a margin and ensure proper meeting of the objectives. The size of the HAWT needed to be at least 3.29 m^2 based on the power requirements. The Micro-hydroelectric turbine was designed base on a weight of 115 lbs, which required 5.3 ft of PVC pontoon floats. The radius of the water wheel was determined to be roughly 28 in.

The most expensive part of each system was the power storage component, and there was little variety to the possible choices. The energy conversion components were chosen to be bicycle dynamos. This allowed for a reduced cost for this component and left a greater budget available for the actual design of the power generation devices. The final concepts were built and met the specified power requirements successfully. The HAWT was made for a total price of US \$49.34, while the MHET was slightly over budget at US \$67.32, which with volume cost and mass production may be reduced to the target budget. The minimum river water speed that the MHET can produce 100 W•h/day is 1.56 m/s. The wind turbine will charge the car battery so long as the wind speed is above 2.2m/s and creates more electricity as the wind speed increases. The 100 W•h/day can be achieved with 4 m/s; however, require 19 hours. Wind speed of 6 m/s can achieve that amount in 10 hours.

II. Introduction

Background/Needs Assessment

In many countries around the world there are people with scarce means of acquiring power. This is mostly due to the lack of financial funds for a centralized power generation facility, or lack of parts that can be combined into a system that can harness energy from natural resources. A power generator would be a very valuable commodity for them and would greatly enhance their standard of living.

With planet Earth's current energy crisis there is a huge surge towards using renewable resources to supply power. Around the globe people are turning to wind, solar and hydro power in order to reduce the amount of carbon emissions they are creating as well as obtain "free" sources of energy. Most common wind applications consist of wind turbines which harness the mechanical energy of wind turning a turbine. Mechanical energy is then converted into electrical energy with the use of either a PM generator or an alternator. Hydropower is another abundant renewable resource that uses falling or moving water to rotate a turbine and produce mechanical energy. This mechanical energy can then be converted into electrical energy, similarly to wind power. Solar power can provide a substantial amount of energy due to the Sun; however, solar photovoltaic cells as well as solar thermal systems are very expensive.

Green energy systems made from new materials have a high cost, and the price is most commonly justified by large scale implementation. For the purpose of this project it is of great importance to provide a small scale device that would be affordable and effective in generating energy. Another advantage of designing the kit in a first world country is the vast majority of trashed or recycled components that are available. These components contain great value that in their current state is overlooked and kept in permanent storage. This abundance in parts is a key element in designing a low cost system.

Problem Statement

Design and construct a power generation device that implements the use of a renewable energy source, and is composed entirely of recycled materials.

List of Objectives

The following are a list of objectives provided by Cummins that were met with final design and construction of the power generation device:

- Power generation unit must be capable of generating 100 W•h/day
- Power generation unit must be capable of storing 300 W•h
- Output of unit must be 12 V Direct Current
- System should take into consideration severe weather

Testing Environment for Objectives

The testing environment consisted of four main criteria, which include: mechanical functionality, power generation capability, power storage, and acceptable cost.

The mechanical functionality was tested using the natural elements that provided the potential energy and realistic simulation to the final operating conditions for the product. It became the first step towards satisfying the objectives, since, a mechanical functional device is necessary to harness the potential energy from renewable energy sources.

Power generation capability and power storage were satisfied with components that would properly convert mechanical energy into electrical energy in conjunction with a storage device.

The cost for the final product was monitored during the construction process, keeping every part as cost efficient as possible.

List of Constraints

The following constraints must also be satisfied with the design and construction of the power generation system:

- Three geographic locations for implementation of the power generation unit must be selected in third world countries
    - Each location must be 100 km away from the ocean and 500 km away from each other
- Final Cost of the power generation kit must be under (US) $50.00
    - Price does not include construction, materials, or labor costs at destination
    - Does not include refurbishment costs for recycled materials

Product Specifications

The overall layout of the power generation devices developed, include four main components. The first is a rotating component; which is a wind turbine, or a hydro-electric paddle wheel. The responsibility of this component is to convert the potential of a renewable source of energy into useful, mechanical energy. The next component is a gearing system; in which a pulley/belt assembly, and a chain and sprocket assembly. The third component is an energy conversion device that can convert mechanical energy into electrical energy; bicycle dynamos. The final component is a storage device; an automotive battery.

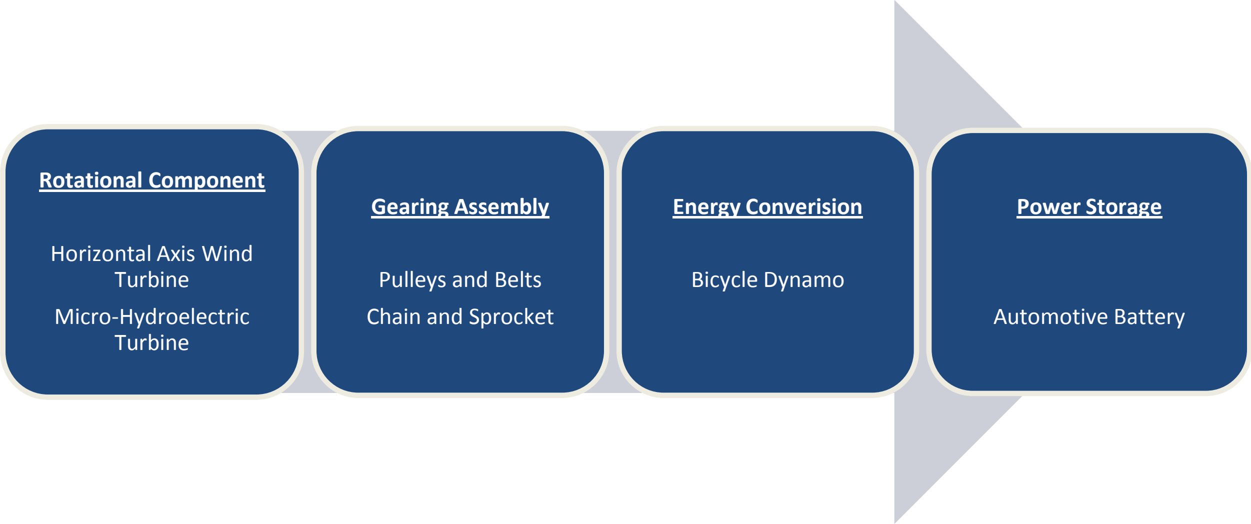


Figure 1 – Functional Diagram for Design Concepts

Rotational Component

The rotational component of the system will have two forms. They are a horizontal axis wind turbine and a micro-hydroelectric paddle wheel. Detailed design of these rotational components will be analyzed in the Concept Generation section that follows.

Gearing Assembly

This component of the power generation is required due to the energy conversion process that follows. The rotational velocities from the rotational components from each design are not sufficient to directly attach to an alternator or the bicycle dynamo. Bicycle dynamos can produce significant power at lower rpm's, and due to its nature, was connected to the outside of the bicycle tire that provided the adequate gearing for operation. The alternator unit used, required the use of a gearing and sprocket assembly of the bicycle as well as a belt and pulley system.

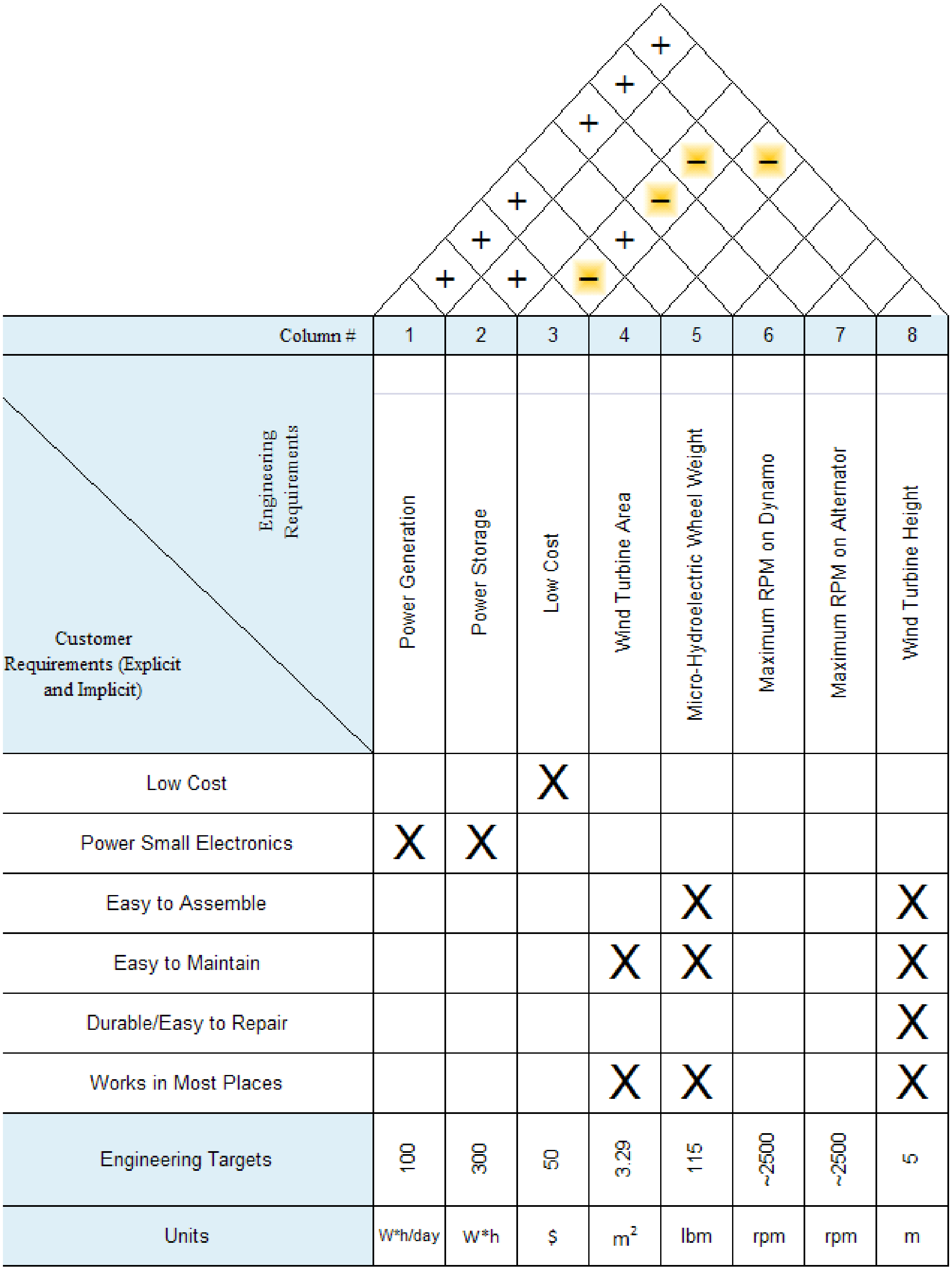
Energy Conversion

The energy conversion component is required to convert rotational mechanical energy into electricity. Bicycle dynamos were successful in performing this task. The components that were selected for implementation onto the designs are discussed in the Concept Generation section under Energy Conversion. The final component selection can be found under the Final Concept section.

Power Storage

The power storage device is crucial for handling fluctuations in power generation. In order to successfully output a 12 V DC current and store a minimum of 300 W•h an automotive battery was chosen. The power storage component that will be integrated into the design is analyzed in more detail in the Concept Generation section under Power Storage.

Quality Function Deployment



Column #	1	2	3	4	5	6	7	8
Engineering Requirements / Customer Requirements (Explicit and Implicit)	Power Generation	Power Storage	Low Cost	Wind Turbine Area	Micro-Hydroelectric Wheel Weight	Maximum RPM on Dynamo	Maximum RPM on Alternator	Wind Turbine Height
Low Cost			X					
Power Small Electronics	X	X						
Easy to Assemble					X			X
Easy to Maintain				X	X			X
Durable/Easy to Repair								X
Works in Most Places				X	X			X
Engineering Targets	100	300	50	3.29	115	~2500	~2500	5
Units	W*h/day	W*h	$	m^2	lbm	rpm	rpm	m

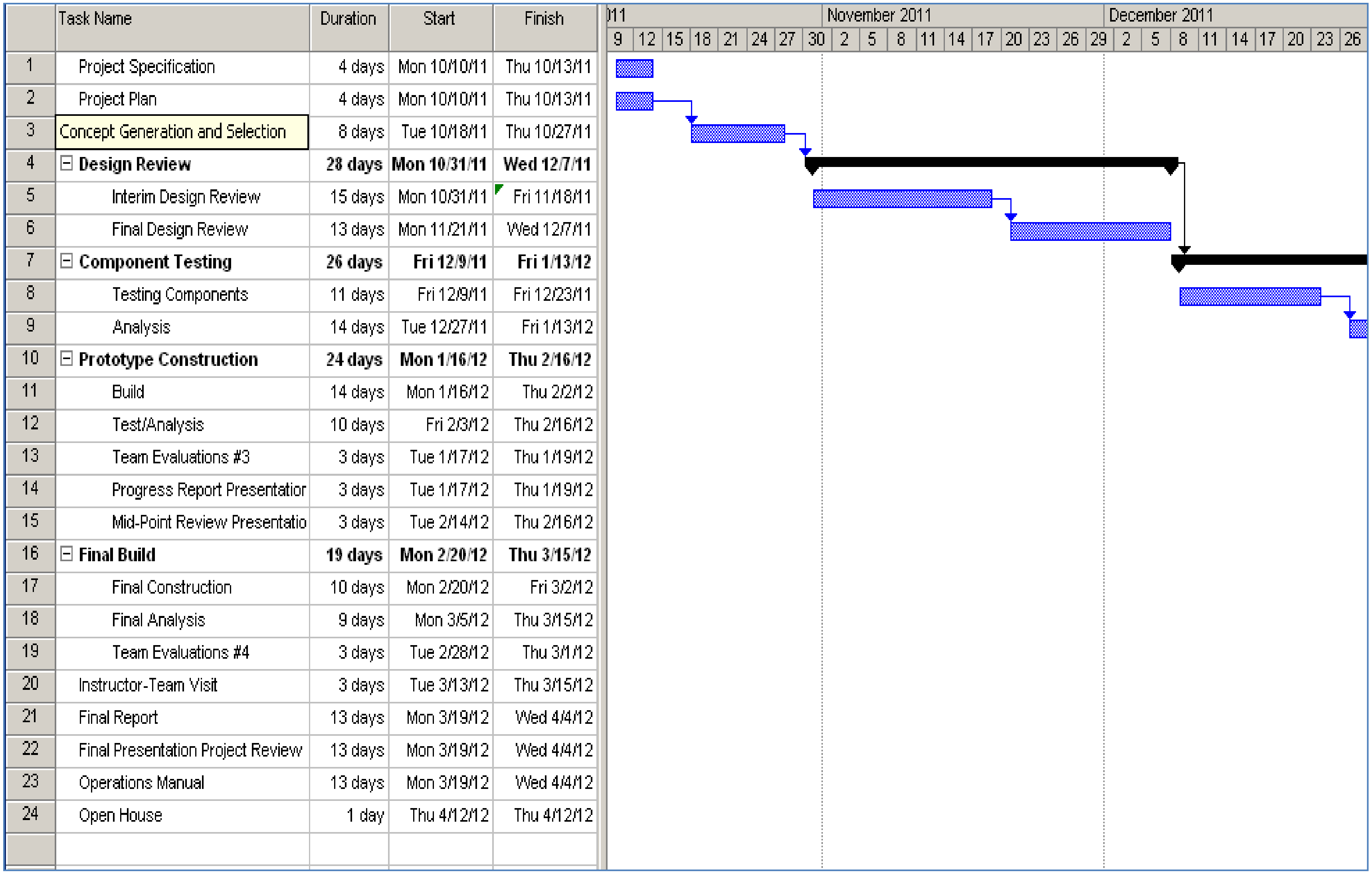
Figure 2 – House of Quality – Template obtained from template from Christopher Battles

The House of Quality shown above compares the different needs of the customers to the engineering requirements of the different designs. The major relationships between the two can be found to be low cost, power generation and power storage. These three relationships are also the main objectives behind the project and demonstrate how the primary motivation behind this project is to satisfy customer needs. The weights and heights that have been outlined in the house of quality are directly related to the power generation and power storage capabilities, as well as to ease the assembly and maintenance for the users. The size and weight of these designs are also important for portability and availability in a large variety of locations.

Project Plan/Gant Chart

The first semester of this project involved the design phase. The design phase included an initial planning of the entire year of design, manufacturing and construction of the product that would be delivered. The conceptual designs were generated and researched to determine whether the given objectives from the sponsoring company could be met. Preliminary calculations were performed and reviewed with the sponsoring company, as well as advising professors to formulate the actual designs that would be pursued during the second semester of the project. At the end of the semester this decision was made and part searching and purchasing began.

The second semester of the project began with the gathering of materials in order to begin the manufacturing and construction processes. It was essential to have all the parts as soon as possible to finish construction and begin testing to determine whether the theoretical performance would indeed be obtained in the end. Once the initial concepts were constructed, several modifications were made on the original design to ensure proper operation and satisfaction of the objectives. The end of the semester entailed fully optimizing the designs, and the production of two operational prototypes was completed.



	Task Name	Duration	Start	Finish
1	Project Specification	4 days	Mon 10/10/11	Thu 10/13/11
2	Project Plan	4 days	Mon 10/10/11	Thu 10/13/11
3	Concept Generation and Selection	8 days	Tue 10/18/11	Thu 10/27/11
4	⊟ **Design Review**	**28 days**	**Mon 10/31/11**	**Wed 12/7/11**
5	Interim Design Review	15 days	Mon 10/31/11	Fri 11/18/11
6	Final Design Review	13 days	Mon 11/21/11	Wed 12/7/11
7	⊟ **Component Testing**	**26 days**	**Fri 12/9/11**	**Fri 1/13/12**
8	Testing Components	11 days	Fri 12/9/11	Fri 12/23/11
9	Analysis	14 days	Tue 12/27/11	Fri 1/13/12
10	⊟ **Prototype Construction**	**24 days**	**Mon 1/16/12**	**Thu 2/16/12**
11	Build	14 days	Mon 1/16/12	Thu 2/2/12
12	Test/Analysis	10 days	Fri 2/3/12	Thu 2/16/12
13	Team Evaluations #3	3 days	Tue 1/17/12	Thu 1/19/12
14	Progress Report Presentatior	3 days	Tue 1/17/12	Thu 1/19/12
15	Mid-Point Review Presentatio	3 days	Tue 2/14/12	Thu 2/16/12
16	⊟ **Final Build**	**19 days**	**Mon 2/20/12**	**Thu 3/15/12**
17	Final Construction	10 days	Mon 2/20/12	Fri 3/2/12
18	Final Analysis	9 days	Mon 3/5/12	Thu 3/15/12
19	Team Evaluations #4	3 days	Tue 2/28/12	Thu 3/1/12
20	Instructor-Team Visit	3 days	Tue 3/13/12	Thu 3/15/12
21	Final Report	13 days	Mon 3/19/12	Wed 4/4/12
22	Final Presentation Project Review	13 days	Mon 3/19/12	Wed 4/4/12
23	Operations Manual	13 days	Mon 3/19/12	Wed 4/4/12
24	Open House	1 day	Thu 4/12/12	Thu 4/12/12

Figure 3- Gant Chart: October 2011 – December 2011

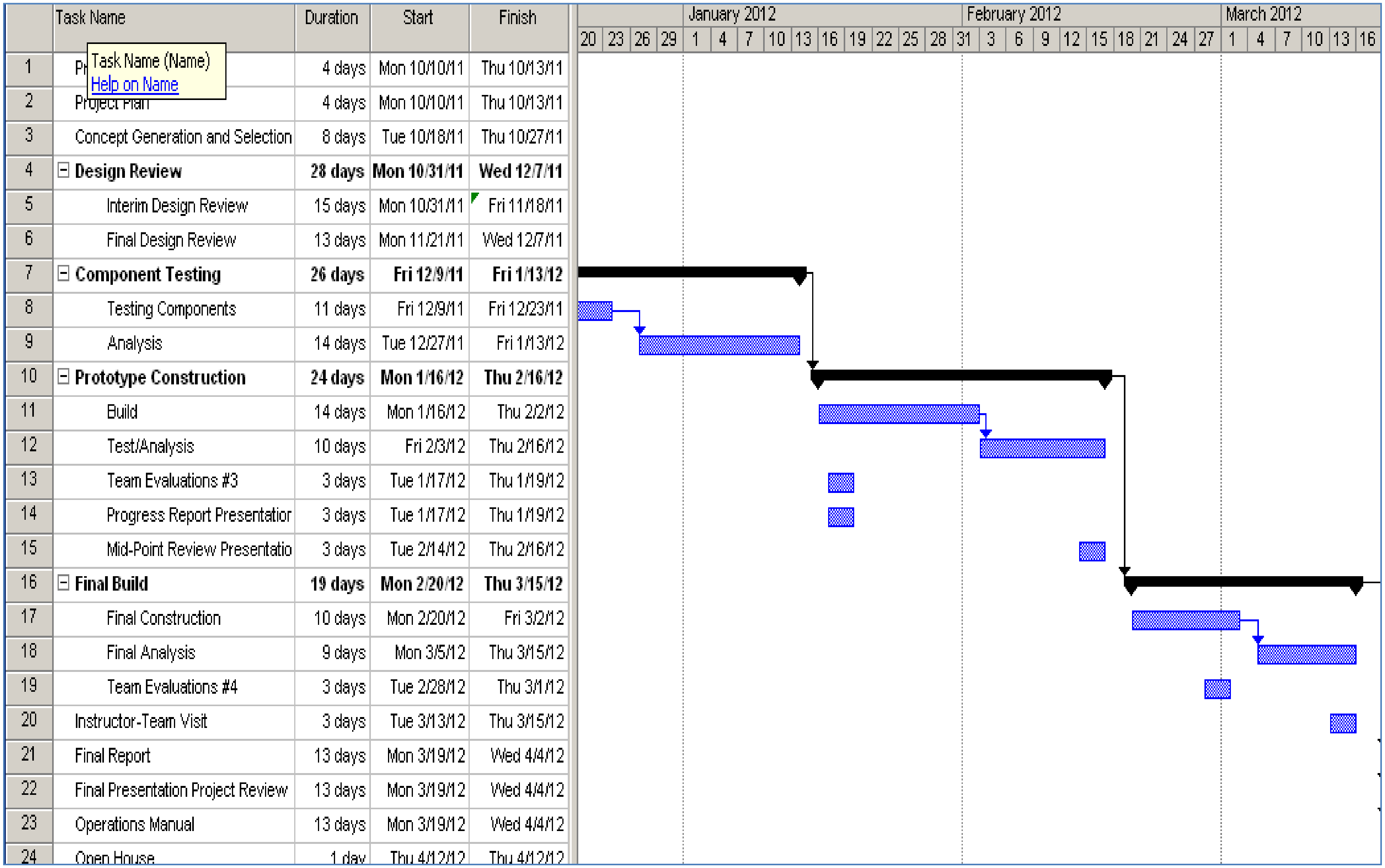


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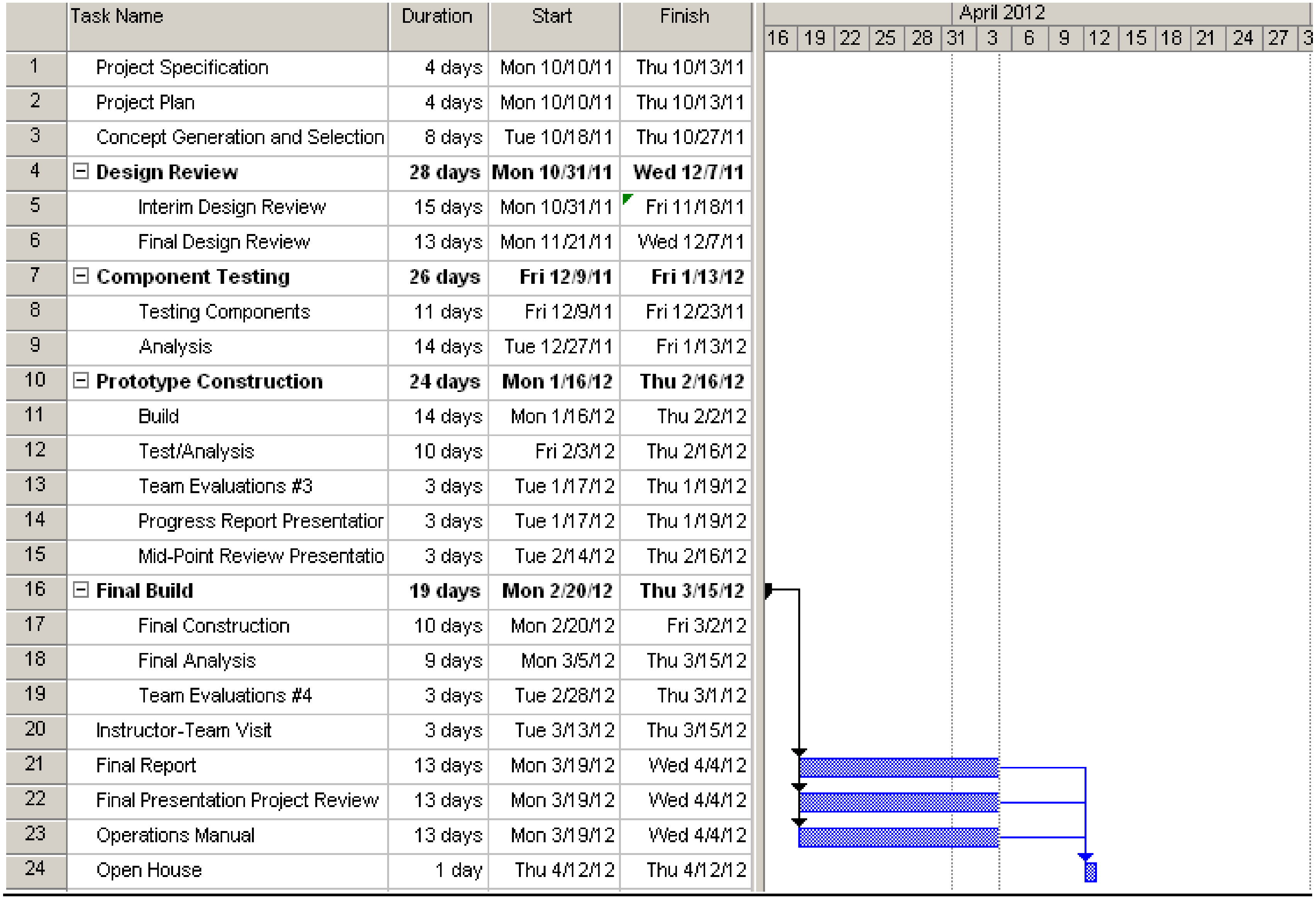
Figure 4 – Gant Chart: December 2011 – March 2012



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24	Open House	1 day	Thu 4/12/12	Thu 4/12/12

Figure 5 – Gant Chart: March 2012 – April 2012

III. Concept Generation

Geographic Location Analysis

The first step into the concept generation phase was to select the geographic locations where the power generation unit would be implemented. In order to select adequate locations, the amount of natural renewable energy available was taken into consideration. The renewable energy sources that were chosen were wind energy, and water energy. Therefore, the analysis of the locations consisted of finding average wind speeds at reasonable altitudes, as well as average flow rates of major rivers in areas far away from a coastline.

Detailed wind speed data in many third world countries is not readily available; however, there is a global map that highlights countries based on their annual average wind speed. An organization called 3Tier is responsible for publishing this information. They can provide highly detailed information, but the data is quite expensive. The three locations that were selected for wind power are: Faya-Largeau, Chad; Santa Cruz, Bolivia; Sen Monorom, Cambodia. Faya-Largeau, Chad has a local airport that provides accurate information on wind velocities at 10 meters in altitude. The average annual wind speed value is 4.6 m/s. The information for Santa Cruz, Bolivia was provided at no cost from the 3Tier organization, and the annual average wind speed at 10 meters is 3.9 m/s. Sen Monorom, Cambodia was demonstrated by 3Tier to have some of the highest wind speeds; and using the local forecast information from the Titi Tudorancea Bulletin, exhibits an average wind speed of 5.1 m/s. The height in Sen Monorom is not published for this information, but the 3Tier organization groups the location in the same range as the other two locations. Figures 6 and 7, show annual trends of wind speeds for Faya-Largeau and Santa Cruz. Figure 8 was developed from the weekly forecast information available from Sen Monorom.

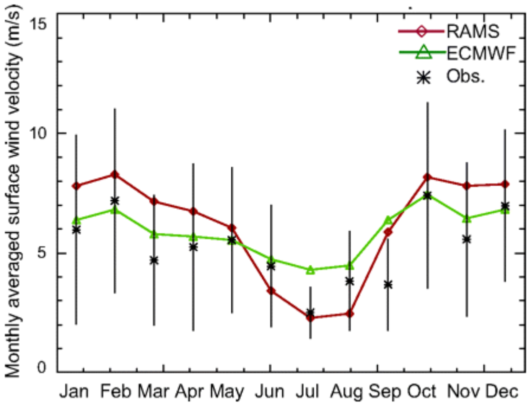

Figure 6 – Faya-Largeau, Chad Annual Average Wind Speed as provided by Proceedings of the National Academy of Sciences of the United States of America organization

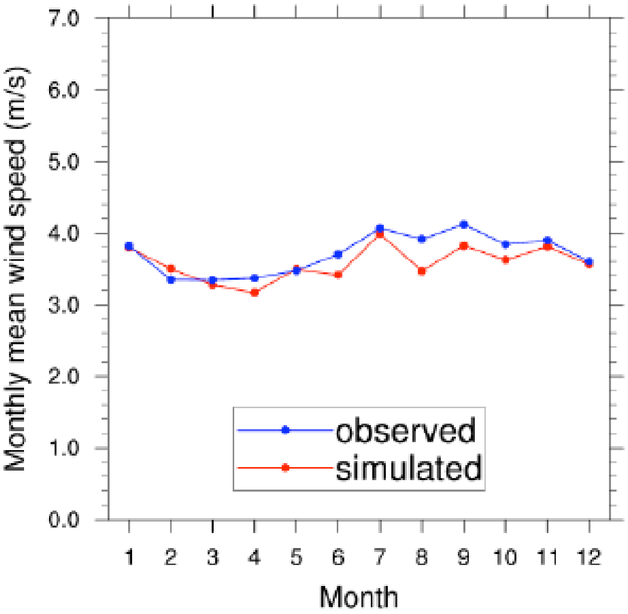

Figure 7 – Santa Cruz, Bolivia Annual Average Wind Speed provided 3Tier Final Report

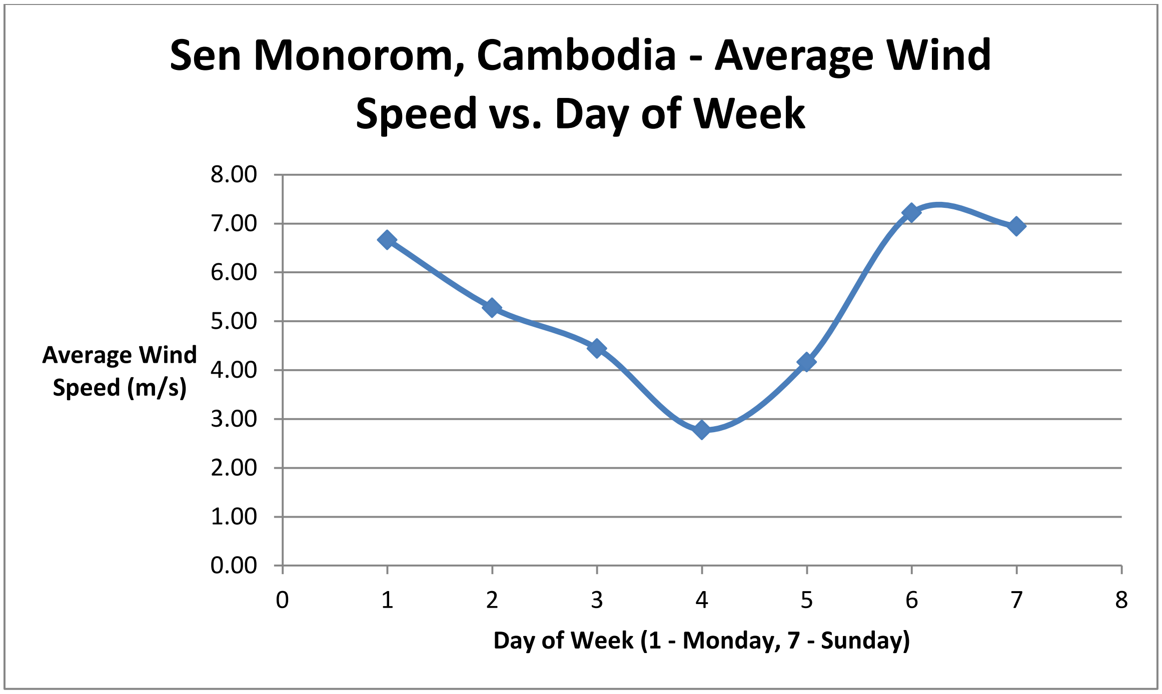

Figure 8 – Sen Monorom, Cambodia – Weekly Average Wind Speed. Data provided by Titi Tudorancea Bulletin Weather Forecast

The water energy locations were chosen based on high volumetric flow rates of rivers. A high flow rate contains a high amount of kinetic energy that can be used directly to spin a turbine, or channeled above a certain height to create a potential head. The three locations chosen were the Atrato River, Colombia; Indus River, Pakistan; Benue River, Cameroon. The average flow in the Atrato River is roughly $2.0 \cdot 10^6$ L/s; the average flow for the Indus River is roughly $6.5 \cdot 10^6$ L/s; the average flow for the Benue River is roughly $1.75 \cdot 10^5$ L/s. These flow rates were taken at locations that were farther than 100 km from the coastlines.

Similarly to the wind speed fluctuations observed in the figures, there are also significant variations in the flow rates of the rivers that will be taken into account for the designs. Ultimately, a velocity threshold will be developed for calculating the total power generated for the three concepts. All six locations are shown in Figure 9 below. The wind locations are circled, and the water locations are marked as "X".

Figure 9 – Global Map – Wind locations are Highlighted in White, Water Locations are "X" in White (3Tier)

Concept Design #1 – Vertical Axis Wind Turbine (VAWT)

A wind turbine uses the mechanical energy of moving wind currents to impart energy onto a turbine, which transfers this energy into rotational kinetic energy. In order to convert this rotational motion into electricity, one must employ an energy conversion device. Once the energy conversion device transforms this mechanical energy into electricity, it is stored in a battery for later use. We will be employing these same basic principles in the design of our systems.

VAWT systems differ from the traditional wind turbines seen in large scale power generation applications. Instead of having a propeller shaped turbine on a horizontal axis, it can have a variety of different turbines mounted on a vertical shaft. This has a huge advantage as it allows the VAWT to be omni-directional whereas the horizontal axis turbine needs to be facing directly into the wind at all times.

There are two basic types of wind turbines: lift and drag based designs. Typically lift designs are used in high wind speed applications as they employ an airfoil design which increases the rotational speed above the speed of the undisturbed wind. This lift technique increases the power production of the system. Since this design will be used in relatively low wind speeds, a drag based design will be ideal.

After extensive research, the Savonius wind turbine design was originally chosen for the VAWT concept because of its simplicity, high performance coefficient, as well as its ability to run at extremely low wind speeds. As seen in Figure 10**,** the Savonius turbine is simply two cylinders placed facing each other with an offset.

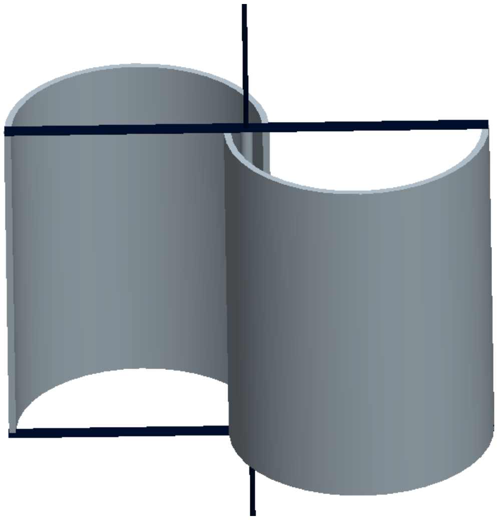

Figure 10 – Savonius VAWT Design Concept #2

The Savonius wind turbine design is known to be a drag based system, although it exhibits flow characteristics because of its design that improves its performance above what a simple drag based turbine can achieve. As seen in Figure 11, the offset of the two turbine blades redirects the flow profile of the wind to travel into the return stroke of the turbine which decreases the net drag experienced by that blade. Also seen in Figure 11, are the units used in the turbine's dimension calculations.

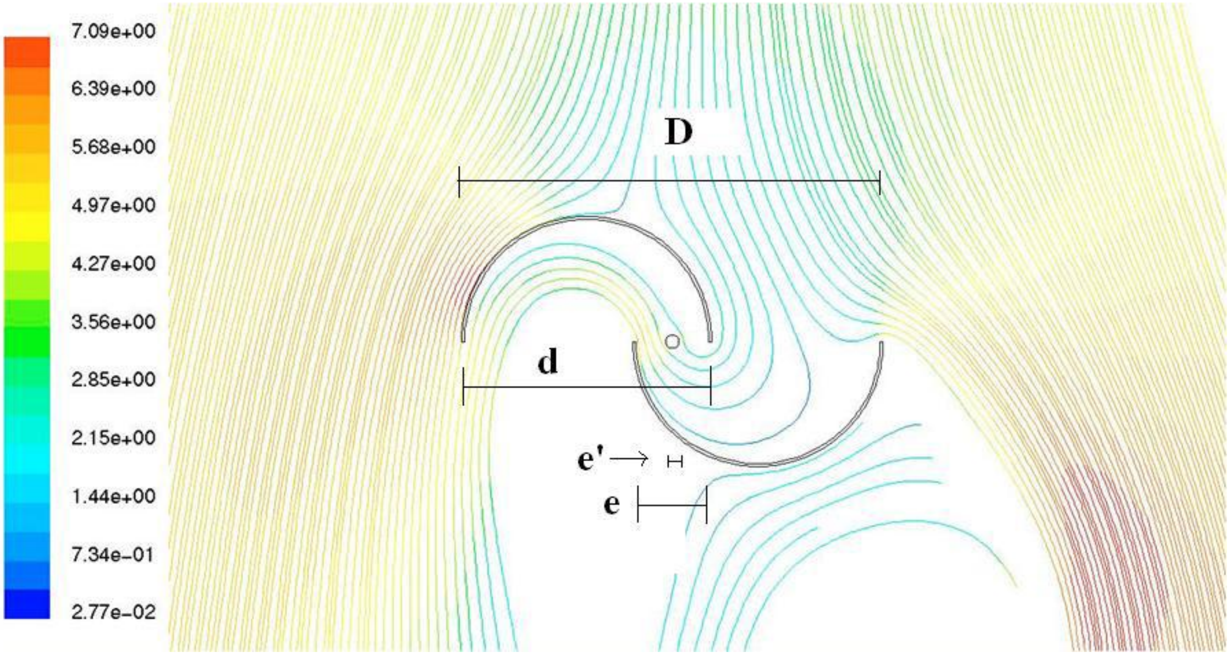

Figure 11 – Static Pressure Flow Field - (Jean-Luc Menet)

In order to create an idealized Savonius turbine, fairly exact specifications must be followed but the design can be scaled to any size. The following equations have been developed for an ideal Savonius turbine:

The aspect ratio which relates the overall height of the system to the diameter seen by the wind is very important as

An idealized Savonius turbine will have a power coefficient of approximately 0.3 which means 30% of the energy imparted on the turbine by the wind will be transferred into rotational mechanical energy.

This is fairly high as the theoretical limit declared by Betz' Coefficient is 0.593. As the design specifications to build an ideal turbine are based only on the dimensions of the cylinder chosen, the offset of the two cylinders, and the diameter of the center rotating shaft; the ideal turbine would be very easy to reproduce. It is also safe to say that a device built out of recycled materials could approach this design; therefore, also approaches the power coefficient of an ideal Savonius turbine. For calculation purposes we will assume that a turbine constructed from recycled materials will only produce 80% of the power compared to an ideal turbine.

To reach a power coefficient of 0.3 from a Savonius turbine, the speed of the far rotating edge must match the speed of the undisturbed wind. This relation is called the tip speed ratio and is denoted with the symbol λ. As seen in Figure 12 this power coefficient is only reached at a tip speed ratio of 1. This is generally impossible to accomplish on a drag-based VAWT system. This is because the drag imparted on the returning turbine blade will not allow the turbine to rotate at exactly the same speed as the undisturbed wind. In order to optimize this design, an external wind vane surrounding the turbine has been devised that will block air flow from hitting the return stroke of the turbine as well as direct more air into the power stroke. As the VAWT is omni-directional, the vane must also be omni-directional. The wind vane will be constructed out of a malleable cylinder that is larger than the rotating components of the wind turbine. The cylinder will have slits cut in the outside wall in between the supporting upper and lower structures, as well as have the created strips of material turned at an angle. See Figure 13 for visualization.

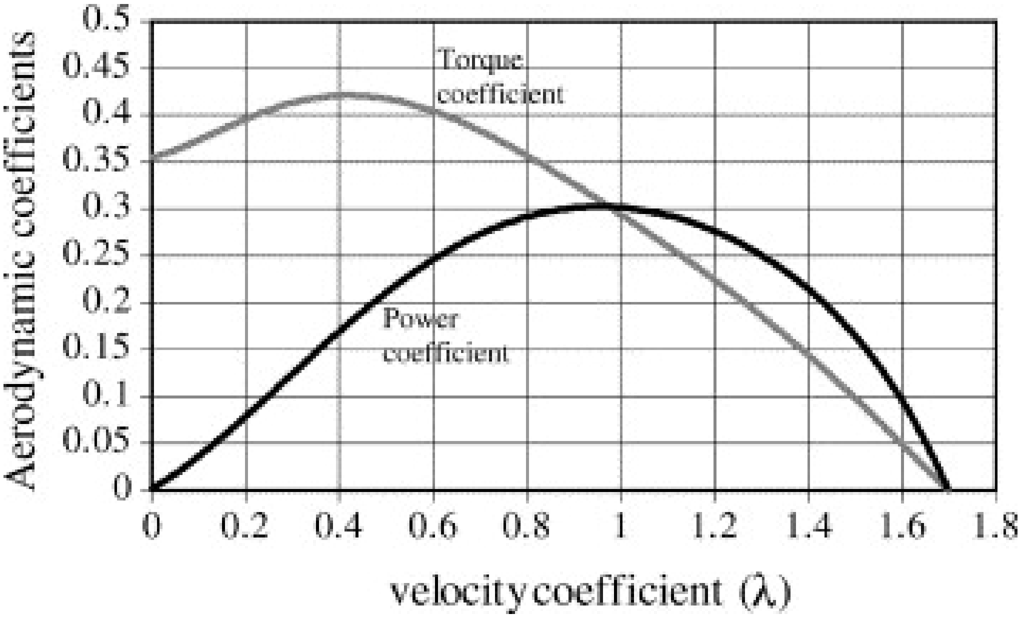

Figure 12 – Savonius Optimization (Jean-Luc Menet)

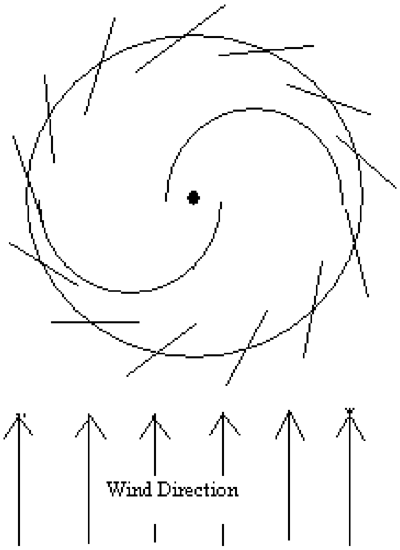

Figure 13 – External Wind Vane Design

An ideal Savonius wind turbine will have at least two steps (turbine stack) stacked on top of one another and attached to the same rotating axis. This provides a few advantages such as allowing the turbine to be self-starting as well as adding the ability to run in even lower wind speed conditions. The two step design will also allow for a greater power output throughout the entire rotation of the turbine, as well as decrease some of the high torque moments seen on the shaft, as seen in Figure 14**.** It has also been proven that endplates on each turbine blade improve performance.

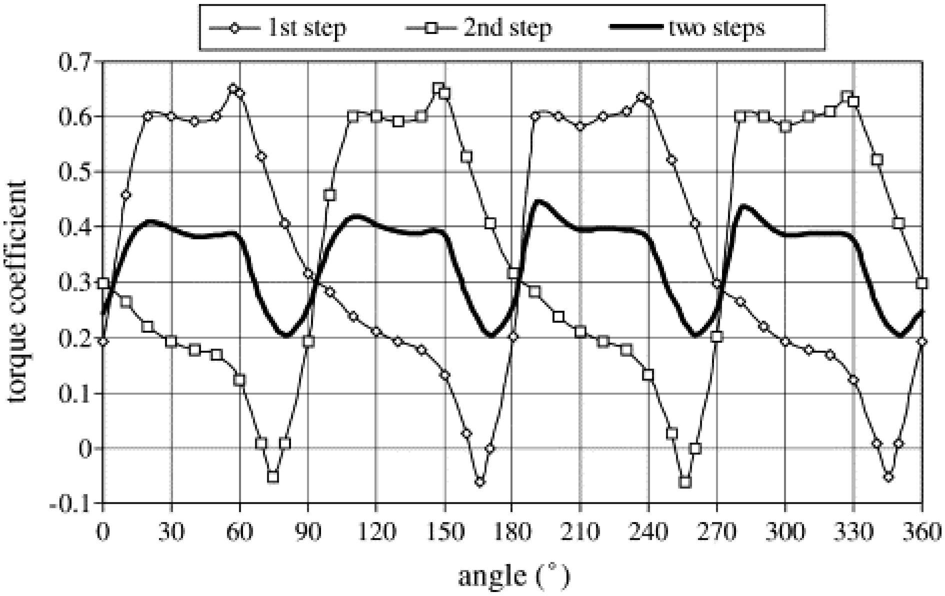

Figure 14 – VAWT Optimization – (Jean-Luc Menet)

As the calculations in Appendix 1 show, the required minimal area to produce 10W is 1.563m^2. 10W was chosen because it will overcompensate for any losses, fouling, or decreased wind speeds that the system may encounter over time. Since materials will come from recycle yards or dumps, this is just a minimum required area and the actual can be anything equal to or larger than this value. All other minimum dimensions are also included in the Appendix. The calculations for possible gearing ratios, if using the bicycle dynamo as the power conversion device, are provided as well. This shows that no other gearing is required as the ratio of diameter of the bicycle wheel to dynamo wheel diameter is 54:1. Appendix 1 is the design drawing of calculated VAWT dimensions.

During the contruction process of the VAWT, it was observed that the most adequate material available at Marpan Recycling for the Savonius blades would be two 55-gallon drums cut in half. This would surpass the required area of the blades as well as provide excellent strength and longevity to the design. In early January, the team easily obtained the first 55-gallon drum to use for the design and it was in excellent condition. Other drums were seen periodically at Marpan Recycling; however, they were damaged and unusable.

An alternative was then established when a series of blower fans were found inside the recycling year. Figure 15 shows the type of blower fans that were found. These blades can be used for a VAWT application by stacking them vertically and connecting them to a central axis. Figure 16 is a design concept of the blower fans in a VAWT application. However, since the fans were designed to intake air from the central area and push it outwards, it was uncertain whether this idea could indeed work towards the established objectives.

Figure 15 – Blower Fan Assemblies.

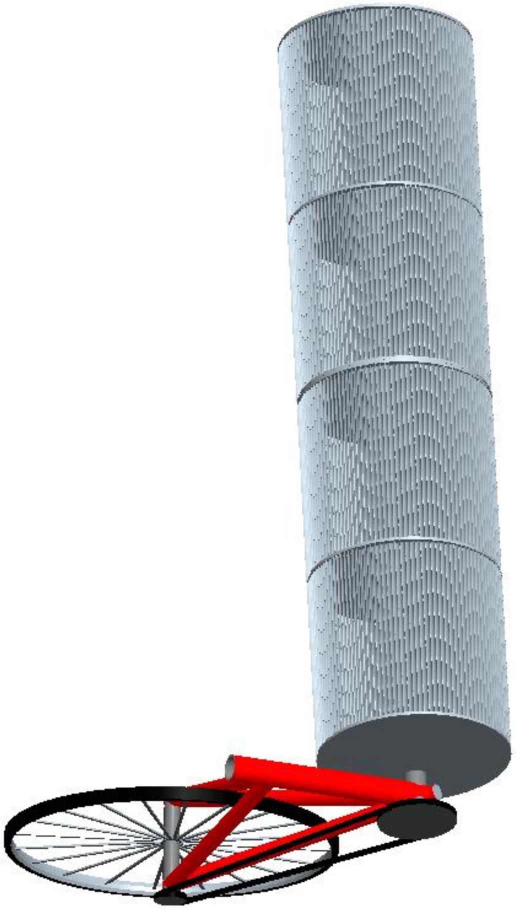

Figure 16 – Sample PVC cuts to approximate airfoil shape.

In mid February, it was decided that the VAWT concept would not be constructed due to impending time constraints. Low availability of materials of the required magnitude was an additional constraint, especially for severe weather applications.

Design Concept #2 – Tesla Turbine

The Tesla Turbine was initially designed by Nikola Tesla and works under similar principles as the previous designs. Figure 16, is a basic Tesla turbine design, with half of the casing hidden in order to see the internal working parts. There are four discs spaced apart and mounted on a central rotating axis, which is the mechanical output of the turbine. Water will enter the turbine at the top rectangular section and will collect in between the discs. This collection of water creates a frictional layer that promotes the rotation of the discs in unison and generating mechanical energy. The water circulates and exits the casing when it approaches the holes located at the center of the discs, upon the slowing down of the turbine. During operation, it is imperative that the flow remain laminar throughout the turbine until the exit point as this will maximize the friction and rotational speed. Compact discs (CDs) have been found appropriate for use as the rotating discs in the system. This is due to the acceptable friction coefficient between water and the plastics that make up the compact discs. However, the material strength of the CDs may be low during operation, and a method of controlling the rotational speed may need to be included.

Tesla turbines have been known to have very high operating speeds. When first invented, the lack of material knowledge at the time hindered production. The original discs were made of steel which warped and destroyed the turbines at high operating speeds.

The disadvantages of the Tesla Turbine far outweigh the advantages. First, the parts required to construct this turbine are not widely available in a junkyard. The only plausible materials are compact discs which are inherently fragile. There would also need to be an additional filtering system in order to keep damaging particulates from entering the turbine. Tesla turbines are fairly efficient especially when ideally designed. Nonetheless the turbine size needed to provide the required power would need to be larger than a simple CD case which would in turn increase the stresses on the materials. This size restriction coupled with the lack of reliability of materials and complicated design has eliminated the design from further research and development.

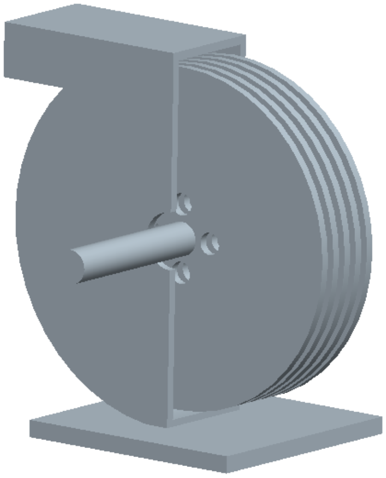

Figure 16 – Tesla Turbine – Internal Working Parts

The Tesla turbine and the VAWT were eliminated from the construction process, and full focus would be placed onto the HAWT and Micro-hydroelectric wheel discussed in the next two sections.

Design Concept #3 – Horizontal Axis Wind Turbine

A horizontal-axis wind turbine system can also be implemented as a lift or drag system. Since the VAWT system defined in design concept #1 uses drag physics, the HAWT will be developed as a lift based system. In order to create the lift effect on the turbine blades, PVC will be cut into an approximate airfoil shape. The process can be performed by cutting the PVC into quarters, and drawing straight lines down the lengths of the tube, as well as diagonal, straight lines to one of the ends of the tube. The PVC pipe will then be cut into quarters once again along the straight horizontal lines drawn along its length. The final cut will be made on each piece to keep the diagonal shape drawn throughout each piece of PVC. Examples of the cuts are shown in Figures 17 and 18.

Figure 17 – Sample PVC cuts to approximate airfoil shape. "YourGreenDream”

Figure 18 – Sample PVC cuts to approximate airfoil shape. "YourGreenDream”

The HAWT system that will be constructed will be composed of three airfoil blades, which has been found to be the best compromise of physical strength and rotational speed. The higher the number of blades, the heavier the system becomes and the greater the effect of gyroscopic forces. However, the efficiency also increases with the increase in the number of blades. When researching two-blade systems currently in use for wind generation, the dynamic calculations governing their behavior are very complex and further strengthened the selection of a three-blade design. The three blade design is shown in Figure 19.

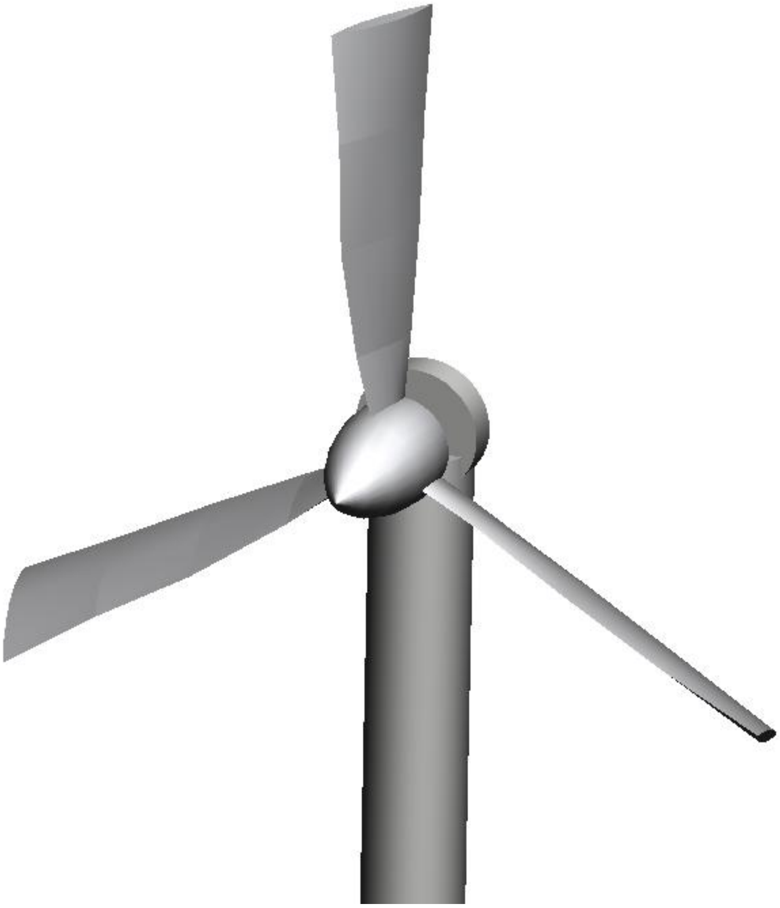

Figure 19 – Design Concept #3 Horizontal Axis Wind Turbine

In order to determine the size of the turbine blades required, data from the National Renewable Energy laboratory was used to estimate the power coefficient of a three-bladed wind turbine design. The ARE442 lift based wind turbine is 7.2 meters in rotor diameter; however, it was the smallest wind turbine with accurate experimental data. A graph comparing the coefficient of power to average wind speed can be observed in Figure 20 for the ARE442.

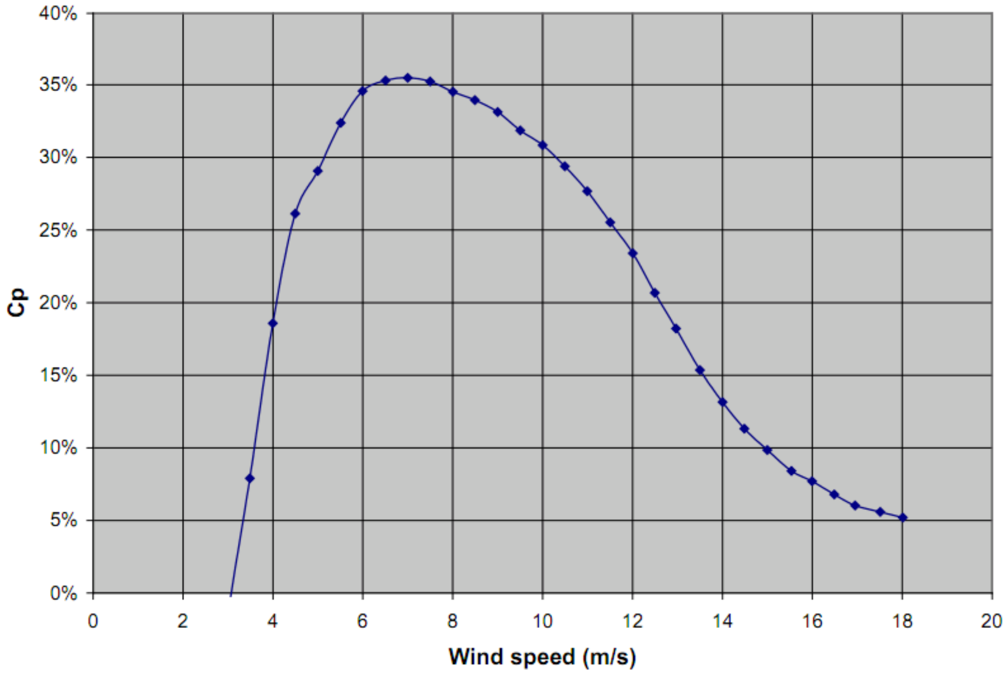

Figure 20 – Coefficient of Performance vs. Wind Speed for ARE442 (NREL) Wind Turbine

Using wind speed data from Faya-Largeau, Chad, an average wind speed of 4 m/s was found at a five meter height. Analyzing this wind velocity, a power coefficient of 19% can be extrapolated from Figure 12. To account for a smaller turbine diameter and an approximate airfoil design, 60% of this 19% was used to carry out the calculations of the design. These imperfections for the wind turbine adjust the power coefficient to a value of 11.4%.

The next consideration that was needed to be examined was the power output requirement of the turbine. In order to achieve the 100 Watts required in one day, and assuming that the 4 m/s is present during a 10-hour period, a minimum power output of 10 W is needed in one hour. Designing for this 10 Watts of power, using Betz Power equation shown below, the area of the turbine was found to be 1.4 m^2. Increasing the margin for error the HAWT turbine blade will have an area of 3.29 m^2. This area accounts for a rotor diameter of roughly 2.05 meters.

–

The ρ shown above represents the density of air at near ground level - 1.225 kg/m^3. The η_{belt} stands for the loss in the belt and pulley system that is required if using an automotive alternator.

The $\eta_{alternator}$ represents the efficiency loss in using an alternator to convert mechanical energy into electrical energy. Since the alternator and belts will be used and refurbished, the efficiencies were set at 80% for the alternator and 85% for belts.

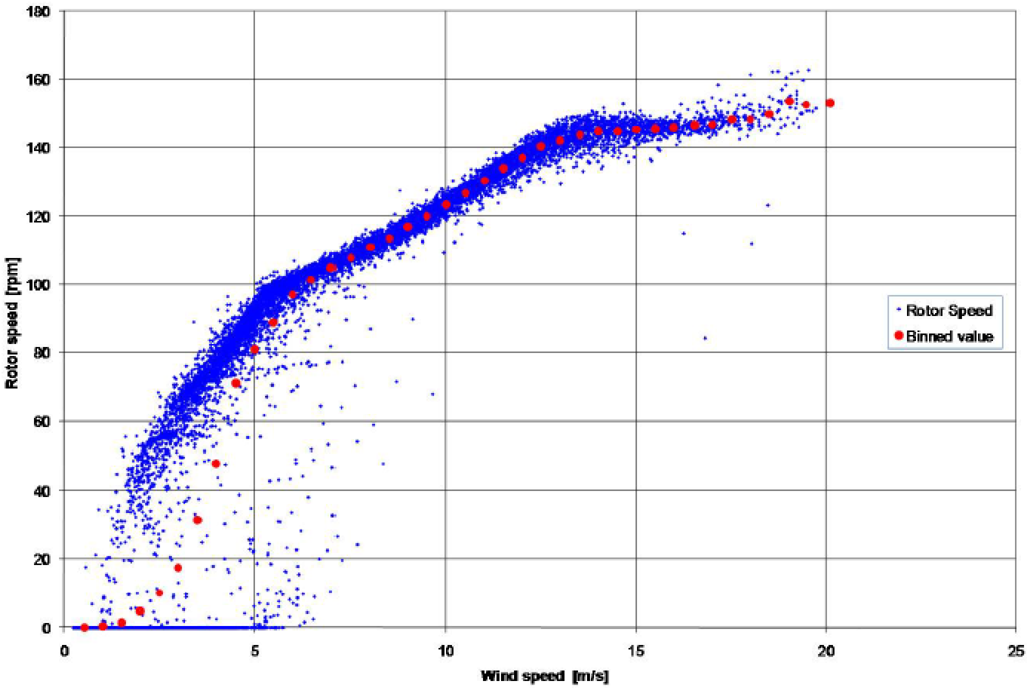

Figure 21 – Rotor Speed vs. Wind Speed for ARE442 (NREL)

Using the belt efficiency, it was necessary to calculate the pulley ratio needed to increase the rotational speed of the wind turbine, to the alternator rotational speed. Using data from the ARE442 turbine shown in Figure 21, an average rotational turbine speed at a 4 m/s wind is 48 rpm. Assuming this same value for design concept 2, the pulley ratio needs to be 15:1.

This was the original design for the HAWT system. However, upon further research, there are a few alternatives to the conversion from mechanical power to electrical power. Permanent magnet DC motors can be used as generators, and some are designed to operate at much lower rpm than alternators, and at the same time maintain a high power generation. A company called Ametek has a variety of permanent magnet DC motors that have proven to be successful in power generation in home-designed wind turbine systems. According to Michael Davis, designer of a home built turbine; an Ametek motor that is rated for 30 Volts at 325 rpm was successful in powering 12 V home appliances. This significantly reduces the amount of pulley ratio that will be required. The new pulley ratio becomes 8:1. This precise motor may be difficult to find due to its grown popularity in home wind turbine designs. However, there are others available that can be successful in power generation, and can be found in trashed components.

Another option that was analyzed was the bicycle dynamo, a type of permanent magnet DC motor. This was the system developed by William Kamkwamba. William incorporates the back end of a bicycle and uses the sprockets and chain to create a gearing system and increase the rotational speed that the dynamo will see to output voltage. This is the method that has been chosen for the design, due to ease in finding a bicycle assembly and having an incorporated gearing system leading to the dynamo. More information on this power conversion route is given in the Energy Conversion section.

The gearing that will take place with the bicycle assembly will be a 67.5:1 ratio and will cause the dynamo to spin at 3025 rpm. Detailed calculations of this can be seen in the Appendix for the HAWT design.

Design Concept #4: Micro-Hydroelectric Generator

The hydroelectric generator will convert the kinetic energy of the flowing water into rotational mechanical energy through the implementation of a paddle wheel. In order to minimize infrastructure that would otherwise be required to direct flow from a source river, the prototype was designed to anchor in the river. In this way the flowing water of the river will spin the paddle wheel. The paddle wheel selected for this design should be made from light weight, and durable bamboo, and be comprised of 6 fins. These fins will be affixed rotor that in turn is coupled to the shaft. This would cut down on the unit price of the product by using a sustainable resource that is present in many third world countries. A bull pulley connected at the opposite end of the rotating shaft will spin the pinion pulley attached to the dynamo, as illustrated in Figure 22. The gear ratio between the belt driven pulleys will depend upon the incoming flow rate of the water, inertia of the system, and resistance from bearings.

Furthermore, the 12 Volt direct current rectified by a germanium diode from the dynamo will be directed into a battery with a minimum capacity of 300 W•h. This battery will be of the automotive variety and stowed inside the pontoon closest to the paddle wheel. These batteries are abundant in most junkyards. While the individual cost of these used batteries is high, a bulk purchase will reduce the cost by 10%. Also, certain measures will need to be taken to prevent water from coming in contact with the charging system. One way to accomplish this would be to use the insert for a car trunk as a type of shroud to protect the electrical components from water splashing back from the paddle wheel.

Since the flow of all rivers varies throughout the year we based our calculations for power generated as a function of the velocity. By setting the surface area of the paddle wheel in contact with the flowing water to be constant we are able to tabulate the potential power produced. Although there is no actual head since the system actually floats on the surface of the water there is still what is called a gross head. The gross head is based upon the oncoming velocity of water, and is proportional to the vertical distance the water would fall to attain said velocity. Table 1 below demonstrates the mechanical power expected our generator to produce at different flow velocities.

Table 1 - Power Output Results – Converts Flowing Kinetic Energy to Head Potential

Power Output (Watts)

Velocity (ft/s)

Gross Head (ft)	3	6	10	15	20
0.139751553	2.993478	5.986957	9.97826087	14.96739	19.95652
0.559006211	11.97391	23.94783	39.91304348	59.86957	79.82609
1.552795031	33.26087	66.52174	110.8695652	166.3043	221.7391
3.49378882	74.83696	149.6739	249.4565217	374.1848	498.913
6.211180124	133.0435	266.087	443.4782609	665.2174	886.9565

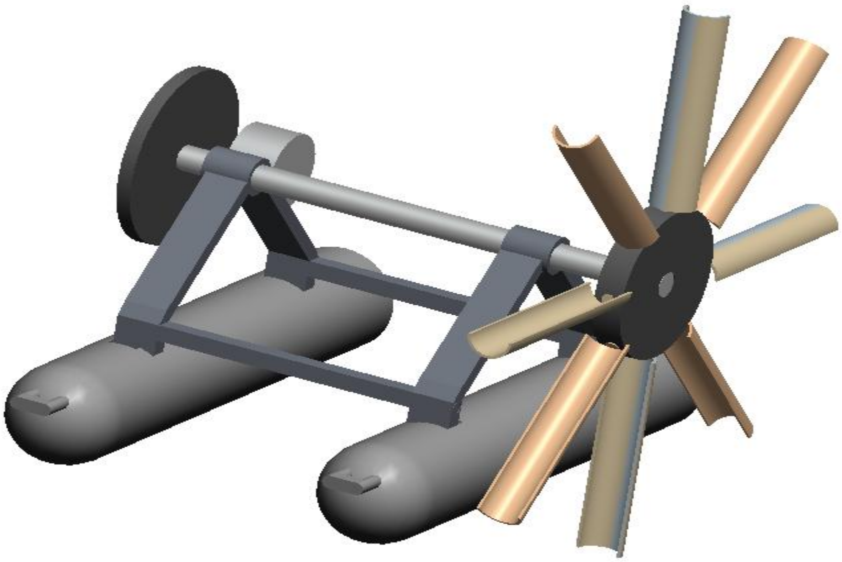

Figure 22 – Micro-Hydroelectric Generator - Potential Prototype

Energy Conversion

The rotational mechanical energy of the turbine will be transformed into useable electricity by a dynamo. A dynamo consists of a spinning rotor with magnetized coils, this spins inside of another set of stationary coils called a stator. As the rotor spins, the two sets of magnetized coils produce an electromotive force, and an alternating current that has a frequency proportional to the rpm of the rotor.

An alternator from a junk car was first considered to perform this function due to the fact that they are equipped with a voltage regulator, and are abundant in most junkyards. The voltage regulator is important in ensuring that the battery is not destroyed by high voltage, or overcharging. It also converts the alternating current seen by the stator coils into direct current, so a battery can be charged. However, through further research, the alternator was found to be cost prohibitive due to the fact that they retail used for about US $20.00. Given that our unit cost must be under US $50.00; this course of action cannot be justified when other cost effective options are available.

One such option is to us a simple, low power electric motor similar to a bicycle-hub dynamo. Since the dynamo is not equipped with a voltage regulator it will produce an alternating current with voltage varying depending upon how fast the dynamo is being spun. The alternating current being produced by the dynamo can be converted to direct current (required for charging a battery) through the implementation of a Silicon or Germanium Diode. A diode allows current to flow in one direction only by means of a P-N junction. This rectification from the silicon or germanium diode comes with a cost though; typically you can expect a voltage drop of 0.65V or 0.1V respectively. Therefore, a germanium diode should be used in order to reduce losses thereby increasing the systems efficiency. The diode connected to the positive leg of the dynamo will convert A/C to D/C while simultaneously keeping current from the battery from spinning the dynamo. This circuit can be seen below in Figure 23.

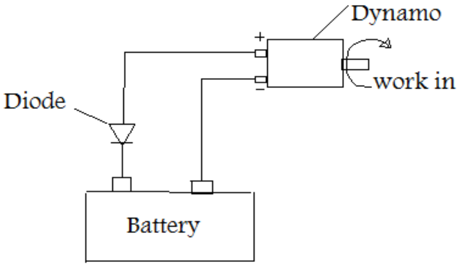

Figure 23 – Energy Conversion Component

Final designs of the electric conversion systems used can be found in the Final Concept section under each system.

Energy Storage

One of the primary objectives of this project is that our system be capable of storing at least 300 W*hrs. Through research into different types of energy storage, the best way to accomplish this task is by using a standard car battery. Car batteries are typically of the lead acid variety and store electricity chemically. A 12 V, lead-acid battery consists of six cells linked in series, and when fully charged produce 2.1-2.45 V. These batteries typically range between 200-300 A•h. Therefore, a new battery has a potential power storage capacity of 3600 W•h. Since the battery used will not be new but refurbished, it can be assumed that it may only be capable of 70 percent of its original capacity, or 2500 W•h.

A dead battery can be fully charged again in as little as 10 hours if a high charge voltage and current are provided. Ideally, the voltage across a charging battery should be maintained constant at around 13 V. However, for our purposes the voltage to the battery may not be constant, as the incoming wind or water flow may be erratic. Although the battery may cycle between periods of charge and discharge while under use it should not dramatically shorten the life of the battery as long as care is taken to prevent the battery from becoming overcharged. This situation can be prevented by the user simply disconnecting the battery from the charging system during periods of nonuse.

In order to keep power from leaking back out of the battery and actually spinning our dynamo we will need to employ the use of a diode. As discussed in the previous section on energy capture the diode will be connected inline on the positive side of the battery. The diode will serve two purposes; convert the alternating to direct current, and prevent electricity from flowing back out of the battery and into the charging unit.

Final designs of the energy storage systems used can be found in the Final Concept section under each system.

Cost

There are two places in Tallahassee that have an ample supply of recycled materials needed for the construction of the three concept designs. Prices in Table 2 (below), will be based off the cost of the parts at these establishments.

The first is Pick-n-Pull – Tallahassee, which is a self-service auto parts store. Since the parts are retrieved by the customer, prices are very competitive with the recycled parts market. After consulting with management, large-scale purchases (over $1000) will receive a 10% discount off of advertised rates. Since the prototype will not reach this amount, the parts will cost this project the full amount. However, if the designs were mass-produced, the 10% discount could be implemented into the cost analysis. Assuming that the design will undergo mass production, the discount has been included onto Table 2.

Marpan Recycling is the second business that recycled parts will be procured from. Marpan specializes in handling Class III (construction and demolition) as well as yard waste. Because of the materials that this plant processes, there are many appliances as well as construction materials (pipes, ducts, motors etc…). This makes it an excellent source for many of the required materials for this project. Marpan Recycling deals with bulk materials and all prices are based on weight. The price of metals, (price of metallic appliances) is $300/ton or $0.15/lb. The price of plastics is $0.02/lb. These low prices render the power conversion device (alternator/dynamo) as well as the battery the highest cost components. Table 2, approximates the cost of the designs relative to the total weight. It is what was calculated for the Fall Semester Final Design. The exact weights were not known; therefore, the values were over-priced to account for a worst-case scenario in cost. Final cost analysis of finished concept designs can be found in the Engineering Economics section.

Table 2 – Cost Analysis for Design Concepts #2-3; December 2011

Cost Analysis	**Concept Design #2: HAWT**	**Concept Design #3: MHET**
Rotational Component	$3.00	$2.00
Supporting Structure	$2.00	$10.20
Energy Converter	$10.00	$10.00
Gearing Assembly	$2.00	$2.00
Bearings	$1.00	$1.00
Energy Storage	$19.79	$19.79
Battery Cables	$3.59	$3.59
Total	$41.38	$48.58

Decision Matrix

The decision matrix for this project (Table 3) analyzes each design against a determined set of requirements. Each design is given a score from one to five based on how well it meets the specification in question. This score is then multiplied to the importance weight of the specification. All scores are then totaled and compared against each other to accurately determine which design best meets the set criteria.

Durability:

The VAWT design received a rating of 5 because of its simplicity and solid construction materials. The turbine blades are the most likely to break and in the VAWT design they are securely fastened and supported. The HAWT design received a rating of 3, because of its PVC turbine blades. They are sturdy but undergo larger gyroscopic forces in higher speeds than the VAWT design. The MHET received a rating of 3 because of its working fluid, as water tends to wear on materials much faster than wind, especially because its turbines are constructed of bamboo. The Tesla turbine received a rating of 1 because its construction materials (CD’s) are very brittle and prone to wear.

Ease of Assembly:

The VAWT design received a rating of 3 for ease of assembly as the exact dimensions are difficult to replicate without full access to tools. It is also a very large and bulky system with multiple components. The HAWT design received a rating of 5 because assembly is as simple as constructing the supporting structure and bolting the blades to the assembly and attaching them. The MHET received a rating of 3 because of its need to be water-resistant and well anchored. The Tesla turbine received a rating of 1 because of its complicated design and exact construction specifications in order for it to operate at all.

Cost:

The cost specification is directly related to the cost analysis of each design, which was explained above.

Maintenance:

The VAWT, HAWT, and MHET designs each received a rating of 3 because of the durability of construction materials. If maintenance is needed on any of these designs it would be very easy to perform. The Tesla turbine received a rating of 1 because it would require constant maintenance and would have to be completely disassembled for any work to be completed on it.

Innovation:

The VAWT, HAWT, and MHET designs each received a rating of 3 because each system has been used in practice before, but the technology still maintain a level of innovation. The Tesla turbine received a rating of 5 because of its ingenious design as well as complexity.

Table 3 – Decision Matrix for the Project

		Concepts							
		VAWT		**HAWT**		**Hydro-electric**		**Tesla**	
Specifications	Importance Weight	Rating	Weighted Scores	Rating	Weighted Scores	Rating	Weighted Scores	Rating	Weighted Scores
Durability	15%	5	0.75	3	0.45	3	0.45	1	0.15
Ease of Assembly	20%	3	0.60	5	1.00	3	0.60	1	0.20
Cost	40%	5	2.00	5	2.00	1	0.40	3	1.20
Maintenance	20%	3	0.60	3	0.60	3	0.60	1	0.20
Innovation	5%	3	0.15	3	0.15	3	0.15	5	0.25
	Score	**19**	**4.10**	**19**	**4.20**	**13**	**2.20**	**11**	**2.0**

Second Decision Matrix

The second decision matrix (Table 4) re-analyzes each of the designs with an added specification of efficiency. This is to show that if the designs were based on efficiency the MHET would win because of its working fluid. Water has much more energy when flowing because it is an incompressible fluid and has a significantly higher density. If the project were to be scaled for a larger power requirement for a low cost, the water wheel would be the most adequate design to choose and implement.

Table 4 – Second Decision Matrix including Efficiency

Durability	10%	5	0.50	3	0.30	3	0.30	1	0.10
Ease of Assembly	15%	3	0.45	5	0.45	3	0.45	1	0.15
Cost	30%	3	0.90	3	0.90	5	1.50	3	0.90
Maintenance	15%	3	0.45	3	0.45	3	0.45	1	0.15
Efficiency	30%	1	0.30	1	0.30	5	1.50	1	0.30
	Score	**15**	**2.6**	**15**	**2.4**	**19**	**4.20**	**7**	**1.60**

IV. Final Concept

Horizontal Axis Wind Turbine (HAWT)

The final concept for the HAWT design includes the four main components described in the functional diagram section. The initial construction of the HAWT followed the design outlined in the concept generation section.

Original Manufacturing and Assembly

The frame of the HAWT was developed using a bicycle assembly. The bicycle assembly was chosen due to the convenience of the sprocket and chain system, multiple axis, rotating mounts and bearings that were already incorporated. The turbine portion was connected via a machined steel rod to the pedaling axis of the bicycle and can be seen on the left side of Figure 24. The engineering drawing for the machined rod connecting the turbine and the bicycle frame can be found in Drawing 04 in the Spring 2012 Drawings section. The HAWT system was supported via the seat mount on the frame. The seat frame provided a socket joint for a 1-in. diameter rod. The spacing between the rod and the socket created a freely rotating axis allowing the turbine to adjust its orientation based on the wind direction, see Figure 24). The originally design involved two gear sets: one from the center sprocket (where the wind turbine is located) to the rear sprocket of the bicycle (Figure 25); the second would come from the rear sprocket turning the rear wheel of the bicycle and turning the dynamo, which would attach at the outside of the tire. The bicycle was found at Marpan Recycling and was in rough shape so a refurbishment was performed to bring it back into decent working order. The bearings on the bicycle center sprocket and wheels were taken apart and cleaned and cleared of debris. They were then well greased and repackaged into the bicycle assembly.

Figure 24 – Energy transfer axis on HAWT

Figure 25 – HAWT rotating support axis

The turbine (rotational component) was constructed out of an 8-in. diameter PVC pipe to replicate an airfoil design. To make the PVC blades, we first quartered the PVC along the long side. Then leaving a 1.5 in length on the tip of the blades, a string and marker were used to map the angled cut that would give the PVC an approximated airfoil shape (See Figure 26). Once the

PVC had been cut, the leading and trailing edges of the airfoil were grinded down to an edge to reduce drag. Holes were drilled to match the central hub, which was found on a used industrial fan at Marpan Recycling. The system was then mounted and the original turbine design was completed.

Figure 26 – Example of both 8-in (gray) and 6-in (white) diameter HAWT blades.

Once the original rotating component was completed, construction of a second set of blades was also performed in an effort to reduce the weight of the rotational component. A piece of 6-in PVC was used in the same manner as the 8 in original design. The two different sets can be observed in Figure 26.

The chain and sprocket set which was originally employed in the system had approximately a 3:1 gearing ratio from the input shaft to the rear wheel. The other speed change which is much more prominent is the difference between the diameter of the rear tire on the bicycle and the diameter of the rotating component on the dynamo. It was approximated to be a 67.5:1 gear ratio, based on a 27 in diameter rear wheel. The dynamo was originally attached to the frame surrounding the rear wheel as used in general practice. It allowed the dynamo to run on the wall of the tire and convert mechanical energy into electricity.

In order to keep the HAWT system oriented into the wind, a rear wind vane was developed. It was constructed out of a piece of steel and cut to a trapezoidal shape; approximating the standard wind vanes located at the rear of traditional wind turbines. Connection to the bike entailed attaching it to a piece of steel conduit. The steel conduit was then connected to the bicycle frame, near the bottom and away from the turbine wake as much as possible. A break-away mechanism was implemented into the conduit, to account for a disengaging mechanism during severe winds.

The break-away mechanism was composed of a hinge, gate locking mechanism, and a large spring. The purpose of the system is to allow the owner to pull a rope that would trigger the spring, and rotate the wind vane to 90° from its normal position. As a result, it would turn the HAWT so that the high winds would not damage the blades, and endanger people. The break-away mechanism can be seen in its cocked position in Figure 27, and in the triggered position in Figure 28.

Figure 27 – Break-away mechanism in cocked position

Figure 28 – Break-away mechanism in triggered position

Design Modifications

Once the HAWT was assembled, it was found that the starting torque on the system was too great for the blades to overcome. The first course of action to reduce the starting torque was to remove the chain tensioner from the chain and sprocket assembly. In order to do this the chain was adjusted and resized to match the correct gearing. The chain was stretched with a series of clamps, and held for several days to allow for the loosening of the system. This reduced the resistance for start-up very slightly, and required further improvement. A drag based turbine with a much larger surface area was the next step. Three blades were constructed out of a 55-gallon drum and attached to the HAWT system. The start-up torque problem was still present and now more difficult due to the heavy steel blades. The blade and hub assembly with the 55-gallon drum can be seen in Figure 29.

Figure 29 – 55 Gallon Drum and Hub Assembly

The next consideration was to remove the chain and sprocket assembly altogether. Using the gearing from the outside of the bicycle wheel to the shaft of the dynamo, it was determined that enough rotational speed would be seen by the dynamo and could properly generate power. The wheel and tire were attached to the same axis as the turbine blade assembly. Another steel rod was machined in order to accomplish this and the engineering drawing can be found on Drawing 05 in the Spring 2012 Drawings section. This completely eliminated the chain and sprocket assembly and vastly reduced the start-up torque. The original 8-in. diameter PVC blades were then reconnected to the HAWT and easily overcame the starting torque with a very slight wind.

Since the rear wheel had been removed from the system, attaching the dynamo correctly required further design. It was necessary to establish contact between the tire and the dynamo's shaft. It was decided that the dynamo could be kept pressed against the side wall of the tire with the spring within the tensioner. The tensioner was successful in producing good contact between the tire and the dynamo, and can be shown in Figure 30.

Figure 30 – Dynamo and Tensioner

The construction of the steel rods that support both the turbine assembly and the wheel were constructed from the nuts that lead into the axis of the pedals. These nuts were welded onto the flat end surface of the rods. Instead of buying a specialty tap to thread the rod, a more economical approach was taken by welding the existing nuts onto the rods. This is an adequate fix as the welds are strong enough to support the weight of the turbine and wheel.

During the testing phase it was found that a voltage multiplier circuit, specifically a voltage doubler was required to properly charge the 12 V automotive battery. The voltage doubler circuit was wired for full wave rectification for the signal and at the same time was capable of the doubling the AC peak voltage into a DC output voltage. It was necessary to ensure that the voltage in the dynamo exceeded 12 V under regular operating revolutions per unit time to allow for charging of the battery. The circuit can be seen below in Figure 31. It was developed from two rectifying diodes rated for 6 A, and two capacitors rated at 0.01 µF. The wiring that was performed can again be seen in the figure below.

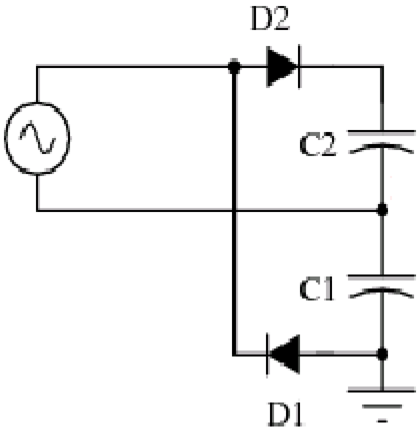

Figure 31 – Voltage Doubler Circuit

Figure 32 below, shows the physical voltage multiplier circuit that was constructed.

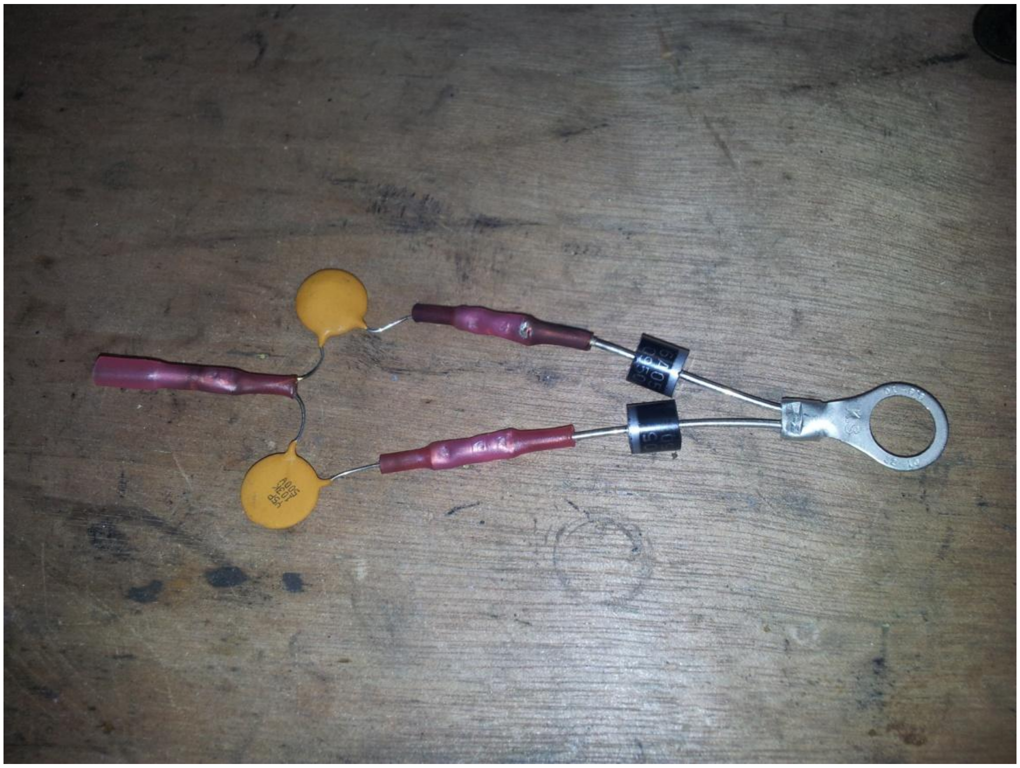

Figure 32 – Voltage Doubler Circuit

It was also necessary to connect an additional diode after the voltage doubler on the positive wire to direct the current to the battery. This would in turn prevent any charge to go from the battery, back towards the dynamo at any time.

If future replicas of the HAWT are being constructed, the following guide will help the producer with design and construction.

Construction Guide

- Builder must have decent mechanical intuition to properly configure provided parts for use.
- Most brands of bicycle frames can be used, though a check of important components must be made.
    - Bicycle must have a working pedal axis after refurbishment
    - Bicycle must have an area to mount wind vane apparatus, preferably away from central rotating axis
- PVC design
    - Drag blade PVC design can be made with any diameter PVC over 6-in diameter
    - PVC blades must have a blade length to PVC diameter ratio of 5:1
    - The smaller gauge of PVC, the better
- A strong hinge must be used for holding the wind vane apparatus as it must support
- The wind vane may be constructed from any available thin sheet metal
- Steel rods
    - Must provide clearance for both the turbine blades to flex 10° as well as the wheel
    - Must keep steel rod at greatest thickness possible at all times for strength
        - Maximum of 1-in. as any greater is unnecessary weight
    - Must connect rod to existing axis on bicycle
        - Threading on existing axis may be unknown. If so, weld existing nuts to steel rod

Micro-Hydro Electric Turbine (MHET)

The final design of the MHET contains all four of the components described in the functional diagram section.

The basic frame of the MHET is composed of two bicycles. This frame was again chosen because of the excellent strength, weight, and built in axes. The first bike is used to support the paddle wheel, while the second supports the transfer of rotational energy to the bicycle dynamo.

The paddle wheel was constructed based on an easy to assemble and easy to repair design. It begins with eight pieces of 4-in PVC. Each piece is cut with a jigsaw to provide a half cylinder shape starting just outside of the paddle wheel. There are two circles cut from particle board and sprayed with a rubber sealant to give waterproofing surface. Nine holes were drilled in the particle board, one for the central rotating axis, and eight for the all-thread to attach the paddles. In the center of the two boards a large washer was made in order to keep the boards completely centered on the axis and eliminate any wobble. An inside look of the paddle wheel can be seen in Figure 33. This washer was made from a 6-in diameter piece of PVC cut at a length of 4.5-in. Inside the washer, there is a piece of 1-in steel tubing cut to a length of 4.5-in. to keep the PVC washer centered. Expanding foam was inserted into the gap and allowed to set, in order to keep both the PVC and steel tubing together and adequately spaced. The foam was then cut to allow a flush fit. The washer can be seen in Figure 34.

Figure 33 – Paddle wheel

Figure 34 – Paddle Wheel Washer

Figure 35 – Paddle wheel

In order to connect the paddle wheel to the supporting bicycle, a specific steel rod was machined. An engineering design drawing of this support rod can be found in Drawing 02 in the Spring 2012 Drawings section, and in Figure 36. In order to keep the paddle wheel from slipping on the axis, a piece of steel plate was welded to the steel support rod. This plate allowed a nut to tighten the paddle wheel against the surface of the wheel. In between the two bicycles another steel rod was machined to allow a transfer of mechanical energy from one bicycle axis to the other. An engineering design drawing of this transfer rod can be found in Drawing 01 in the Spring 2012 Drawings section.

Figure 36 – Machined Steel Rod and Plate Supporting Paddle Wheel

The second bicycle transfers the rotational mechanical energy from the connecting steel rod to the attached chain and sprocket system in order to rotate the rear wheel. It is the original gearing system provided from the original bike. The gearing was set to give the most rotational speed at the wheel and provides approximately a 3:1 speed change. The tensioner was left on the chain as overcoming the static friction of the system is not as crucial with a hydro powered system.

The original design of the paddle wheel involved the use of an alternator to convert mechanical energy to electrical energy. This alternator was taken from an electric exercise bicycle, which was refurbished at Jerry's Automotive. It was attached to the second bicycle near the rotating back wheel via a bracket support system. This was accomplished with two pieces of steel plating, which were cut with by water jet. In order to transfer the rotational mechanical energy from the rotating wheel to the alternator, a belt was created from the inner tube of the bike tire as it stretches very easily and created the required friction to spin both the alternator shaft and the bicycle wheel. One of the two steel pieces was designed with a long groove cut long ways. This cut allowed adjustment of the alternator’s position and could accommodate for the length of the belt.

The flotation of the system is provided by two 8-in. diameter PVC pipes cut to a length of 64 in. These pipes provide the outer shell of the flotation device. They require the ends to be water-tight in order to provide the buoyancy. In order to cap the ends two pieces of plywood were cut for each end. One is cut to just under an 8-in. diameter in order to fit inside the PVC, while the other is cut to the outside diameter of the PVC. A piece of all thread is inserted into the smaller diameter piece of wood. A washer and nut are tightened on either side of the wood to grip it tightly. Next the wood and all thread are inserted into the PVC so that 1 in of all thread is visible outside the exit plane of the PVC. Next expanding foam is inserted around the edge of the wood as well as filling the gap between the wood and exit plane. The foam was left to dry for several minutes, and at the same time, the other piece of wood is secured on the all thread with another washer and nut. They were then tightened to create a waterproof seal with the foam expanding inside. In order to get the foam to adhere to the PVC, it was vital for the PVC to be sanded so that the surface became very coarse. It is important that particle board is not used for the end caps as it is not waterproof.

To help give support to the system while in the water, 6 pieces of steel conduit were attached across the two PVC tubes and attached with two-hole ½-in conduit straps. This required drilling self-tapping screws into the PVC. In order to seal these holes against water leakage, Gorilla glue was inserted into the holes before the screws as well as after around the edge of the screws as seen in Figure 37. To attach the bicycles to the PVC, bolts and nuts were used to hold the bicycle seats in place very tightly. They were also reinforced with Gorilla glue as seen in Figure 38. Other contact points for the bicycles are the handlebars, which were strapped down using the contour of the PVC as seen in Figure 39.

Figure 37– Conduit Held to Floating PVC

Figure 38 – Bicycle Seat Held to Floating PVC

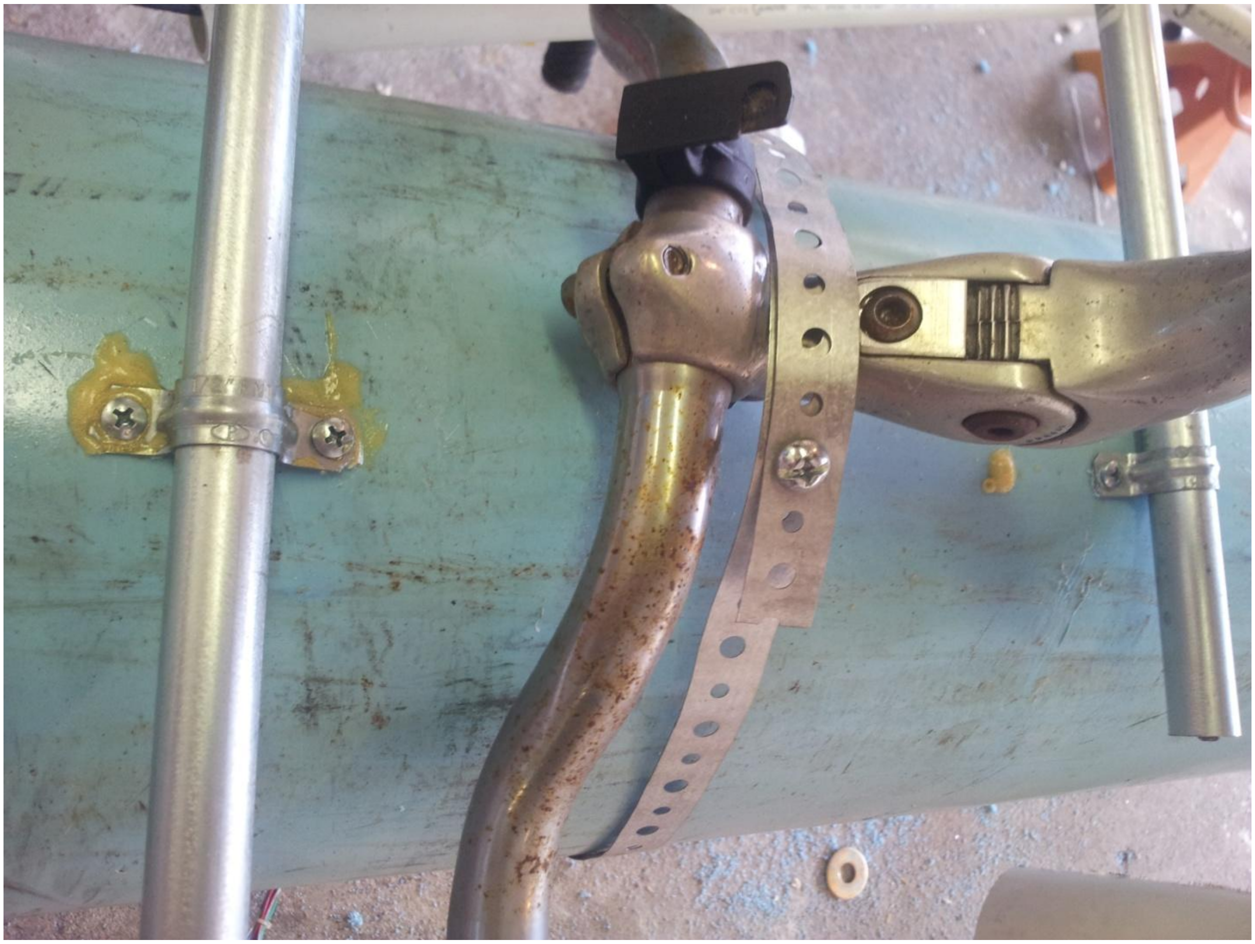

Figure 39– Straps Holding Handlebars of MHET against Floating PVC

The final design of the paddle wheel required a change in the converter from mechanical to electrical energy. It was realized during testing that the alternator obtained from the exercise bicycle, required a very significant amount of revolutions per unit time to provide adequate excitation to the coils. The excitation was required to produce reasonable electric power, and could not be reached with the paddle wheel specifications. Therefore, it was necessary to turn torwards the power generating device that was used for the wind application. Since the bicycle wheel and frame were present in this design as well, it was very easy to attach the bicycle dynamo to the frame to run against the tire. The dynamo used was also rated for 12 V and 6 W, like the one used in the HAWT. Even though the paddle wheel would rotate at lower revolutions per unit time, the sprocket and chain system were still in place and combined with the dynamo shaft making contact with the outside of the tire. This provided adequate mechanical power production, to rotate the dynamo. The dynamo was also wired using a voltage multiplier circuit, which would provide full wave rectification for the signal, and at the same time multiply the peak AC voltage, by a magnitude of two as DC voltage.

V. Engineering Economics

The budget given by the sponsoring company Cummins was a total of US $2000.00. However, the total kit that was to be delivered would need to cost under US $50.00. This placed high limitations on the materials that could be used, as well as the electrical generating and storing components.

Marpan Recycling provided the majority of the materials used in the construction of the horizontal-axis wind turbine, the micro-hydroelectric wheel and the attempts initially made on the vertical-axis wind turbine. Marpan provided prices based on weight and material. Metals were priced at US $300.00 a ton or US $ 0.15 a pound, and plastics (including PVC) were priced at US $ 0.02 a pound. All of the raw materials were purchased at this site, as well as the alternator used in the micro-hydroelectric turbine. The alternator did require refurbishment, which was performed at Jerry's Automotive. The first bicycle dynamo was obtained from Bicycle House, a bicycle store that contained several used bicycles that were being repaired, and therefore used dynamos. An additional two dynamos were purchased, because the first one that was obtained was only rated at 6 V and 3 W. The two new ones were rated for 12 V and 6 W, and even though the new price was higher than what used ones can be found for, proper operation was preferred for accurate demonstration. Dynamos can be found in some old radios as well as flashlights and lanterns and can increase the generating voltage using a voltage multiplier circuit, as explained above. The alternator refurbishment was US $ 92.00, and the two new dynamos came in a kit which included lights, supports, and a cell-phone USB adapter and holders had a total cost of US $ 100.00. The automotive battery was obtained from pick-n-pull for a total of US $ 19.79. The packing foam that was used to fill the pontoons was priced at US $4.00, and one can was enough to fill both pontoons. Bolts, nuts, screws, and washers were purchased separately from Home Depot, as well as Tractor Supply, by weight and combined to a total of US $ 9.50.

Considering mass production of these designs, the cost of the majority of these items can be reduced significantly due to high volume purchasing. Table 5 shown below, gives the overall breakdown of the budget for both designs. It can be seen that the horizontal axis wind turbine met the cost objective given by Cummins. However, the micro-hydroelectric turbine went over budget by a total of US $ 17.72. The majority of the cost comes from the dynamos and batteries, and it is based on values of used and/or refurbished components in the Tallahassee area. If volume purchasing of these components is considered, as well as varying prices by region, it may be possible to reduce the cost of both designs.

Table 5 – Budget Breakdown for HAWT and MHET

HAWT		MHET	
Part	**Cost (US $)**	**Part**	**Cost (US $)**
Blades	0.27	Metal (Bicycle Assemblies/Steel Rods/etc.)	12.75
Hub	0.3	Wood	0
Bicylce assembly (Wind Vane)	3.15	U straps	2
Fasteners	3.5	PVC	1.5
Mount	1.65	Foam	4
Dynamo	15	Wires/diodes/capacitors	5.5
Wires/diodes/capacitors	5.5	Fasteners	6
Battery	19.97	Gorilla Glue	1
		Dynamo	15
		Battery	19.97
Total	49.34	Total	67.72

VI. Results and Discussion

Horizontal Axis Wind Turbine (HAWT)

The first stage of testing entailed the dynamo's power generating capability. In order to test the dynamo, it was attached to the HAWT assembly without the turbine attached. The wheel was rotated at several different revolutions per unit time to create a power curve of different operating speeds. The wheel was spun by hand, using a metronome to match the correct tempo with rotational speed. Two multi-meters were attached to the output and were video-recorded over the period of 1-minute. This was performed over a one-minute time period to obtain an overall average value for the signals, and account for any variation in speed throughout each stroke. Using slowed video playback all values were entered into a spreadsheet, tabulated and averaged to determine the average current and voltage of a certain rotational speed. The power was then calculated using Equation 7. P is the power generated for a specific voltage (V), and current (I).

This following table (Table 6) was developed from the tabulated data collected from the multi-meters for specific revolutions per minute. This provided information and a representative power curve shown in Figure 10.

Table 6 – Tabulated Results from Power Generating Testing

Wind Speed (m/s)	Wind turbine Rotational Speed (RPM)	Dynamo Rotational Speed (RPM)	Power Output (W)	Voltage (V)	Current (A)
2.2	36	1296	2.41	12.04	0.20
4	66	2376	5.35	17.30	0.31
5	78	2808	8.62	22.58	0.38
6	90	3240	9.23	22.63	0.41
8	123	4428	12.55	25.10	0.50

Once the dynamo was proven to contain the power generating capability, the translation of wind speed to wind turbine speed needed to be determined. In order to test this, the wind turbine system was assembled and mounted in a truck which drove at a variety of speeds in order to simulate wind against the turbine. Tests were conducted from 2.2m/s to 8m/s and results can be seen above in Table 6. All three group members were needed to complete this test. One group member drove the truck, which carried the wind turbine. One held the turbine in place allowing it to rotate and the last followed in a chase car taking footage. The values obtained are slightly under operating conditions as some of the wind flow was blocked by the truck cab. If complete air flow was allowed through the wind turbine, slightly higher power generation could be obtained. Once the turbine was up to speed, the rotations per time were simply calculated via slowed video footage and values were obtained for all rotational speeds. Once these values were found, it is very simple to see the electrical output vs. revolutions per minute for constant wind speeds. Table 7, demonstrates the number of hours required for producing the 100 W•h/day, for the constant wind speeds tested. As long as the wind speed is 4 m/s or above, the HAWT has proven capable of generating over 100 W•h of electrical power in one day. These wind speeds are present at the locations chosen for the project. The initial design calculations were based off a low average of 4 m/s wind speed.

Table 7 – Hours Required for Power Generating Objective

Wind Speed (m/s)	Power Generated (W)	Time Required for 100 W•h (hours)
2.2	2.41	41.53
4	5.35	18.69
5	8.62	11.60
6	9.23	10.83
8	12.55	7.97

In order to find the rotational speeds of the dynamo, the ratio of the bicycle wheel to dynamo diameter was taken into account for the speed change. As seen in the Table 5, a wind speed of just over 2.2m/s is required to begin charging the battery as the voltage output needs to exceed the 12.54 battery voltage. Data for the wind locations selected for the project, demonstrate the wind rarely flows below 2.2m/s every day.

Voltage, current, and power curves were created and be can seen below in Figures 40, 41 and 42. They show a similar increasing trend throughout the range of revolutions per minute the dynamo was tested for. Figures 40, 41, and 42 show a steady increase as the mechanical power transferred to the dynamo is increased.

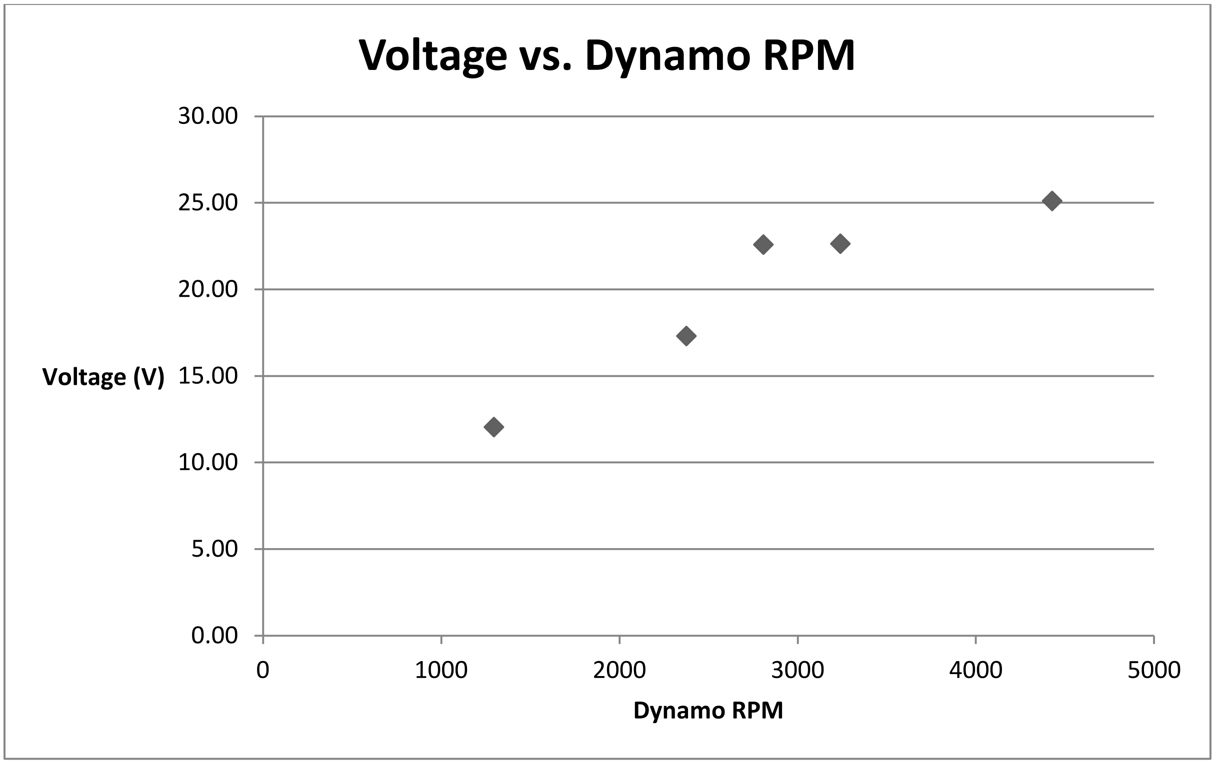

Figure 40 – Voltage Generated vs. Dynamo Revolutions per Minute

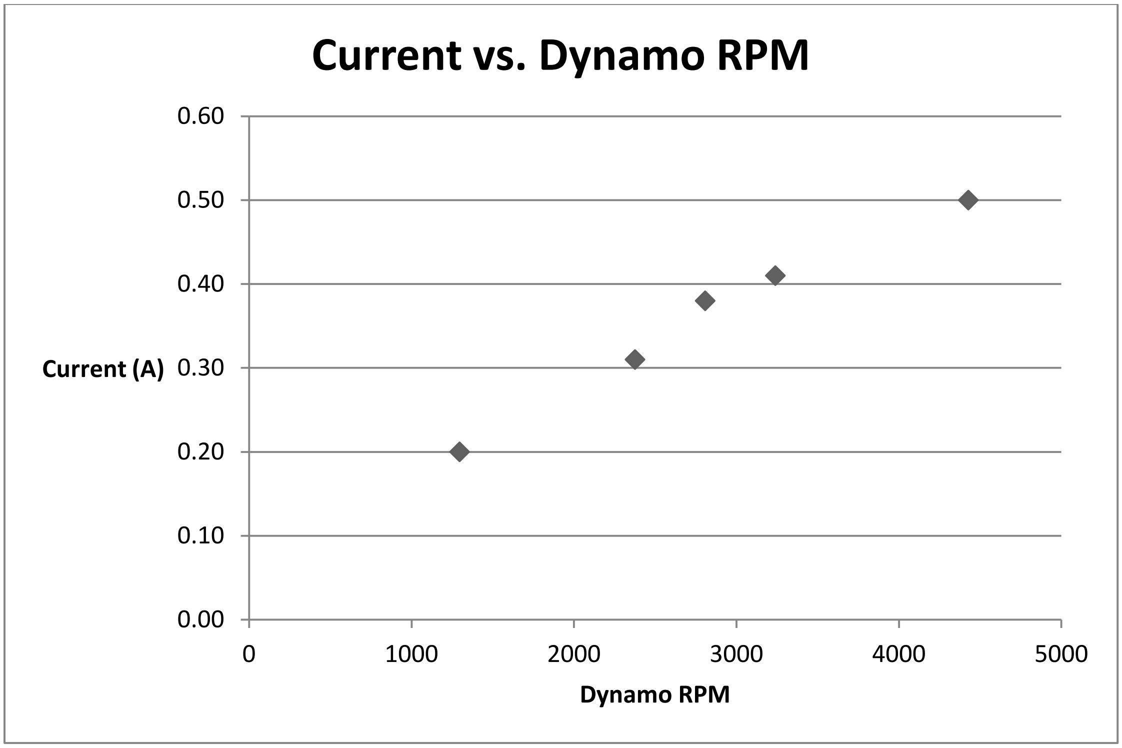

Figure 21 – Current vs. Dynamo Revolutions per Minute

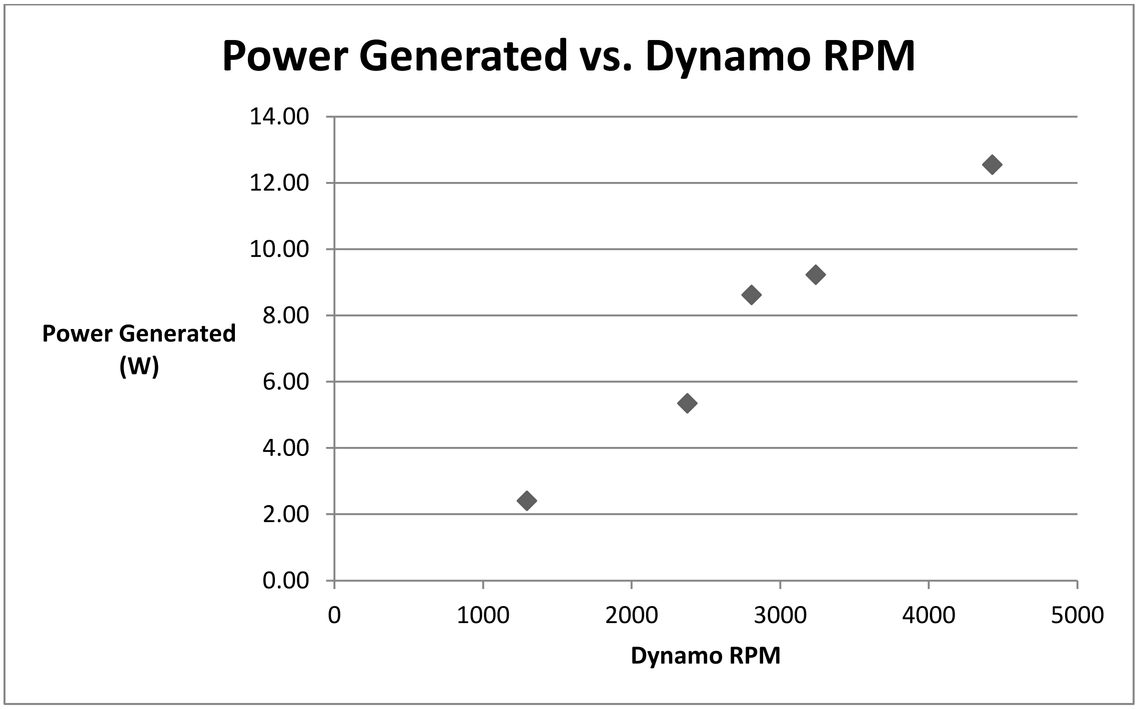

Figure 42 – Power Generated vs. Dynamo Revolutions per Minute

Figures 43, 44, and 45 are voltage, current and power curves that were developed for the wind turbine revolutions per minute. They show the same behavior as those for the dynamo; however, give information of the wind turbine rotational speed needed to achieve the signal values through the dynamo.

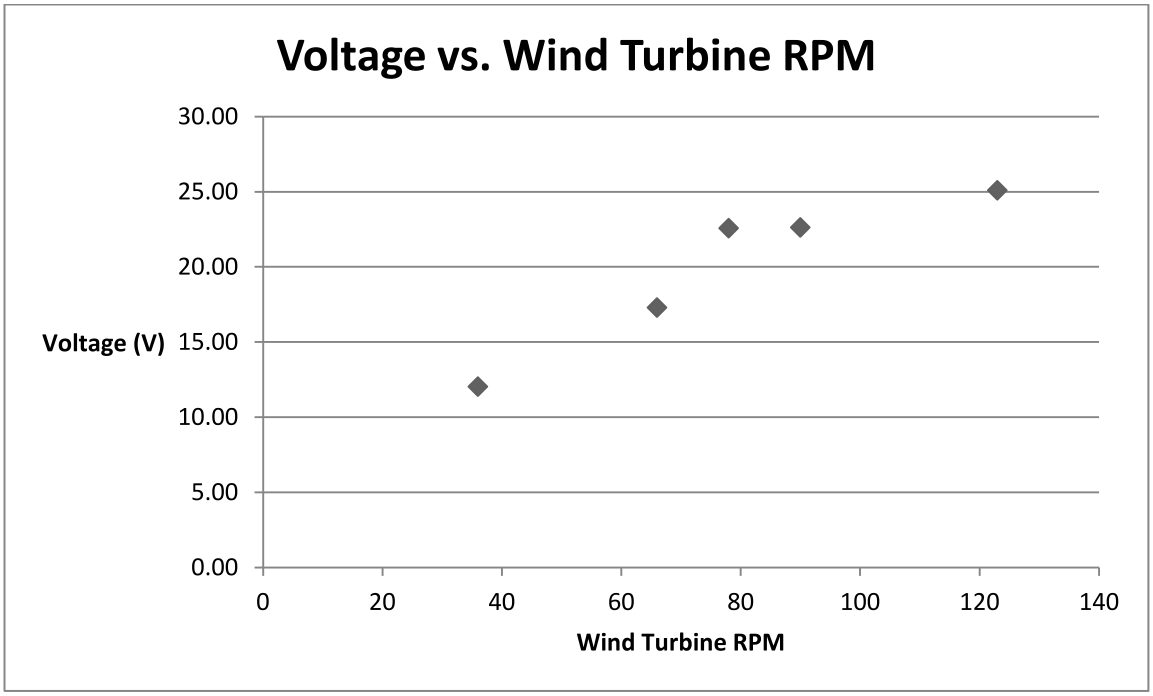

Figure 43 – Voltage vs. Wind Turbine Revolutions per Minute

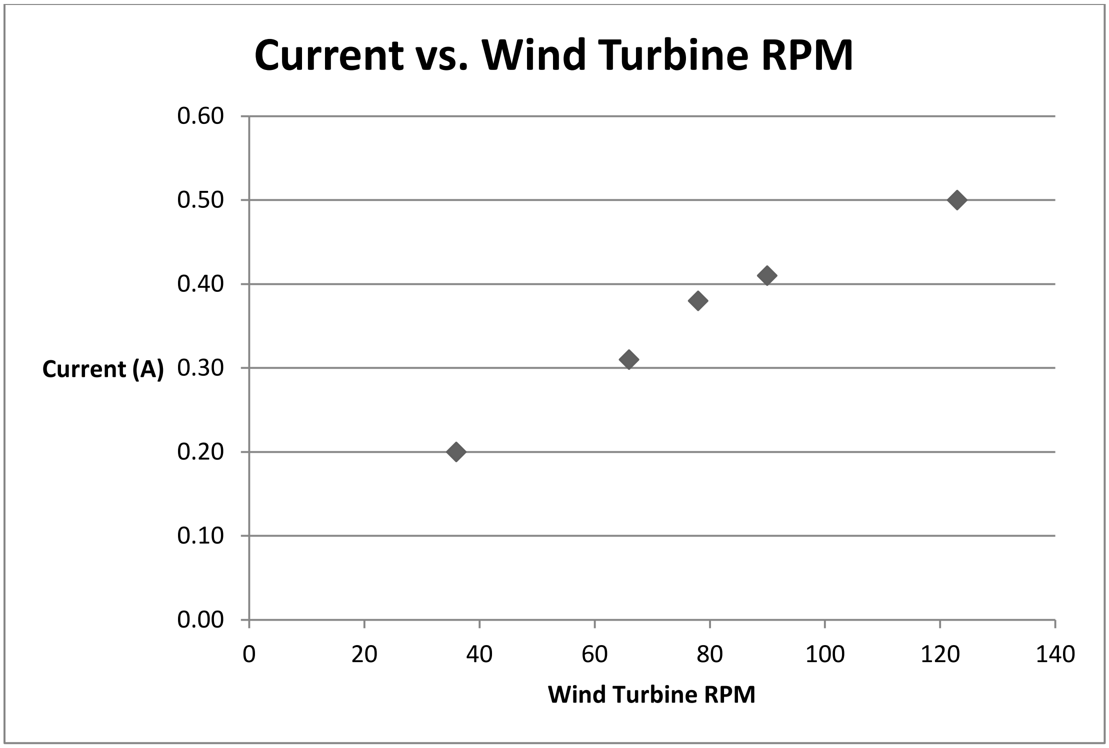

Figure 44 – Current vs. Wind Turbine Revolutions per Minute

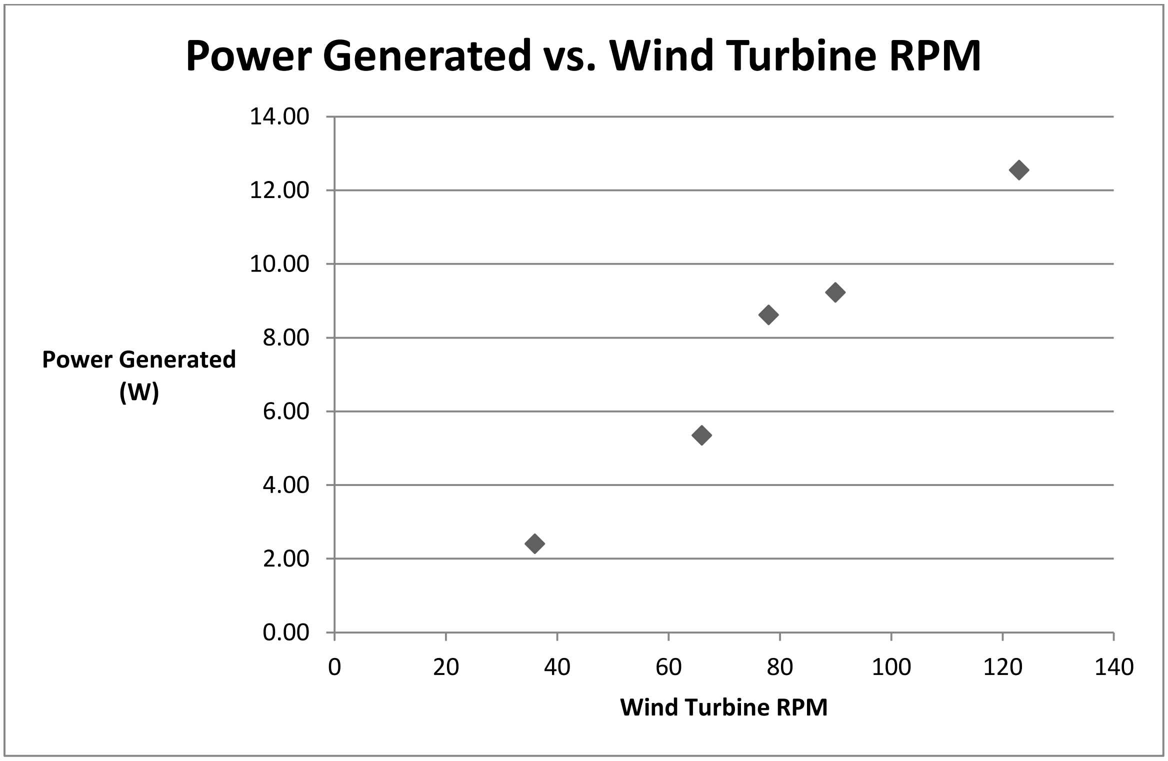

Figure 45 – Power Generated vs. Wind Turbine Revolutions per Minute

Micro-Hydro Electric Turbine (MHET)

The dynamo data determined from the horizontal axis wind turbine was used to calculate the minimum water speed required to create 100 W•h/day. The assumptions used behind calculating this number is that the water speed will be constant throughout the 24-hour period. Due to the little resistance seen by the paddle wheel assembly and the strong force exerted by the turbine blades being submerged 8 inches into the water, it is assumed that the tip speed of the paddle wheel will be 80% of the water current speed. This value of 80% was obtained from experimental testing that has been performed for undershoot paddle wheel systems. The minimum water velocity that the system will require to meet the power requirements needs to be 1.56 m/s or 3.48 mph. This is possible due to the gearing of the bicycle pedal axis to wheel axis is approximately 3:1. Even though the wheel the dynamo rotates on is smaller than the one in the HAWT, it is still possible to achieve these rotational speeds, due to the added sprocket to chain gearing. To see calculations performed for these results see the Required Water Velocity Calculations section in Appendix 1. This is a relatively slow water speed, and one that the rivers chosen for implementation of the project can easily exceed. Some ways to extract maximum water velocity in a river is to position the MHET as far away from the edges as possible in order to reduce the forces caused by the boundary layer and the no-slip condition at the interface between ground and water. For slower flowing rivers it is also possible to channel the water into a smaller area, therefore increasing its speed through the principle of mass conservation.

VII. Environment, Health and Safety

The problem statement for the project asked for the use of a renewable energy source to produce electricity. The environmental impact from using wind and water power in these two design concepts is negligible. This is also because the materials that have been used to design them must also originate from recycled materials and do not require new production of materials.

Last semester, the Restriction of Hazardous Substances (RoHS) was mentioned to the team regarding the automotive battery. It was determined last semester that RoHS must only be in compliance if the electronic component is shipped to an EU member. Also, if the battery contains adequate marking and is disposed off correctly, compliance with RoHS will be met regardless of where the battery is shipped. As part of the design objectives, the three locations that needed to be chosen are located in third-world countries, and compliance can be demonstrated in the accompanying operations manual for the designs.

The packing foam that was used to fill the pontoons contains a RoHS compliance sticker and demonstrates that it is environmentally safe to use.

The battery located on the MHET design has been researched based on the possibilities of water contact through the terminals. It was found that automotive batteries can safely come into contact with water, as they are used in automobiles that can submerge themselves under water and use snorkel systems for the exhaust. The terminals of the batteries are left exposed and the only disadvantage of water contact is that it will discharge if left in contact with the water.

Severe weather consideration was another objective of the project and it was successfully built in to the HAWT. The MHET will be anchored down securely and can be also secured to land for more protection.

VIII. Conclusion

The horizontal-axis wind turbine was successful in meeting all the objectives, and the micro-hydroelectric paddle wheel was successful in all of the objectives except for the cost. The mechanical designs were made from recycled materials; and were powered by a renewable source. They were capable of generating 100 W•h/day and the automotive battery provides the required 300 W•h of storage capability. The HAWT was constructed for a cost of just US $50.00. The MHET was a total of $67.72, but as stated in the economics section, could potentially be reduced when examining volume cost, as well as regional availability of materials.

As initially planned in the concept generation phase, the designs involved mechanically driven systems powered by wind or water. The four main components were incorporated to achieve electrical power. The rotating component, gearing system, energy conversion, and storage device provide the main infrastructure of the design and work properly.

The horizontal axis wind turbine meets the requirements, but also produces more than the required power given average daily wind conditions. Using high local winds, the drag-based turbine converts the mechanical energy of the wind into rotational mechanical energy that turns a bicycle wheel. Once the wheel is turning a dynamo converts the rotational mechanical energy into electricity in the form of AC. In order to convert the AC into DC in order to meet the requirements for power output, a voltage multiplier (doubler). This serves as a full wave rectifying circuit as well as doubles the peak AC voltage into total DC voltage. This voltage multiplier also allows the output voltage to exceed 12 volts which will allow it to charge the 12.54 volt battery.

The dynamo was successfully tested and is shown to exceed energy requirements. Overall the systems are sturdy and will last a significant amount of time without any maintenance. If parts get damaged, new ones can be easily obtained and replaced at low cost. Substitutions can be made on the current designs with local materials the customer may have available.

The micro-hydro electric turbine was created and exceeds the required output but falls above the necessary US $50.00 requirement. This is due to its greater material requirement as well as higher complexity. Large scale production and volume cost will allow a much lower price that may meet the objectives. If a proper alternator can be procured, a village-sized model could potentially be created and implemented with the larger power production capability.

Reproduction of designs will follow the same general guidelines outlined in the Final Concept section. Depending on available parts the manufacturer may need to customize the assembly in order to ensure proper threading on machined parts.

IX. Acknowledgments

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X. Appendix

VAWT Area Calculations

$C_{p.ideal} := 0.3$	Ideal Savonius Power Coefficient
$V := 4\frac{m}{s}$	Wind Speed
$C_p := 0.8 \cdot C_{p.ideal} = 0.24$	Reduced Turbine Power Coefficient
$\eta_{motor} := 0.8$	Estimated Efficiency of Motor
$\eta_{pulley} := 0.85$	Estimated Efficiency of Pulley
$\rho := 1.225\frac{kg}{m^3}$	Density of Air
$P := 10W$	Power
$D := 1m$	Initiating Diameter of Whole Turbine Assembly
$H := 4 \cdot D$	Ideal Height to Diameter Ratio
$HD := 4D^2$ $\quad A := HD$ $A := 4D^2$ $\quad D := \frac{\sqrt{A}}{4}$	Ideal Dimension Derivation Equations
$A := 2 \cdot \frac{P}{\rho \cdot V^3 \cdot \eta_{motor} \cdot \eta_{pulley} \cdot C_p} = 1.563\,m^2$	Minimum Required Area
$D := \sqrt{\frac{A}{4}} = 0.625m$	Minimum Required Diameter of Turbine Assembly
$d := \frac{3}{5}D = 0.375m$	Minimum Required Diameter of Cylinder
$e_{opt} := \frac{d}{6} = 0.063m$	Turbine Offset
$e_{prime} := 0.242d - e_{opt} = 0.028m$	Diameter of Central Axis
$H := 4 \cdot D = 2.501m$	Height of Combined Turbines
$H \cdot D = 1.563m^2$	Check

Gearing Calculations for VAWT

$D_{dynamo} := 0.5in$	Diameter of Dynamo
$D_{wheel} := 27in$	Diameter of Bicycle Wheel
$P_{dynamo} := \pi\ D_{dynamo} = 0.04m$	Perimeter of Dynamo
$P_{wheel} := \pi\ D_{wheel} = 2.155m$	Perimeter of Wheel
$Ratio := \frac{P_{wheel}}{P_{dynamo}} = 54$	Ratio of Perimeters
$\lambda := 0.5$	Tip to Wind Speed Ratio for decreased turbine Cp (See Figure)
$V := \lambda \cdot 4\frac{m}{s} = 2.32\frac{m}{s}$	Velocity of Rotor Tip
$P_{vawt} := \pi\ D$	Perimeter of Rotor Swept Area
$r_{vawt} := \frac{D}{2} = 0.313m$	Radius of Rotor
$\omega_{vawt} := V \cdot \frac{r_{vawt}}{\frac{2}{r_{vawt}}} = 70.88rpm$	Angular Velocity of Rotor
$\omega_{dynamo} := \omega_{vawt} \cdot Ratio = 3.828 \times 10^{3} \cdot rpm$	Angular Velocity of Dynamo
$\omega_{dynamo} > 3000rpm$	Check

National Renewable Energy Laboratory (ARE442)

$C_{pARE442} := 0.190$	Power Coefficient of ARE442 turbine, as obtained from Figure X
$D_{rotor} := 7.2m$	Rotor Diameter of ARE442 turbine
$\omega_{rotor} := 48rpm$	Angular Velocity of ARE442 turbine, as obtained from Figure XX

Horizontal Axis Wind Turbine (HAWT)

$P_{gen} := 10.0W$	Power generation requirement
$\eta_{motor} := .80$	Mechanical Efficiency of used motor
$\eta_{belt} := .85$	Mechanical Efficiency of used belt and pulley system
$C_{pDC2} := .60 \cdot 0.190$	Power Coefficient of wind turbine

$C_{pDC2} = 0.11$

$\rho_{air} := 1.225 \frac{kg}{m^3}$	Density of air at sea level
$V_{ave} := 4 \frac{m}{s}$	Average Wind Speed at 5 meter height. Faya-Largeau

$$A_{turbine} := \frac{2P_{gen}}{\rho_{air} \cdot V_{ave}^{3} \cdot \eta_{motor} \cdot \eta_{belt} \cdot C_{pDC2}}$$

$A_{turbine} = 3.29m^2$ Area of turbine

$$D_{rotorDC2} := \sqrt{A_{turbine} \cdot \frac{4}{\pi}}$$

$D_{rotorDC2} = 2.05m$ Rotor Diameter

$$R_{rotor} := \frac{D_{rotorDC2}}{2}$$

$R_{rotor} = 1.02m$ Rotor Radius

Bicycle Dynamo Belt and Pulley System

$D_{dynamo} := 0.4in$	Diameter of Dynamo
$D_{wheel} := 27in$	Diameter of Bicycle Wheel
$P_{dynamo} := \pi\ D_{dynamo} = 0.03m$	Perimeter of Dynamo
$P_{wheel} := \pi\ D_{wheel} = 2.15m$	Perimeter of Wheel
$Ratio := \frac{P_{wheel}}{P_{dynamo}} = 67.5$	Ratio of Perimeters
$\omega_{dynamo} := \omega_{rotor} \cdot Ratio = 3240rpm$	Angular Velocity of Dynamo
$\omega_{dynamo} > 3000rpm$	Check

Dynamo Revolutions per Minute for Required Power Generation

$D_{dynamo} := 0.75\,in$ Diameter of Dynamo Shaft Used

$D_{hawt} := 27\,in$ Diameter of Bicycle Wheel Used in HAWT

$D_{mhet} := 24\,in$ Diameter of Bicycle Wheel Used in MHET

$D_{turbine} := 48\,in$ Diameter of Paddle Wheel Used in MHET

$gearing_{mhet} := 3$ Center Sprocket to Rear Sprocket Gearing Ratio

$Power_{req} := 100\,W \cdot hr$ Minimum Power Storing Requirement per Day

$Power_{hr} := \frac{Power_{req}}{24\,hr} = 4.167\,W$ Minimum Power Generation Requirement Throughout One Hour

$V_{hawt} := 52\,rpm$ Revolutions per Minute of Rear Wheel

$V_{dynamo} := \frac{V_{hawt} \cdot D_{hawt}}{D_{dynamo}} = 1.872 \times 10^{3} \cdot rpm$ Revolutions per Minute on Dynamo Shaft

$V_{mhet} := \frac{V_{dynamo} \cdot D_{dynamo}}{D_{mhet}} = 58.5\,rpm$ Revolutions per Minute of Bicycle Wheel on MHET

$V_{turbine} := \frac{V_{mhet}}{gearing_{mhet}} = 19.5\,rpm$ Revolutions per Minute on Paddle Wheel

$Turbine_{efficiency} := .8$ Paddle Wheel Efficiency in Converting Water Velocity into Rotational Velocity

$V_{water} := V_{turbine} \cdot \frac{D_{turbine}}{2} \cdot \frac{1}{Turbine_{efficiency}} = 1.556 \frac{m}{s}$ Minimum Velocity of Water Required to Produce Required Power

$V_{water} = 3.481 \cdot \frac{mi}{hr}$

Energy to Boil Water

$t_{boil} := 10min \qquad \Delta T_{boil} := 75K \qquad m_{water} := 1kg \qquad Cp_{water} := 4187\frac{J}{kg \cdot K} \qquad Power_{available} := 2500W$

$Q_{boil} := m_{water} \cdot Cp_{water} \cdot \Delta T_{boil}$ $\qquad Q_{boil} = 3.14 \times 10^{5} J$

$Power_{boil} := \frac{Q_{boil}}{t_{boil}}$ $\qquad Power_{boil} = 523.375W$

$Capacity := \frac{Power_{available}}{Power_{boil}}$ $\qquad Capacity = 4.777$

Therefore the system has the capacity to boil up to 4.7 liters of water.

Energy to Sanitize Water

$\Delta T_{san} := 55K \qquad t_{san} := 20min$

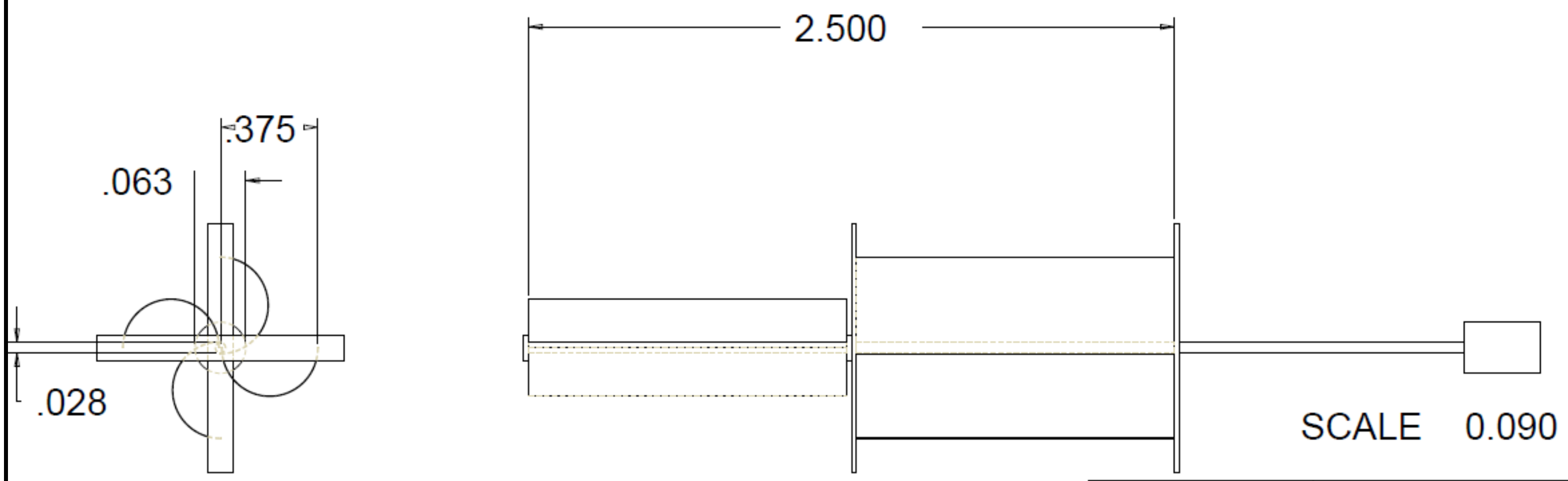
$Q_{san} := m_{water} \cdot Cp_{water} \cdot \Delta T_{san}$ $\qquad Q_{san} = 2.303 \times 10^{5} J$

$Power_{san} := \frac{Q_{san}}{t_{san}}$ $\qquad Power_{san} = 191.904W$

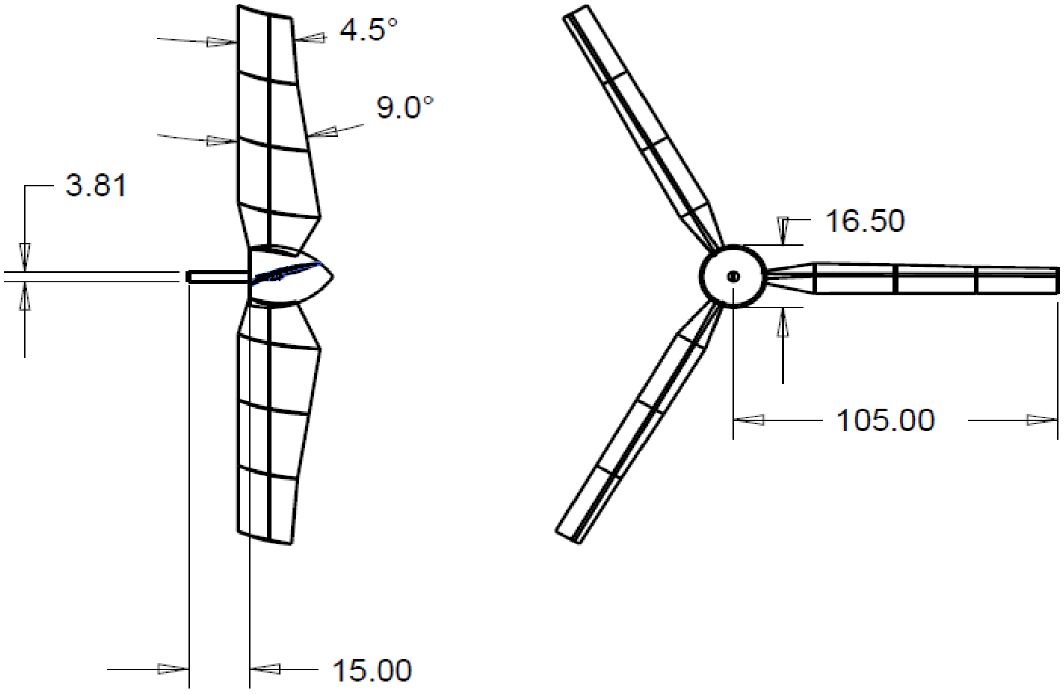
$capacity := \frac{Power_{available}}{Power_{san}}$

XI. Drawings

Fall 2011 Part Drawings



Part Name	VAWT
Project Name	Sr. Design
Drawn By	Jonathon Miller
Date	12/7/11
Rev	0
Part #	F11-SD1-VAWT-P001



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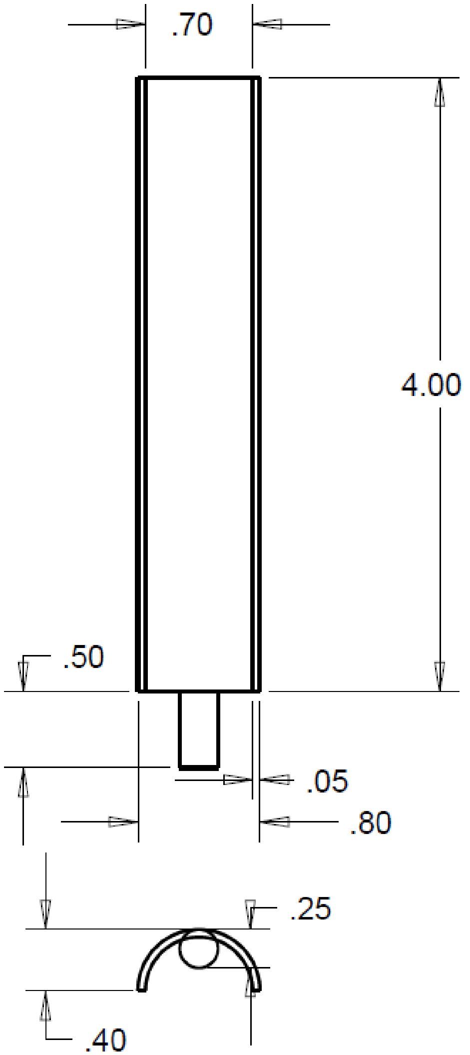
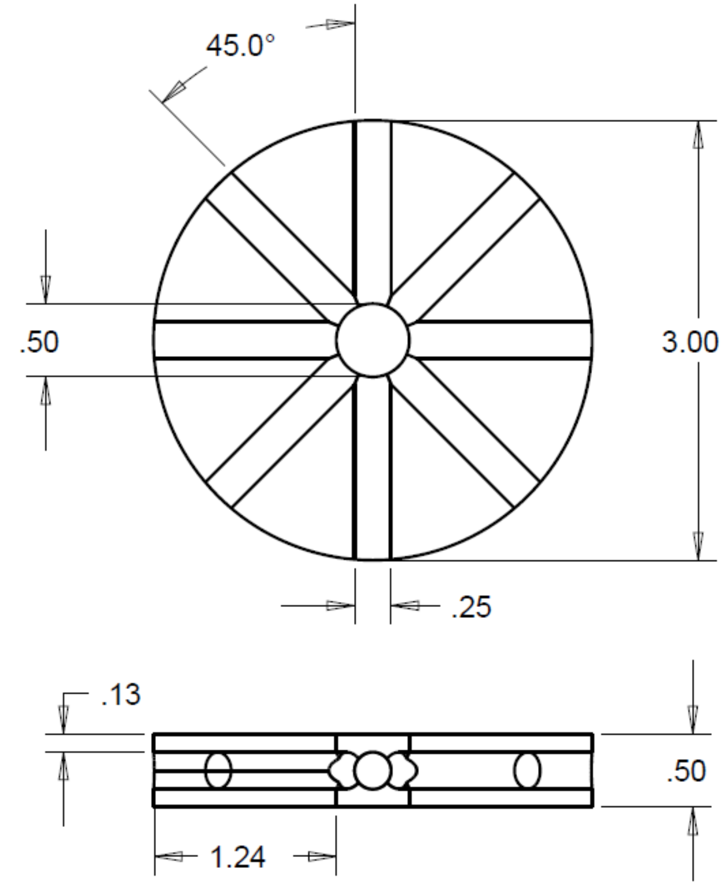
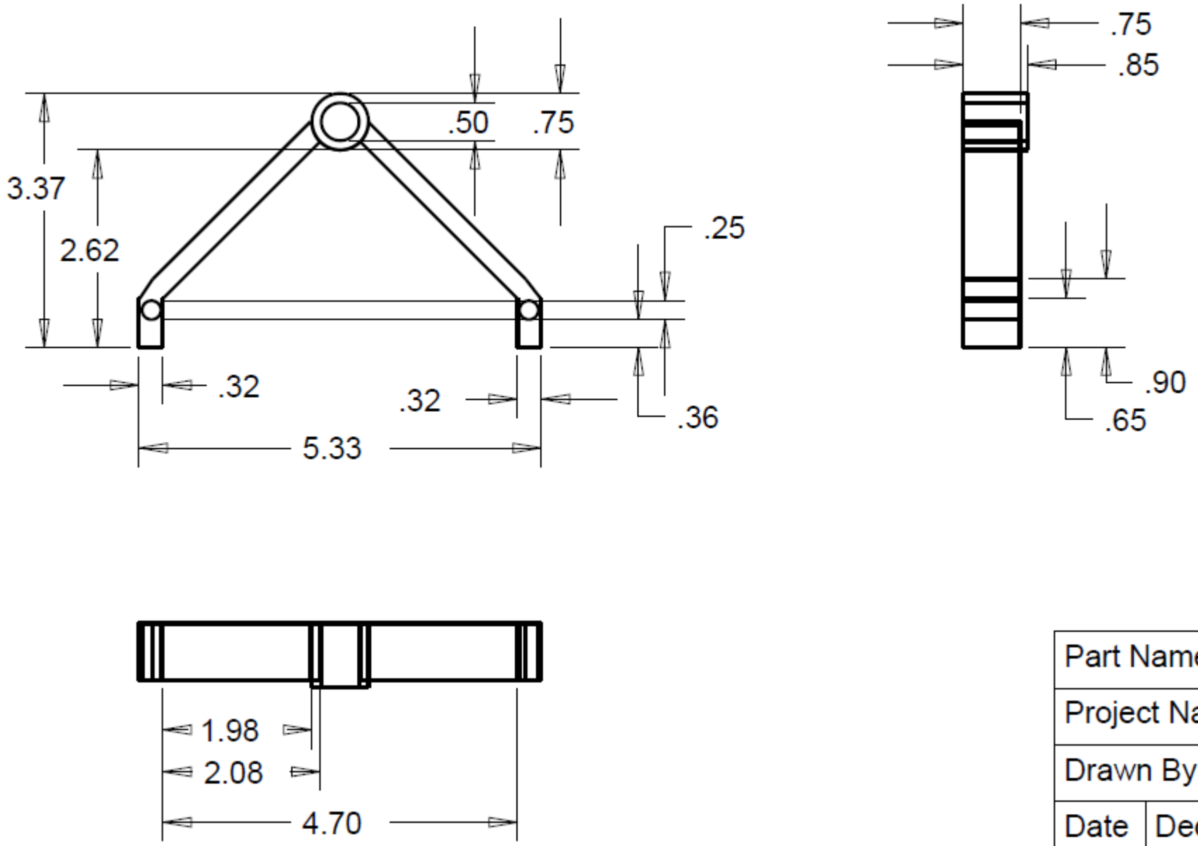
Part Name:	Airfoil Blades
Project Name:	Sr. Design
Drawn By:	Carlos Novelli
DATE:	December 8, 2011
Rev	0
Part #:	F11-SD1-HAWT-P001



Part Name	Fin
Project Name	Sr. Design
Drawn By	Sean Stege
Date	December 8, 2011
Rev	0
Part #	F11-SD1-MHEW-P001

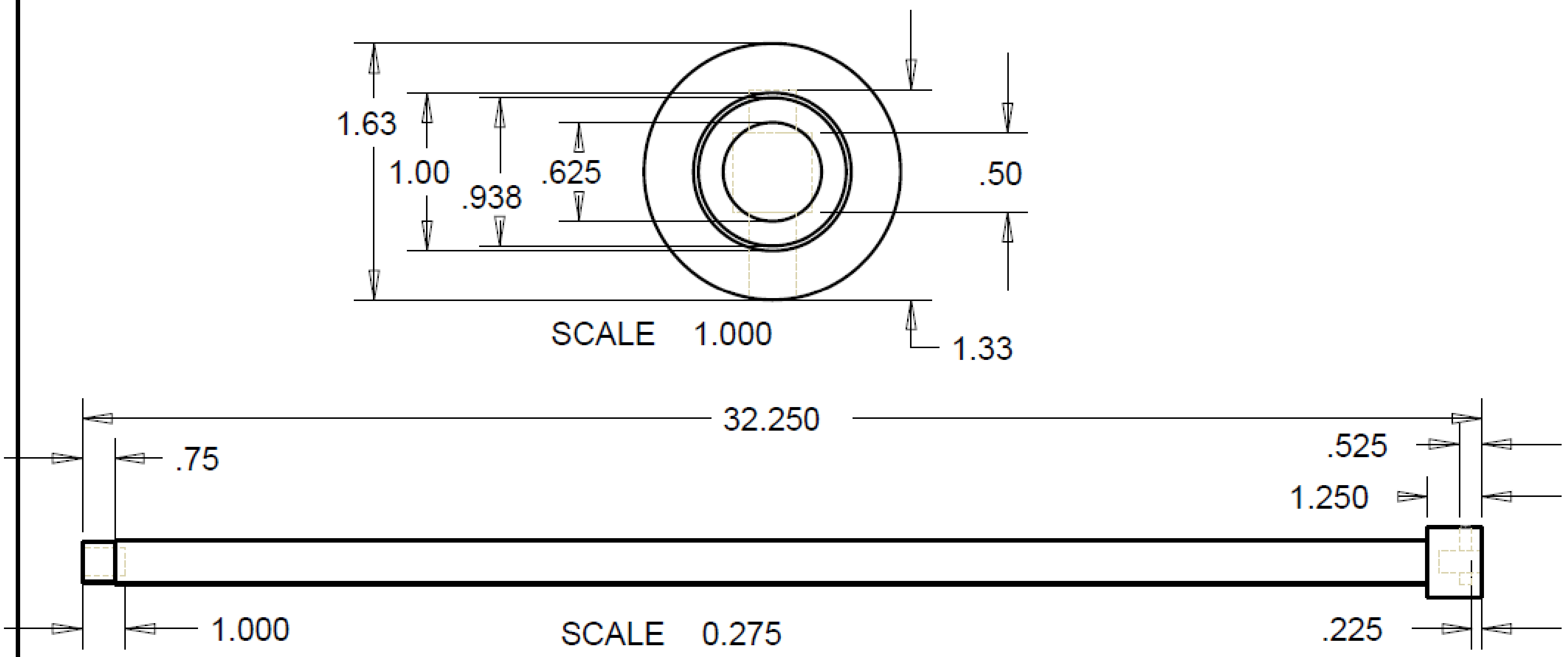


Part Name	Fin Rotor
Project Name	Sr. Design
Drawn By	Sean Stege
Date	December 8, 2011
Rev	0
Part #	F11-SD1-MHEW-P002

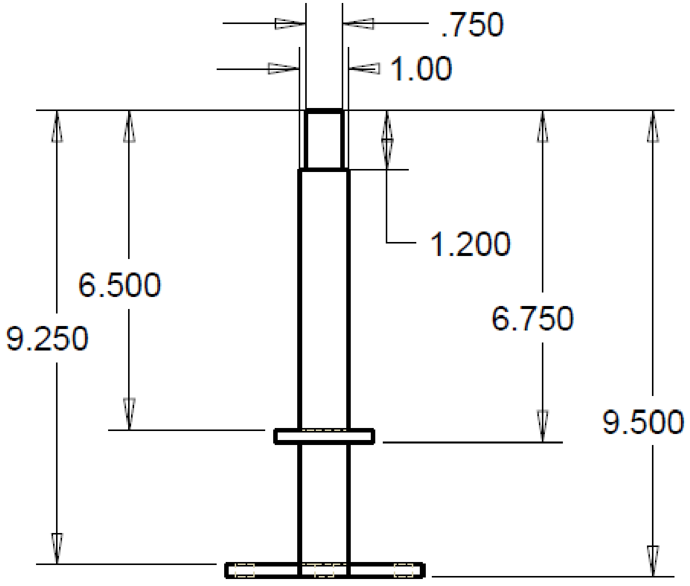


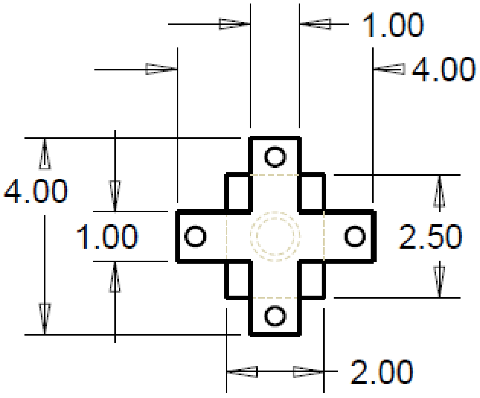
Part Name	STRUT
Project Name	Sr. Design
Drawn By	Sean Stege
Date	December 8, 2011
Rev	0
Part #	F11-SD1-MHEW-P003

Spring 2012 Part Drawings



Part Name	Coupling Rod
Project Name	Cummins
Drawn By	Sean Stege
Date	April 05, 2012
Rev	01
Part #	01





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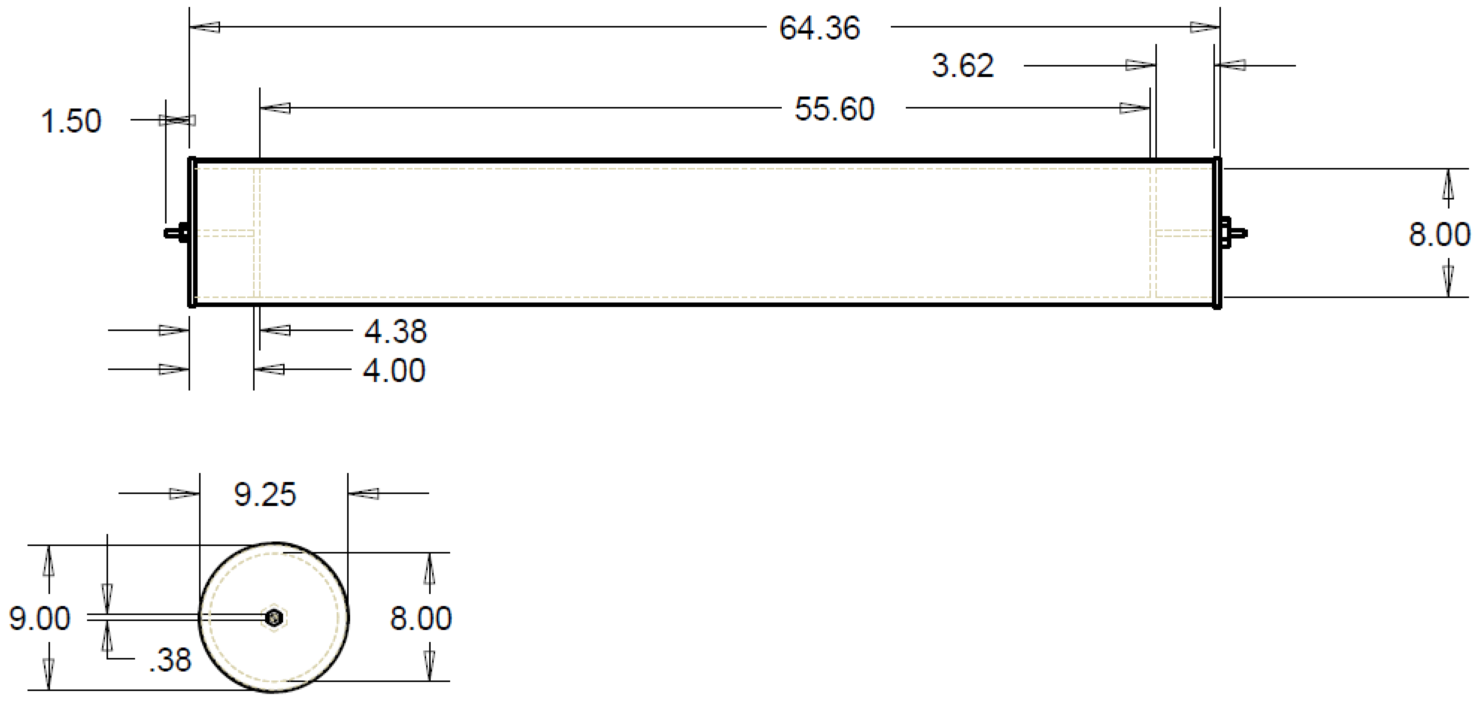
Part Name	Paddle Axil
Project Name	Cummins
Drawn By	Sean Stege
Date	April 5, 2012
Rev	01
Part #	02



Part Name	Pontoon
Project Name	Cummins
Drawn By	Sean Stege
Date	April 5, 2012
Rev	01
Part #	03

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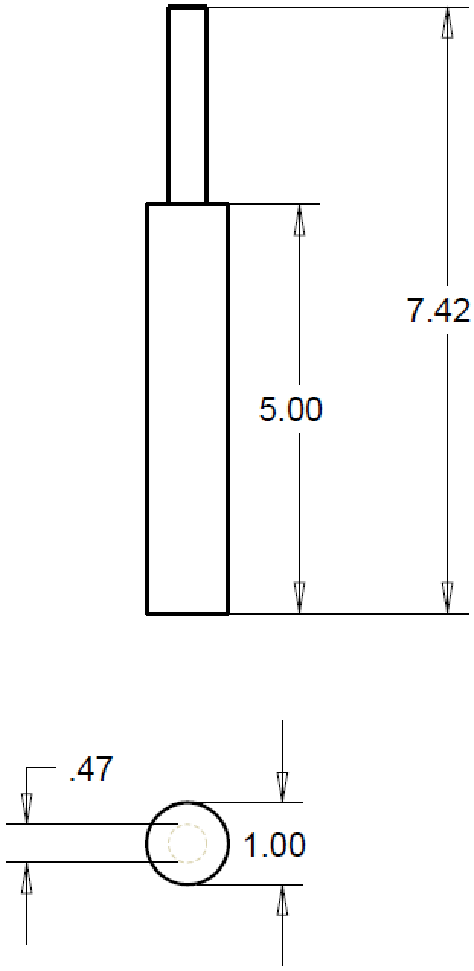

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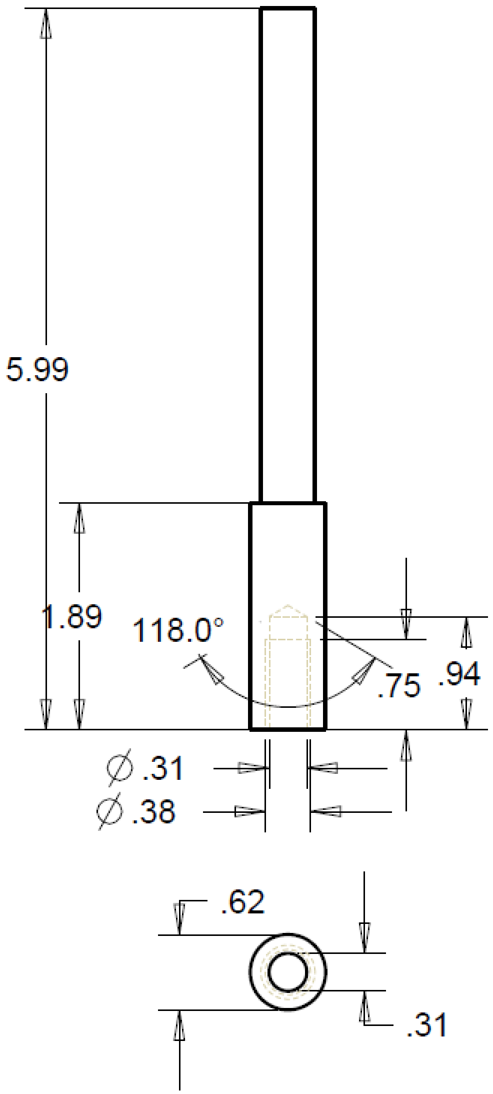
Part Name	VAWT SHAFT1
Project Name	Cummins
Drawn By	Sean Stege
Date	April 5, 2012
Rev	01
Part #	04



SCALE 0.750

Part Name	VAWT Shaft2
Project Name	Cummins
Drawn By	Sean Stege
Date	April 5, 2012
Rev	01
Part #	05

XII. References

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XIII. Biographies

Carlos Novelli:

I was born on November 15th, 1989 in Cumana, Venezuela. My father is Italian and my mother is Venezuelan. I moved to Miami in the 1995 due to my father's job relocation and began primary school. I lived in south Florida until I moved to Tallahassee for college. In high school I determined that I would follow a career in a STEM discipline; however, was undecided on a specific track. When I arrived in college, I decided to pursue a chemistry major. I eventually found a much stronger interest in physics and in moving bodies, and switched towards a mechanical engineering major. I found mechanical engineering to be a challenging journey towards professionalism; however, one that I have truly enjoyed throughout the last four years.

Jonathon Miller:

I was born on May 21st, 1989 in Delray Beach, Florida. My father is an emergency room physician and has always encouraged me to excel in academics and sports. I realized I wanted to be an engineer when I learned of exactly what an engineer does and what makes a good engineer. I have always had an interest in how things worked and how to make things mechanically better and decided that mechanical engineering was naturally the way to go. I have not stopped once since then to rethink my decision as I have "enjoyed" every minute of my education at Florida State. I am extremely happy with all that I have learned and think I have been provided an excellent education to further my career in the professional world.

Sean Stege:

I was born May 27, 1986 in Jacksonville, Florida. My parents moved the following year to Tallahassee, Florida where I reside to this day. From a very early age, I have been interested in all manner of mechanical systems. This interest/curiosity has been the driving force behind my pursuit of a mechanical engineering degree from Florida State University.