The Pennsylvania State University
Wind Energy Club
Business Plan and Wind Turbine Technical Design
Submitted to
NREL Competition Operations Manager Elise DeGeorge/ AFC-7-7 0044-07

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1. Executive Summary

In this document, Green Lights, LLC. describes and supports an investment opportunity with a ROI of 43% in 3 years. This company sells portable wind-powered lighting systems to rental houses. These lights are designed to be used by construction companies, replacing the current diesel systems, which will help these companies to save money by not having to purchase fuel while furthering their green initiatives. Market research and customer validation confirm this business model to be successful when targeting Philadelphia in the first six months and expanding thereafter to areas surrounding the hub of manufacturing which will be set up in Erie, in the middle of the Great Lakes region.

Figure 1: PSU Test Turbine

The lighting system includes four batteries, which can continually sustain the lights for 5 days, given average wind resources in the Great Lakes Region. When not deployed, the system can be plugged into the grid to help the system charge the batteries for subsequent uses.

The investment is needed to manufacture more units than are currently being produced and to expand our market region beyond Philadelphia with the intent to reach breakeven at 18 months. Currently, the team has successfully completed small-scale testing in a wind tunnel at Penn State that validates the turbine design used in the product, which meets design goals over an extensive operating envelope. The turbine-generator design and computer code will also be confirmed by an independent third party in wind tunnel testing in similar operating conditions at the Department of Energy's Collegiate Wind Competition in May, 2018.

Figure 2: Market Turbine Design, Wind-Powered Lightning

The investment opportunity is described in three sections: Business, Deployment, and Technical sections, each corresponding to a team within Green Lights. Sections 2 and 3 of this report covers the business model development of Green Lights LLC. Within these sections, core areas of the business model are described, including: development and operations, marketing, financial forecasting, management team, and the business' deployment strategy. These areas are essential to the business planning process and help in understanding how and why the final business decisions were arrived at. Section 4 details the technical design of the market and test turbine. The market turbine section covers the design process and analysis techniques used to create the turbine and confirm its functionality and safety while the test turbine section describes the processes used to design the turbine components, analyses to confirm their optimization, and tests to ensure their actual, experimental compatibility.

2. Business Plan

2.1 Business Overview

Green Lights, LLC is a company to be based in Erie, Pennsylvania that will specialize in the manufacturing of unique wind energy powered light towers. The company was founded by Andrew Marzullo, Michael Allan, and Colben Holland, three Penn State students that share an equal passion for wind energy. These wind-powered light towers are projected to provide services at a level above the competition. By using the wind as an energy source, which is freely available throughout the day, the lights run more efficiently than solar-powered devices and are more environmentally friendly than the leading diesel powered competitors. Additionally, our wind turbine generates less noise than diesel units, while producing the same amount of light. The anticipated journey from concept to reality of Green Lights' emerging green lighting solution business has been broken down into four phases.

Phase 1 - Company Formation to Acquisition of Expansion Funds

As of May 10th, 2018, Green Lights will not have obtained any investment capital except that of the three founders' remaining college funds. This small initial investment will provide enough capital to start the company and maintain it for six months. Green Lights will be working out of Erie, Pennsylvania due to its strategic location along several major interstates, the wind resource in the Great Lakes region, and the ability to obtain a warehouse location. The company will begin selling primarily to the Philadelphia area for this initial Phase 1 period based on the company's background research showing a large demand for light towers and an existing relationship with one of our outside consultants.

Phase 2 - Investment Acquisition to Break Even Point

At the point of investment acquisition, Green Lights will have the capital to expand the company's business beyond the original market in Philadelphia. The company is planning to attend trade shows throughout Pennsylvania but will primarily be marketing to the Western PA area, including Erie and Pittsburgh, since it is the closest to Erie. Additional hourly workers will be hired to assist the three founders and increase unit production. An investment of $777,600 would accelerate our production immensely and we will be able to generate a 43% return on investment to our generous benefactors by offering a 19% total stake of the company.

Phase 3 - Breakeven Point to Investment Return

Although our company has been in business for 6 months, our official fiscal year will begin in July 2018 when Green Lights receives its first investments, allowing the company to reach break-even in February 2020. The company is expecting to be reaching across state lines by this point in time, primarily to Ohio and New York in the Cleveland and Buffalo regions due to their proximity to the company's already discovered markets. The breakeven point is based on selling two units per month after receiving the initial investment capital.

Phase 4 - Investment Return to Exit Strategy

Upon completion of Green Lights' third fiscal year, the company will have officially gained enough capital to return 43% of the investor's money. As previously stated, Green Lights plans to have a large competitive advantage over its competitors based on the product's ability to outperform traditional lighting units in efficiency and cost-savings. These two years post-ROI will be key to the company's ability to further its lean manufacturing plans and provide stable growth opportunities in the future. At this point, the founders plan to renegotiate terms of a possible new deal with the investors.

Green Lights' timeline of these phases can be found in greater detail in section 2.4, Development and Operations. Additionally, the marketing strategy and research can be found in section 2.2, management in section 2.3, and the financial forecasting in section 2.5 as well as the appendix.

2.2 Market Opportunity

Green Lights's wind turbine-powered construction lights are unique and there are no similar, competing wind powered products in today's market. We have been able to outsource information and suggestions through a start-up consultant from the Happy Valley Small Business Development Center (SBDC) in State College, PA. We have also found a local company, Dominight that offers a solar-powered lighting product and has worked with the same development center. Through this research, we learned light towers are the one of the most rented items in the country, which defines solid market potential for innovative, green and cost efficient light towers.

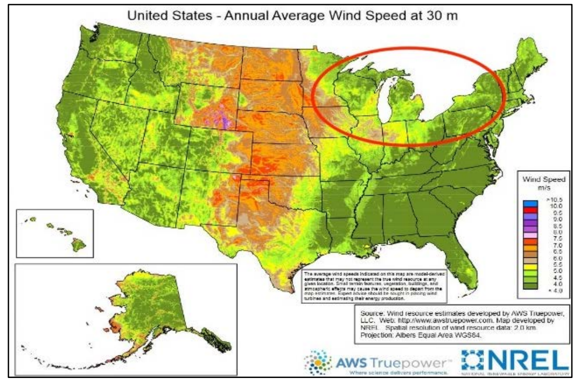

Figure 3: United States Wind Resource[1]

Location

Our geographic target market lies primarily in the Great Lakes Region which consists of Illinois, Michigan, Pennsylvania, New York, Ohio, Minnesota, Wisconsin, and Indiana. Within the region, our company plans on establishing our manufacturing facility near Erie, PA. This region accounts for booming construction industries and thus a skilled workforce, a convenient location, and ample wind resources, shown in Figure 3. Because of the central location of the Great Lakes target market, we are not limited to this region. There is room for expansion elsewhere. Our location allows for competitive pricing and flexibility when marketing our product.

Market Opportunity

Traditional light towers are predominantly powered by diesel generators; however, companies and venues are becoming more aware of their environmental impact, which provide a motivation for companies to go green. In the case of Green Lights, greener is better, not just for the environment, but for safety and consumer profitability. To reiterate, we have not found any similar wind-powered product, which will allow us to access a completely **untapped** market.

Lighting systems are one of the most in-demand items in the country, due to the need for and cost-effectiveness of renting temporary, portable lighting. Our company expects to compete in the construction industry by providing a renewable energy option never before seen in competing products. Our largest competitors are traditional diesel-powered lighting systems. While relatively safe, reliable, and easy to manufacture, they have several weaknesses that we hope to capitalize on. We have developed a product that improves efficiency, safety, and is more easily transported compared to traditional systems.

Diesel lighting units emit substantial amounts of exhaust fumes and create noise pollution for surrounding areas. They also consume fuel at approximately 3 gallons per hour, which makes them rather expensive to run in addition to regular maintenance requirements. Our product is different because the user does not need to worry about any of these issues. While operating, Green Light's product runs off clean power, which is generated by a wind turbine attached to a sturdy base. Our system does not require fuel or oil and does not create any fumes or significant noise. Simply set it up and walk away; it takes care of itself. Diesel engines are not very efficient and three lighting units running on a regular basis can cost a company upwards of $15,000 in fuel over the course of a year. We save our consumers money by being able to offer a product that has a great return on investment. While our units have a larger initial cost compared to their diesel counterparts, they will provide customers a total return on investment within the first year.

Since it runs on batteries powered by a wind turbine, our light tower is much quieter than traditional generators used in diesel powered light towers. Having a relatively silent product will mitigate many dangerous situations stemming from high-noise operations. Wind turbines can generate sound emissions on the order of 40-50 dB[2] depending on the distance from the device, while standard diesel generators can operate at 65 – 75 dB[3]. Also, the product promotes and aids in the emerging sustainability and environmentally friendly initiatives by offering an alternative to fossil fuels. Our customers will save money compared to solar powered units because our product costs less to build, buy, or rent. Solar panels are highly taxed through a recently imposed 30% tariff on imported panels. Solar power also operates on a complete off-phase cycle with the intended use of the lighting system, as the panels can only charge the battery during the day, while the lighting is needed at night. On the contrary, wind power can be harnessed anytime of the day in any weather conditions.

The components of our turbine are easy to assemble, durable, and easy to replace, making it ideal for any location. Our product can be setup by a single person in approximately 10-15 minutes. The setup is similar to the conventional diesel systems in that the light tower is cranked up by hand, however, our system has a second, separate tower for the wind turbine. The turbine tower will have additional support via guy wires. Only a truck or SUV is needed to transport the unit to a suitable location for use.

In addition, a light tower market report done by Markets & Markets[4], noted that the demand is growing rapidly. In 2017 alone, the market has generated an estimated $2.02 billion in revenues. Over the course of five years (2017-2022), sales within the sector are expected to increase at a compounding annual growth rate of 6.1%[4]. Additionally, the renewable energy sector will be on the rise given that the U.S Government is planning to have renewable energy produce at least 20% of the country's energy by 2020[5]. Both the construction and renewable energy industries are growing exponentially as we approach the turn of the decade. Paired with increasing environmental concerns, the U.S. Government is investing more in renewable energy resources, which our company will be ready to capitalize on.

Our system does include a backup generator for the rare times that the wind energy stored cannot support the load through the full demand period, but our modeling shows this should be very rare. Additionally, the systems will rely on the electric grid to resume a full state of charge during periods when they are not in use. Thus, the emissions of the local electric grid should be considered in any corporate social responsibility analysis which includes Green Lights' use. At an electric rate of $0.10/kWh, the cost to the consumer to charge the batteries would be $66/yr.

Reaching our Target Market

Our main customers are construction rental houses who rent construction equipment to businesses such as construction and mining companies, as well as those in the oil & gas industries, in addition to recreation groups, and public safety applications. Rental houses, such as Eastern Highreach, will be entitled to a government subsidy because they will be purchasing a "green product" from us which they will then rent out to their customers. Eco-Rental Solutions, which has offices in upstate NY as well as Chicago, is a rental house which already specializes in environmentally friendly products in this space, and thus would be a prime target market as well.

To reach our target markets, we plan on establishing our name and product in the marketplace primarily through trade-shows. Trade-shows will provide us the opportunity to showcase a demo model of our product, gain publicity within the industry, network with attendees, and build a group of new potential customers. To accomplish this, we intend on attending the AmCon Design & Contract Manufacturing Expo at the David L. Lawrence Convention Center, Pittsburgh, PA from October 2-3, 2018. We will continue to attend trade shows in the future to further advertise our product and company.

In addition to trade shows, Green Lights is devoted maintaining relationships with our consumers by being easily accessible. Our website can be reached at https://greenlightsllc1.wixsite.com/gogreen. We decided upon an eCommerce plan that offers a $300 ad voucher, Google Analytics, a site booster app, online store, and form builder app which will be utilized to optimize our audience awareness. Given this, we will be able to efficiently and effectively market our company name, information, and product to the public.

Capitalization

Green Lights was established by three founders including Andrew Marzullo, Colben Holland, and Michael Allan. Each are students at the Pennsylvania State University on scholarships and decided upon reinvesting their college funds into this start-up. Using these funds, our company was able to boost our initial capital to around $100,000. Note, the cost of attendance at the Pennsylvania State University typically ranges between $25,000-$50,000 depending on whether the student is a PA or non-PA resident. Additionally, Andrew, Colben, and Michael have been working summer full-time jobs since the start of college. Both Colben and Michael have been working part-time for Andrew for free in their spare time. Generous family members and friends have also contributed roughly $10,000 through our crowdfunding efforts. Our plan is to build up the company as fast as possible as we look to exploit an untouched market. We are currently looking for expansion capital to bring in Michael and Colben as full-time workers with a salary of $25,000 each during the start-up phase. With three full-time workers, we'll then look to bring in one or two hourly-waged workers at a rate of $15 per hour to manufacture upwards of 2 units a month. In the future we plan on acting as a hybrid company offering our product B2B (business-to-business) and B2C (business-to-consumer).

Being a start-up, our company plans on competitively pricing each unit compared to the diesel-powered counterparts. We determined our selling price to be around $18,000 with a cost of around $8,530.56 to produce one unit. In the first year of production we project to sell two units per month to establish credibility for Green Lights. By selling at this rate, the company will be able to keep costs down while remaining on track to breakeven at 18 months. Based on this, the total sales for the first 18 months are projected to be roughly $648,000. Additionally, with our cost of goods sold being $204,925.44, our projected first 18 mo profit margin will be $340,899.84.

2.3 Management Team

Andrew Marzullo	*CEO, Founder*	*Dr. Frank Archibald*	*Outside Consultant*
Michael Allan	*Founder*	*Mr. Michael Archer*	*Outside Consultant*
Colben Holland	*Founder*	*Joseph Shenko*	*Outside Consultant*
Dr. Susan Stewart	*Advisor*	*Brendon Hong*	*Outside Marketing Strategist*
Dr. Maria Spencer	*Business Consultant*	*Parth Patel*	*Outside Financial Planning*

2.4 Development and Operations

Prior to Green Lights launching in January of 2018, a business plan that encompasses four phases was developed. These phases are highlighted within this section and appear in chronological order.

Phase 1 - Business Launch to 6 Month Expansion Investment

Diesel powered light towers are the most abundant and most rented type of light tower on the market today. However, Green Lights has identified numerous problems associated with the use of these systems:

1) Safety: Units are very loud, especially at construction sites
2) Environmental/Health: Units emit large amounts of air pollutants
3) Efficiency: Units consume substantial amounts of fuel
4) Mobility/Durability: Units demand constant refueling

Green Lights is seeking to solve these problems through the application of wind energy, which offers solutions to the problems. Wind energy is a low noise, clean, renewable source of energy that can operate for extended periods of time without refueling or maintenance, which make Green Light's lighting units very mobile, durable, and perfect for use in remote locations. It is important to note that this unit can be set up or taken down by a single person.

Original product design consists of two towers: one supporting the lights and one supporting the wind turbine as shown in Figure 2. Green Lights also designed several innovative solutions to enhance the user's experience.

These designs include:

1) A rotational base to allow for 360 degree unrestricted light coverage
2) Simplified lighting adjustments at the deployment state
3) Secure transportation mode for safe transportation

It has been determined that based on cost of living, ability to obtain an inexpensive warehouse, and proximity to major highways and metropolitan areas, the business will be based in Erie, PA. Additionally, Green Lights' two major markets will be construction and special events. Green Lights will deal mostly with rental houses for at least the first six months of operation. There has been a vested interest in the product by rental houses in the Philadelphia area as per Joe Shenko, who is an active sales member of this industry in this region. Other future markets Green Lights will explore are emergency relief, developing countries and recreational sporting events.

In the preliminary phases of the product development phase, Green Lights has been consulting with Michael Archer, who is a tech investor from New York. Green Lights has also been consulting with Maria Spencer, who is a consultant with the small business development center. Green Lights plans on staying in contact for continual support and information in the future.

Phase 2 - 6 Month investment gain to Break Even Point at 18 months

After being in business for approximately 6 months producing 2 units per month, the founders have decided to obtain investment for expansion purposes. It has been found that a total investment into the company of $777,600 will provide the necessary resources to build 2 units per month to achieve a breakeven point of 18 months. Based on these projections, the first-year revenue for the company will come out to be $432,000, with a total profit of $211,025.28. These numbers are based on conversations and financial projections done with Joseph Shenko, a vice president of sales at a major rental house in the Philadelphia area, and our financial advisor, Parth Patel. Green Lights plans to pursue more leveraged relationships with rental houses closer to the Erie area once investment money is obtained to build more products per month and expand the company's network base beyond Philadelphia and into our target region.

Based on the projected success in Phase 1 with the market in Philadelphia, Green Lights will be planning to pursue opportunities in Western PA including Erie and Pittsburgh.. Green Lights also plans to attend more trade shows in the area in the future to continue showcasing the product to potential customers. While the primary market will remain construction lighting solutions, Green Lights plans to expand not only into the Western PA region, but also into other surrounding areas that can benefit from the product, including Cleveland and other areas surrounding the Great Lakes.

Phase 3 - Break Even Point at 18 months to Return on Investment at 3 years

Eighteen months following the first investment acquisition, it is projected that Green Lights will financially break even. At this point in time, it is planned that Green Lights will begin to move across state lines from Pennsylvania into New York and Ohio to further expand the customer base. The company will continue its planned course to financially build the foundation of Green Lights. The product will also be on the market for several years by then, allowing for the name and recognition to begin spreading into other areas of business that Green Lights hopes to enter. While construction will remain the primary end user, the product can begin to be used for other purposes such as special events because it will have performed well over a wide array of operating conditions, proving its worth over the traditional units.

As the return on investment point approaches at the third fiscal year, Green Lights will be preparing for a return of 10:1 to each of its investors from May 2018. At this point, it is estimated that the company will have obtained approximately 43% of the market based on growth patterns from the first 3 years and rate of expansion in the region. This will allow for a complete return to the investors, while providing enough funds back to the company to further expand its base.

Phase 4 - R.O.I at 3 years to 5 years and Renegotiation

Considering a 3% growth rate for the first 3 years of business operations, Green Lights forecasts a gross profit of $334,831.76. Considering the 18-month required investment of $777,600, our return on investment for the end of the third fiscal year is calculated to be 43%. Working off this margin, the founders will plan to renegotiate a possible investment deal with the original investors from May of 2018. Within this, the founders hope to gain a long-term plan with the investors either through a possible financial exit by them with a buyout by the founders, or a renewal of investment capital.

At this point, it is also planned that additional workers will be hired for production purposes by Green Lights. Depending on year four and five sales, the company will be able to properly determine how many workers will be required for continuous growth. This will be found by additional financial forecasting following year three and finding the growth rates and units to be sold by Green Lights.

2.5 Financial Analysis

Green Lights determined its sale price to be $18,000 per unit while the cost will be $8,530.56 per unit. Currently, Green Lights is aiming for a 53% ROR per unit which will then be reinvested into the company. The profit margin of 53% is calculated by subtracting the variable costs per unit from the sale price per unit, divided by the sales price per unit.

By selling two units a month for the first 18 months, Green Lights' projected total revenue will be $648,000 during this period. Additionally, cost of goods sold during this period is estimated to be $307,100.16, resulting in a projected 18-month margin of $340,899.84.

Due to the nature of Green Lights being a young startup company, it will allocate 2 months prior to initiation of business operations of its fiscal year strictly to the construction and assembly of the products. These measures will be conducted to ensure a stable grounding is formed in the company's infancy while also promoting future company growth and productivity.

As a result of this business decision, Green Lights' official fiscal year will begin in July 2018. With the alliance of its generous investors, it is forecasted that Green Lights will breakeven in March 2020. According to our financial analysis, the anticipated target breakeven point for Green Lights is to occur 18 months from the initiation of business operations. Assuming variable costs of $8,530.56 per unit, fixed costs of $178,530, and a sale price of $18,000 per unit, the number of units sold to break even is estimated at 19 units for the 18-month period.

As a startup business entity that projects to sell approximately two units per month, Green Lights is valued by its gross revenues which accumulate to $648,000. The founders of Green Lights will be offering a 19% stake of the company to its investors while maintaining 79% ownership of the company in equity. An investment of $777,600 would accelerate Green Lights' production immensely, resulting in a payback period of 1.82, based on cash flows from year one and two, for its generous benefactors and shareholders.

3. Deployment Strategy

The deployment strategy for Green Lights encompasses several aspects of both the product and the business, including: turbine manufacturing, necessary equipment for the company to operate, transportation, employees.

Turbine Manufacturing

The light towers will be mostly prefabricated before entering Green Lights' warehouse in Erie to reduce equipment costs and minimize the pressure on an inexperienced manufacturing team. Product components such as the housing, telescoping towers, rotating base, and turbine blades, will be outsourced through different companies. Once the necessary parts are created and prefabricated, the founders will complete the assembly process in the Erie headquarters warehouse. The turbine's design and prefabrication allow for this assembly stage to be performed with basic power tools that do not require special training such as welding. This also helps to lower startup costs since purchase of expensive assembly equipment is not necessary.

Equipment

As previously mentioned, the parts necessary for producing Green Lights' product will be prefabricated, thus allowing only basic assembly equipment needed for production. Compressed air tooling will be used due to the ability to change tools quickly and provide ample tightening power. These can be purchased at a basic hardware store and will be included under initial costs when the company launches.

Operating space is needed to perform the final assembly and act as a headquarters for the company. A warehouse in Erie, Pennsylvania has proven to be an ideal location and is within a reasonable price range that will provide substantial housing for the company in the upcoming years. This area also serves as the front-office for the company and will be where the sales and management team operate.

Transportation

Green Lights will be handling all transportation of the product to the customer once it has been manufactured. Currently, the founders have been transporting the product to the end-user via rented U-Haul pickup trucks with a single unit in tow. Transporting a single unit to Philadelphia takes approximately 6 hours one way, and for the first six months this was done by the founders. As the business grows after a financial insurgence, transportation will be outsourced to a fleet corporation that will allow for multiple units to be sent to customers at a single time.

Employees

To increase production rates to keep up with market demand, Green Lights will employ one to two hourly full-time workers at $15 per hour. These employees will deal strictly with assembly to assist the founders and allow them to dedicate more time to sales. More employees will be acquired as the company grows and demand rises. These workers, however, will need to provide their own private insurance for any work place accident.

4. Technical Design

4.1 Design Objective

The technical design objective is twofold: to create a design for the market turbine that satisfies the product requirements in the business plan and to design and construct a test turbine that validates the market turbine's functionality. The information presented on the market turbine provides conceptual design-level detail, whereas the test turbine section details the complete design process for an engineering review of the turbine and its subsystem operating properties.

4.2 Methods of Design and Analysis

The market and test turbines' blade shape and structures were designed using SolidWorks[6]. Finite-Element Analysis was also performed in SolidWorks for both turbines to ensure their structural integrity at maximum operating conditions. HOMER Pro[7] as well as Excel modeling were used to analyze and optimize the microgrid design. In-house Excel codes were used to design the test turbine generator as well as the test and market turbine blades. Xturb-PSU[8], a turbine blade analysis tool, was used to confirm the Excel code generator designs and provide data about the blades' performance.

4.2.1 Aerodynamic Design of Blades

This section provides an overview of the design process the team used to design the test turbine blades and market turbine blades. The initial design is generated with an in-house blade element momentum Excel-based code. Blade element momentum theory breaks down a blade into a finite number of radial positions so the forces at each radial position from the root to the tip can be calculated. This code calculates forces at 31 equally spaced radial positions. The design of a blade is defined by three parameters along the radius; airfoil selection, chord length, and twist. For both the market and test turbine's blades, these parameters are determined according to the wind conditions as well as generator torque and speed requirements. A blade can only be optimally designed for one wind speed and one generator RPM. For the test turbine, control of power and rotor speed is achieved through active pitch of the blades. The design tip speed ratio for both systems was determined through an XTurb power curve analysis. The XTurb design analysis will be further described in section 4.2.2. An airfoil is selected through XFOIL[9] analysis and comparison of C_L and C_D vs angle of attack curves in the Reynolds number range of interest. The desired airfoil is then distributed throughout the span of the blade. Air density is also considered in the design process.

The important output parameters to consider are torque and the coefficient of power (C_p). For the generator to spin at a desired RPM, the blades must generate a certain amount of torque that matches the generator torque required at that RPM. The relationship between the generator RPM and torque required is determined through dynamometer testing. Maximizing the C_p of the blades is also important for design purposes. The design process involves iterating a range of angles of attack along the span to output a geometric design of the blade that is comprised of twist distribution (blade flow angle minus angle of attack at each radial station) and chord distribution. The effectiveness of the blade is assessed by checking if the required torque has been met and if the C_p is of sufficient value, ≈ 0.35. The iterative process is continued and refined until a blade of sufficient performance is reached.

4.2.2 Aerodynamic Analysis of Blades

X-Turb-PSU[8] is an in-house blade analysis code that runs an input blade geometry through specific conditions and outputs performance characteristics. X-Turb also uses blade element momentum theory to analyze the blade.

The input file consists of blade geometry, airfoil polars, wind speed conditions, rotor speed, and pitch settings. The blade geometry is defined the same way as in the Excel code discussed in the previous section; chord and twist along the span. Airfoil polars are assigned to specific locations along the blade's span based on predicted Reynold's numbers throughout the span. Tip-speed ratio (TSR) is comprised of two sections in the input file, a section for wind speed and a section for the corresponding rotational speed to the blades. The last section of analysis in the input file is the pitch setting. The code allows for the pitch to be set to any angle of interest, which allows us to sweep through a list of pitch angles and determine the ideal pitch angle at each wind speed.

The output files generated after running the code give us performance values at each condition such as torque, C_p , C_L, C_D, Re's number, total power, and circulation. C_L, C_D, and Re's number are mainly used to adjust the input airfoil polar settings. The main values of interest in terms of performance are C_p and torque. The torque is analyzed at low wind speeds to assess start-up conditions. The goal of the start-up analysis is to minimize the wind speed at which the turbine can begin to spin. The generator team used dynamometer testing to obtain torque vs. RPM data. This data was used to find how much torque is required to start spinning, which allows us to determine the optimal pitch to achieve the start-up torque at the lowest wind speed. C_p is analyzed at higher wind speeds to assess how much power our turbine can theoretically generate. For the test turbine, the goal is to find the pitch angles that maximize the amount of power the turbine can generate at wind speeds that hold the heaviest weights according to the competition scoring guidelines. The design process for the market turbine is in the next section.

4.3 Market Turbine

4.3.1 Overview

The market turbine was designed around the end user, for instance construction workers, so it needs to be affordable, reliable, portable, and user friendly. Affordability is important so our customers will see a faster ROI compared to diesel systems. Reliability is crucial because the turbine needs to function effectively for many years in all weather conditions. Designing a portable system is essential for the intended market because construction sites and areas that need lighting are constantly moving. Having a user-friendly system was also emphasized because the construction workers need to be able to set up and take down the unit quickly. Compared to current lighting systems, our product will be just as reliable and portable while also saving our customers money over the product's lifetime.

The market turbine presents a new method adopted for maximum utility and convenience of setting up lights powered through wind energy. As shown in **Figure 2** in the Executive Summary, the system has two telescoping towers, one for the turbine and one for the light structure. This tower design allows the masts to be shortened while not in use or being transported. The tower height is controlled by hand cranks on the base structure. The market turbine is an upwind turbine design with a tail that will keep it oriented into the wind. If the wind speed exceeds the operational range of the system, a furling mechanism that will turn the turbine out of the wind is the overspeed protection.

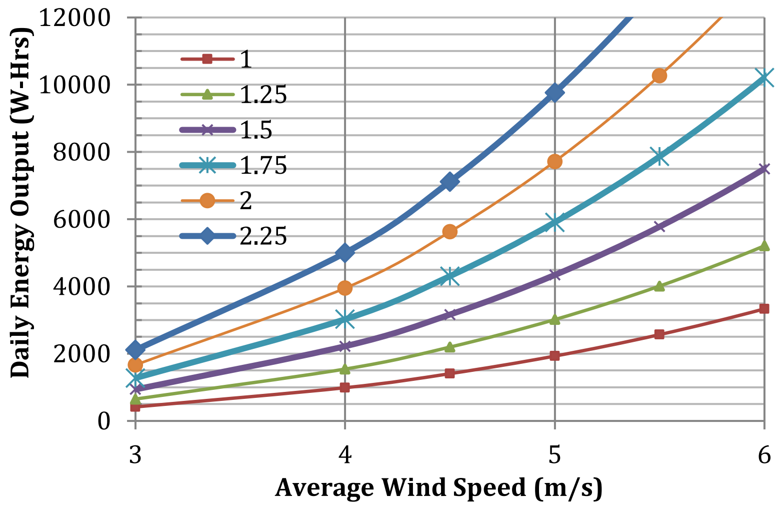

Figure 4: Energy Production vs Wind Speed for Varying Turbine Radii

The turbine's rotor diameter and tower height were determined from the design load requirement of three lights that produce at least 75,000 lumens. This luminosity is obtained by using a 300 W, 40,000 lumen LED light as well as two 150 W, 20,000 lumen LED lights, thus totaling 600 W. This power requirement and an average annual wind speed of 4.5 m/s in the Great Lakes region were the design criteria for the turbine's general sizing. **Figure 4** assumes a Rayleigh distribution of wind speeds with a range of different annual averages as well as different blade sizes to initially scale the market turbine. A C_p value of 35% was assumed for these calculations as a baseline for this initial sizing.

Using the sizing figure shown in **Figure 4,** a daily energy load requirement of 600 W running for 7 hours per day uses 4200 W-hrs. With an average wind speed of 4.5 m/s, a blade size of 1.75 meters and tower height of 6.7 m (22 ft) will harness an adequate amount of power.

The housing unit design was driven by the need for parts of the system to be replaceable by the customer if needed. The unit also had to be big enough to be able to fit the electrical equipment, batteries, blades, guy wires, and other tools inside.

Three guy wires support the turbine tower via expanding anchors in the ground. The light tower holds the three lights and is positioned so that the lights face away from the wind turbine. The lights may be tilted up or down as needed. The lights are arranged in a triangle such that two lights are on top of the third. The two lights on the top are attached to arms that fold down, creating a T-shape with the tower. A hand crank on the side of the housing unit is used to fold these arms. The two towers will be attached and supported on opposite sides of a circular, rotating disk that sits on top of the housing unit. The user can rotate/adjust the circular disk to reposition the lights if needed but needs to detach the guy wires first. After detaching the guy wires, the user would then rotate the disk using a hand crank on the side of the housing unit.

The housing unit will store the necessary electrical equipment, turbine blades, guy wires, and any other necessary tools while the unit is being transported. A PMG 270-4 generator will be used. The user can protect the retracted towers from inclement weather and other possible sources of damage by pulling up a hollow, cylindrical casing, which will usually be stored in the housing unit. The user would then cover the towers with a circular top that will usually be stored in the same compartment as the blades. As shown in **Figure 5**, the housing unit will have supporting "legs" on each side that can be pulled out to provide extra support to the system when it is being used. There is a tow hitch on the front of the housing unit that can be attached to the back of a truck for transport.

Figure 5: Front View of Market Turbine

The housing unit will be constructed of replaceable parts, so that if a specific part breaks or wears down, the user can order a new part and replace it themselves. A rudimentary toolbox will come with the product and will be stored in the housing unit. If a part needs to be replaced the user can easily do it themselves. This way, the entire system does not need to be shipped to the Green Light's warehouse to be fixed. Instead, the customer can save time and money, and the company can save resources.

The blades will be 1.75 m (5.74 ft) long and the nacelle will be 6.7 m (22 ft) tall. The lighting tower will be 4 m (13 ft) tall and each of the arms of the lighting mast will reach 23 cm (9 in) away from the mast and 1.75 m (5.74 ft) feet up when deployed. The unit is designed to fit within the boundaries of a standard road lane, which is 12.1 feet wide. The guy wires will be 6 m (20 ft) long, and the expanding anchors will be 10 cm (4 in) long.

4.3.2 Blade Design and Performance

The market turbine blade was designed using XTurb and Excel codes described in sections 4.2.1 and 4.2.2. The blades were found to output roughly 2700 W of power with a tip speed ratio of approximately 7.5 and a coefficient of power of 0.356 in optimal pitch conditions of 9.5°. These results were obtained at a wind speed of 11 m/s, spinning at 450 RPM. The resulting power curve for this design is shown in **Figure 6**.

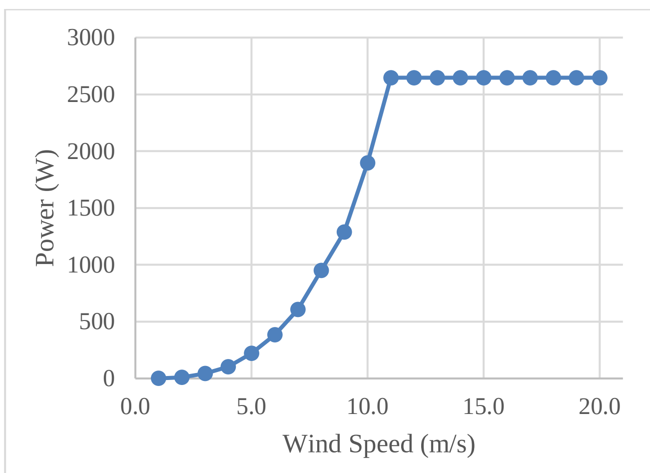

Figure 6: Market Turbine Power vs Wind Speed

The blades were modeled using fiberglass reinforced plastic and tested in static SolidWorks simulations. This was to ensure the blades were structurally sound and could maintain integrity under the prescribed conditions. The resultant velocity was calculated and applied as a distributed load across the blade. At a wind speed of 11 m/s the blades had a calculated factor of safety of 11.9. At low speeds of approximately 2.5 m/s, the turbine blades will begin to spin at 5.5 Nm of torque.

4.3.3 Overspeed Control

The market turbine protects itself against high-wind stress through an automated furling mechanism, which reduces blades' angle of attack. The furling mechanism is passive and controlled by springs so that the hub and turbine blades will yaw the face of the blades so that at a maximum furl, the area will be perpendicular to the wind flow velocity when maximum power is reached. This prevents the turbine from over-spinning and cause the blades to fail due to stress. The hub and tailfin are attached at a furling hinge on the tower so that as the rotor furls, the edge of the tailfin will continue to yaw in the direction of the wind. This ensures the hub can reorient itself when the angular velocity or wind flow velocity are stable, the hydraulic-spring system can yaw the rotor back perpendicular to the wind flow.

4.3.4 Generator Selection

As a departure from the Test Turbine design, a commercial off the shelf generator was sought for the market turbine to reduce the man-hours in hand building axial flux generators that would be necessary. A permanent magnet generator was selected to provide the best match of torque and RPM with the blades designed for this application. By examining the radius and power coefficient curve the ideal design TSR was needed to produce the rated power of the generator and the optimum power coefficient. Using a design radius of 1.75 m (which was decided upon based on the analysis of the load requirement above), and examining the power coefficient curve, it was found that an ideal design TSR at 11 m/s for the market turbine is λ_p = 7.3, and $C_{p,r}$ = 0.45 shown in **Figure 7**. This gave us a target in terms of choosing a generator size and RPM. With limited models on the market, the results will give us an operating range in the right ballpark. The PMG 270-4M is rated for 3500 kW and 80 Nm of Torque at 450 RPM, producing ~180 V, which meets the needs of this design.

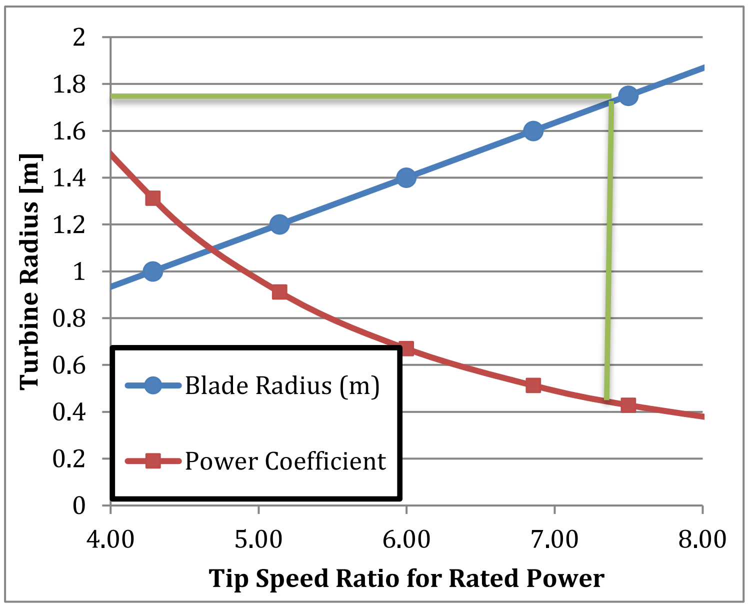

Figure 7: Power Coefficient as a Function of Turbine Radius and Tip Speed Ratio

4.3.5 Storage System Design & Operation Strategy

The lighting system includes a 300 W, 40,000 lumen LED light as well as two 150 W, 20,000 lumen LED lights, requiring 110 V AC power each. Thus 600 W/ 110 V = 5.4545 Amps. If we use a 12 V battery system and an inverter, the Amperage will go up. Converting from 110 V to 12 V, this ratio is 110/12 = 9.16 and thus the Amperage on the DC side is 50 Amps. Using a 20 Hr Rating for a battery, this means the system will require ~50 Amps x 20 Hr = 1,000 Ah.

A 6V 525 Ah flooded lead acid battery was selected for this application. Four batteries would be required in total, two in series to achieve the desired 12 V and two in parallel to achieve the required minimum 1,000 Ah. The total energy which can be stored in this system is 12.6 kWh.

The typical usage cycle was determined to be 5 days of continuous use followed by two days off (for instance weekends) in which the system would be charged by the grid to the full capacity of the batteries. The system was designed to operate for 7 hours each night, with a typical usage time between 10 PM and 5 AM. In **Figure 8**, this usage cycle is shown with 10 min average 80 m & 100 m wind data from the Eastern Wind Integration Data Set[10] for a location near Erie, PA, extrapolated down to the hub-height of the wind turbine of the light-tower the system. It can be seen from the simulated year of data above, the wind powered lighting system in this year would not officially require any backup generation, besides the grid, for the base use case described above. Options are provided, however, for the customer to go with a generator system as a backup, for jobs which cannot afford the risk of no load. Solar panels could also be another option for backup, if a client wished to run entirely on renewable sources, but this option is not included in the cost analysis. Simulations show that the wind and sun complement nicely with a 200 W system addition.

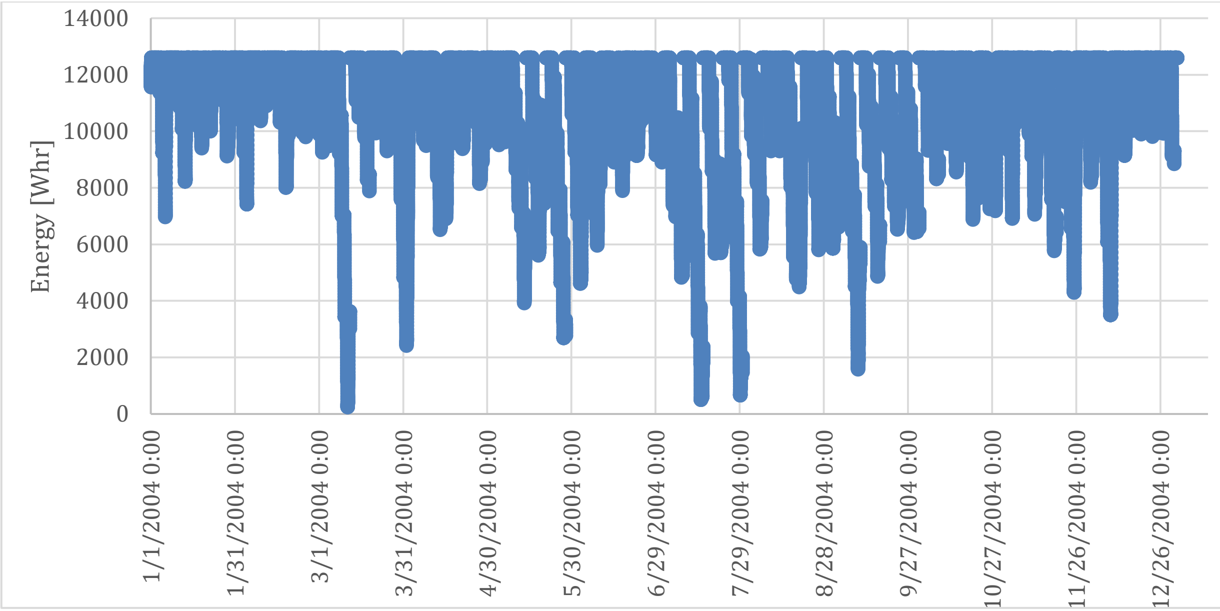

Figure 8: Simulated Energy Production for Usage Cycle of Market Turbine in Erie, PA

4.3.6 Manufacturing

4.3.6.1 Selection of Materials and Costs

The market turbine's materials were selected to ensure the system's structural integrity. The telescoping towers for the lights and turbine are made of 6063-T6 aluminum, as this is the strongest alloy when doing cost-price analysis (with a factor of safety of 3). This aluminum has a strong resistance to corrosion, which is favorable due to various weather conditions in which the product will be deployed. This alloy also allows the turbine to sustain a maximum torque of roughly 1000 N-m. The main rotating disc is also made from of 6063-T6. Steel was not chosen, because this disk must be able to sustain the gravitational force of the shafts whilst being light enough to rotate. The full description of materials for the conceptual market turbine system can be found in Table 1, including estimated costs to manufacture this system.

It is important to properly estimate the market turbine cost so the business team's investment plan and financial analysis, in section 2.5, will have the greatest chance of success. The towers, lights, batteries, casings, blades, generator, guywires, and disk, consisting of a pin system and aluminum 6063 alloy, results in a total cost of $8,530.56.

Table 1: Market Turbine Bill of Materials

Part Number	Part Name	Unit of measure	Quantity	Unit Cost	Total Part Cost	Company
Turbine Tower With Disk						
1	Blades	each	3	$478.00	$1,434.00	Xcentric Mold & Engineering
2	Aluminum 6063 Disk	each	1	$315.00	$315.00	Sharpe Products
3	PMG 270-4 Permanant Magnet Alternator	each	1	$316.00	$316.00	PM Generators
4	T344316 - 6063-T6 Aluminum Square Tube	each	1	$190.33	$190.33	Metals Depot
5	T344316 - 6063-T6 Aluminum Square Tube	each	1	$178.60	$178.60	Metals Depot
6	T344314 - 6063-T52 Aluminum Square Tube	each	1	$127.30	$127.30	Metals Depot
7	T344314 - 6063-T52 Aluminum Square Tube	each	1	$110.33	$110.33	Metals Depot
8	T34414-6063 - T52 Aluminum Square Tube	each	1	$50.14	$50.14	Metals Depot
9	WW624B Guy Wire (24')	each	3	$84.95	$254.85	Survival Unlimited
10	Expanding Anchor For 5/8" or 3/4" Rod J8135	each	3	$14.70	$44.10	A-Aerial Service Company
11	Thimble Open 1/2 Guy Strand J1058	each	3	$1.44	$4.32	A-Aerial Service Company
12	Steel Cotter Pin - 92390A929	each	4	$5.45	$21.80	McMaster Carr
13	Nacelle & Hub	each	1	$100.00	$100.00	Xcentric Mold & Engineering
Light Tower						
	40,000 Lumen 300 Watts Lights	each	1	$369.99	$369.99	LED light experts
	20,000 Lumen 150 Watt Lights	each	2	$219.99	$439.98	LED light experts
	T34414-6063-T52 Aluminum Square Tube	each	1	$132.31	$132.31	Metals Depot
	T331218-6063-T52 Aluminum Square Tube	each	1	$73	$73	Metals Depot
	SQ33-6061-T6511 Aluminum Square	each	1	$308	$308	Metals Depot
	SQ31-6061-T6511 Aluminum Square	each	2	$9	$18	Metals Depot
	SQ31-6061-T6511 Aluminum Square	each	2	$50	$100	Metals Depot
	2111530 Mount Bracket L-Shaped Versatile Slot	each	3	$1	$3	Jameco Electronics
	Steel Cotter Pin - 92390A929	each	2	$5	$11	McMaster Carr
	Steel Cotter Pin - 98306A735	each	3	$0.47	$1.41	McMaster Carr
	6 volt Batteries	each	4	$301	$1,204	Crown Batteries
Box						
	Box Housing - Outsourced Prefabrication	each	1	$2,000.00	$2,000.00	Construction Cam
	22 in. Pro Tool Box	each	1	$39.00	$39.00	Home Depot
	VENTUS V2 24 inch diameter wheels	each	4	$79.92	$319.68	Hancook
	Champion Power Equipment 1200 Portable Generator	each	1	$198.87	$198.87	
Electrical						
	Misc wires		1	**$15.00**	$15.00	
	Charge controller (PWM)		1	**45.99**	$45.99	
	Inverter			**69.99**	$69.99	
	600-Lb. Load Capacity Hand crank	each	2	17.99	35.98	Northern Tool
				Total	$8,530.56	

4.3.6.3 Structural analysis

The market turbine's finite-element analysis was done to ensure the functional safety of the product. This was done using the wind turbine's tower (since it will exert the greatest moment on the base plate) and without guy wires attached. It was found that the turbine's tower was able to withstand stresses of up to 1000 N-m without yielding in any direction. Such analysis was done by evaluating the effect of high forces, through wind, on the highest point of the tower, as to create the greatest moment on the structure. Additionally, when the use of guywires is implemented, the turbine can sustain even higher forces at its greatest point of elevation. These standards have been set by IEC so that the Green Lights turbine is able to be applied in a safe setting. Furthermore, gust models and load designs from said document (IEC 61400-1) were used to set a standard of performance for the entire system. Wind conditions assessed included: extreme wind, turbulence, variations of wind distribution, wind shear, and various dynamic events. These conditions, when applied to the Green Lights product, are withstood by the 22 ft tower when fully deployed.

4.4 Test Turbine

4.4.1 Design Objective

The objective of the test turbine is to validate the market turbine's operationality as a product but also to perform well as a part of the Department of Energy Collegiate Wind Competition wind tunnel testing challenges. Thus, an objective for the test turbine design was to further improve the cut-in wind speed while maintaining power production compared to Penn State teams in years past.

The table below highlights some of the differences which can be found between the market turbine and the test turbine. The reasoning behind and consequences of the differences presented in this table will be explained further in this test turbine section.

Table 2: Market and Test Turbine Design Comparisons

	Market Turbine	**Test Turbine**
Blades	Fiberglass Reinforced Plastic	3D printed SLS plastic
Safety	Furling mechanism	Pitch blades out of wind
Cut-In	No pitching	Pitch blades steeply into wind
Generator	Permanent magnet	3-Stage axial flux
Electrical System	PWM Charge Controller into batteries	Turbine control and load circuits
Structure	Integrated into light tower system	Single turbine tower

4.4.2 Test Turbine Blade Design and Performance

The blades of the test turbine were designed to maximize points in the competition. The wind speeds of 6 and 7 m/s have the greatest weight in the power curve task at a factor of 1.2. This led the team to design a blade with a slightly larger chord distribution than that of the blade designed by Penn State in previous years. The tip chord of the 2017 design was 1.25 inches. For the inner 60% of the new blade, the chord was unchanged. This chord distribution was determined using the in-house Excel design code previously described. The outer 40% of the span was increased linearly starting from the tip. After analyzing various cases from a tip chord of 1.28 inches to 1.5 inches, 1.33 inches was determined to be the optimal tip chord length. This design also has the added benefit of improving startup performance by

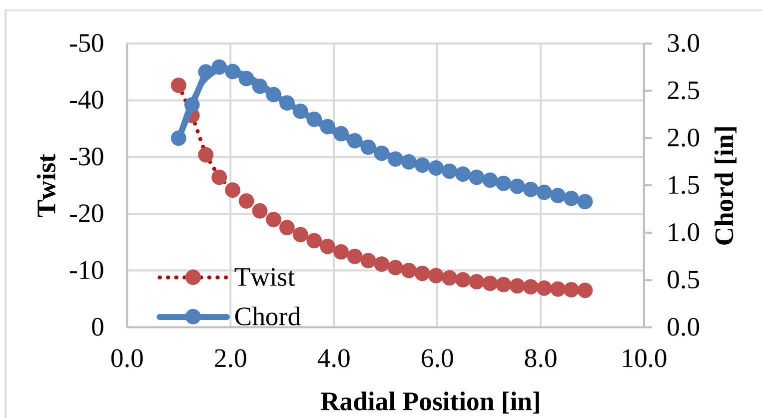

Figure 9: Chord and Twist Distribution of Test Turbine

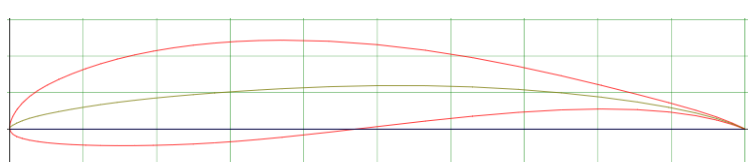

Figure 10: FX 63-137 Airfoil, 13.7% smoothed

increasing the torque generated by the blades at very low wind speed, thus decreasing cut-in wind speed. The chord and twist distribution for our blades are shown in **Figure 9**.

The airfoil used for our blades is the FX 63-137 13.7% smoothed shown in **Figure 10**. This was chosen because it was originally designed to be a low Reynolds number, high lift airfoil for human powered aircraft. At low Reynolds numbers airfoil camber is crucial in creating lift. At higher speeds this would increase the risk of stall, however for our usage, we will not likely face this problem.

The blade design of the test turbine differed from the market turbine primarily due to scale and competition scoring. Because the test turbine blades are significantly smaller, torque and cut in speed become an extremely important factor. The test turbine had to have enough torque to start up the generator, and cut in at a wind speed of 2.5 m/s for competition scoring, so efficiency at low speeds was not as important. For the larger blades of the market turbine, start-up torque was not a primary concern with performance and efficient C_p values being a large design factor. Due to the differences in design concerns, the test and market blades were designed at TSRs of 3, and 5 respectively. Due to differences in design and performance concerns, the test and market blades were designed at TSRs of 3, and 5 respectively.

4.4.3 Blade analysis

4.4.3.1 Aerodynamic analysis

The test turbine was analyzed at various speeds and conditions to maximize its overall performance. Low speed efficiency is crucial to the performance of the turbine. Low speed analysis was performed to see where our blade could cut in and begin to produce power. The optimal blade for a low tip speed ratio, is not the best blade for a high tip speed ratio, and vice versa, so testing the turbine under a multitude of wind speeds is extremely important. After running X-Turb analysis at TSR 1, and a parked blade case, the results were compared. The pitch required to achieve maximum torque output, decreases as TSR increases. Meaning with each increase in wind speed, a decrease in pitch is needed to operate efficiently and maximize torque. The turbine outputs a maximum torque at angles of 36°, and 66°, for TSR 1, and parked respectively. This is demonstrated by **Figure 11.** When the blade is parked, 66° of pitch results in the highest torque. However, in wind speed conditions like this, the turbine does not have enough power to actively pitch the blades. Therefore, once the blades start spinning, they need to be able to continue to efficiently spin without utilizing the pitching mechanism. Therefore, the pitch at the point of intersection of TSR 1 and parked blade would be the ideal pitch angle to begin at. **Figure 11** shows the point of intersection to be at about 41° at a torque of 0.009 Nm. The generator's low torque requirement of 0.006 Nm allows us to get our parked blade to begin moving at a low wind speed and continue spinning efficiently.

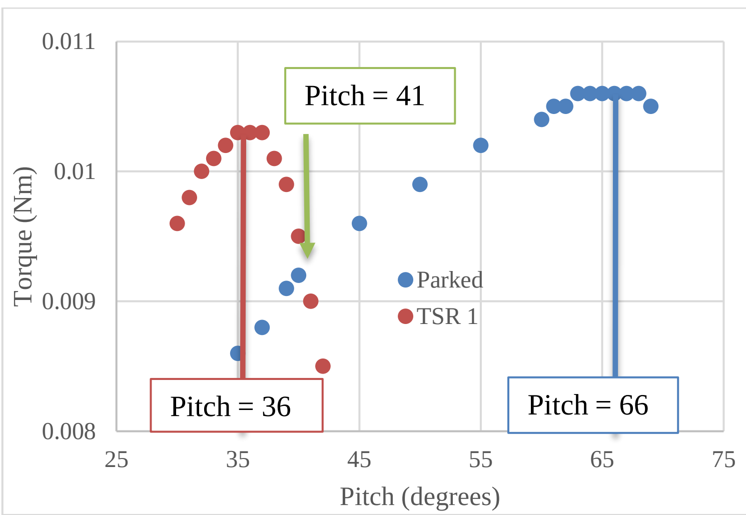

Figure 11: Test Turbine Start-up Torque vs Pitch Analysis

Through wind tunnel testing of our test turbine, the optimum startup pitch angle was determined to be 21°. XTurb does not consider the variable resistance in the turbine. It is possible that this has affected the optimum startup pitch of the blades.

To assist the electrical team in their design process, we utilized XTurb to determine the power output in the entire range of wind speeds. **Figure 12** shows the results of this analysis for both the test turbine as well as the market scale turbine. **Figure 13** shows the chord distributions for both the test turbine and the market turbines as well. They are very similar, except the test turbine has a wider chord near the tip to help achieve extremely low start up speeds as per the competition. The twist distributions for both sets of blades were identical, as shown previously in **Figure 9**.

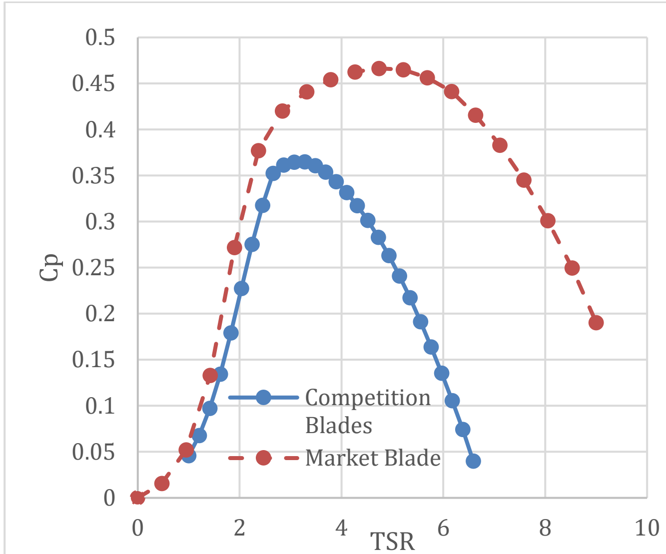

Figure 12: Cp vs TSR for Market Turbine & Test Turbine

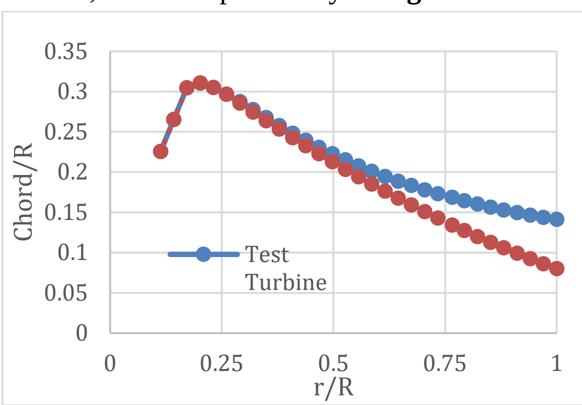

Figure 13: Market & Test Turbine Chord Distributions

Through a Rayleigh distribution of wind speeds and the test turbine's power curve with a maximum power of 54.08 W and the Market Turbine's power curve with a max power of 2700 W, we were able to calculate the annual energy which would be produced for each different annual average wind speed condition. We calculated the Rayleigh distribution by using the various wind speeds, a scale factor of 2, and a lambda value derived from the average wind speed. In order to get the weighted energy we then multiplied the Rayleigh distribution values by the power curve wattage times the number of hours in the year. The annual energy for each average wind speed is then the sum of all the weighted energies. **Figure 14** displays the average annual energy production curve produced for each given average wind speed for both devices.

4.4.3.2 Structural analysis

Carbon fiber blades were considered as a replacement for the 3D-printed ones. The reason the team considered this was to see if carbon fiber blades could potentially perform better than the 3D-printed ones. The biggest issue facing the carbon fiber application was that there is no structurally easy way to connect the carbon fiber blades to the wind turbine rotor. The root of the 3D-printed blades has been designed in SolidWorks specifically to fit into the rotor. The mold that we have for the carbon fiber blade does not have

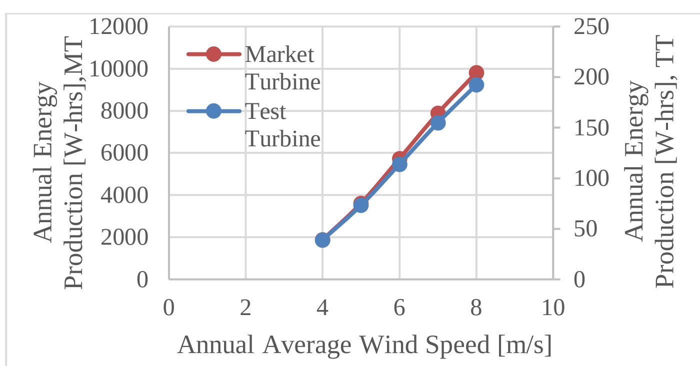

Figure 14: Test Turbine Annual Energy Production

this special geometry or hole to fasten it to the hub. The team eventually determined that the design of the 3D printed blades was paramount to carbon fiber modifications. Carbon fiber will be reconsidered in a future design.

The material chosen to 3D print the blades was Nylon 12 GF (glass filled). The glass fibers add strength and rigidity to the blades. It is crucial for the blades to be stiff enough to resist bending in the wind yet not so stiff that they become fragile. We determined that this material was most appropriate for our application.

An important part of the structural analysis of the blade was doing Finite Element Analysis (FEA). By using FEA on the blade design in SolidWorks, we examined how the force of the wind on the blades would affect its structural integrity, in terms of the stress and deflection induced. To start this process, first a CAD model of the blade was uploaded in SolidWorks. Then using the Simulation feature, a point force was applied at the center of mass of the blade. The formula that was used to calculate the point forces is $F = \frac{1}{2}\rho v^2 S$. The value for air density, ρ, was determined to be 1.269 kg/m^3 for Chicago. The value for surface area, S, was found using the SolidWorks and came out to be 0.0193 m^2. The velocity varied from 6 m/s to 20 m/s, there was analysis at five wind speeds in that range; 6 m/s, 7 m/s, 10 m/s, 15 m/s, and 20 m/s. After some calculation, the magnitudes of the forces that were applied to the blade were: 0.442 (N), 0.601 (N), 1.227 (N), and 2.761 (N), and 4.908 (N).

The material specified for the analysis was Nylon 12 GF, which is a glass filled nylon polymer. A fixture was modeled at the base of the test turbine blade, made to mimic the actual fixture. After inputting the magnitude of the force and the location to which it will be applied, the next step was to run the simulation. FEA analyzes the of stress, the displacement, and the strain on the blade. The magnitude of stress on the blade was the focus of the analysis. The first force to be tested was 0.442 (N) which corresponds to an incoming wind speed of 6 m/s.

Figure 15 shows the stress on the blade due to the 0.442 (N) force. The majority of the blade was not affected by the force, save for the stress near the fixed end of the blade. The cases for greater magnitudes of force had similar results with the highest magnitude force, 4.908 (N), having a stress of 1.398e+002 N/m^2 around the fixed end of the blade. Because of the small magnitudes of stresses that were experienced by the blade, it was concluded that the structure of the blade would withstand the stresses imparted by the incoming wind with little to no impact on the aerodynamic performance.

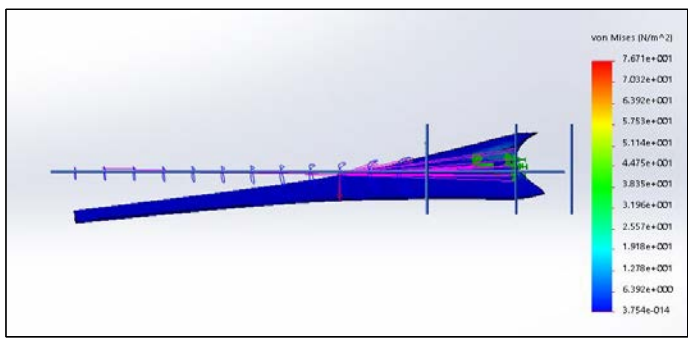

Figure15: FEA Analysis of Test Turbine Blade

To further analyze the breaking point and determine the factor of safety (FOS) of the blades, there was physical testing done in the lab to see how the blade would withstand a force of about 5.00 (N) at the center of mass. For the testing, the blade was clamped at the root to simulate the actual fixture to be used. As shown in **Figure 16**, weights were hung from a string tied around the center of mass of the blade. The figure shows 4.00 lbf, or the equivalent of 17.293 (N), hung from the blade. At this point, it was concluded that the blade would withstand the forces imparted by the wind speeds discussed earlier. The blade endured minimal displacement at the tip due to the force, therefore more weight was added to find the breaking point of the blade. As more and more weight was added, there were high stresses at the root of the blade near the clamp. Eventually the blade yielded when a force of 307 (N) was applied. It resulted in the fracture shown in **Figure 16**.

 

Figure 16: Blade Strength Testing to Failure

4.4.4 Tailfin Design for Yaw Control

The vertical stabilizer is an integral part of the turbine design, as the wind turbine must face into the wind at all times. To achieve this condition a symmetric airfoil was utilized, the reason being that a symmetric airfoil does not create lift at zero angle of attack. The airfoil is also more effective at producing lift than a flat plate, which was used in previous designs.

When the base of the turbine is rotated by the turntable, the nacelle will begin to turn out of the direction of the wind, decreasing power production. As the nacelle rotates, the tailfin will be at a positive angle of attack, creating a lift force in the direction opposite of rotation. Thus, stabilizing the turbine into the proper orientation. This will properly orient the rotating nacelle into the wind with a vertically fixed tailfin, an incredibly useful property when trying to keep a wind turbine facing into the wind.

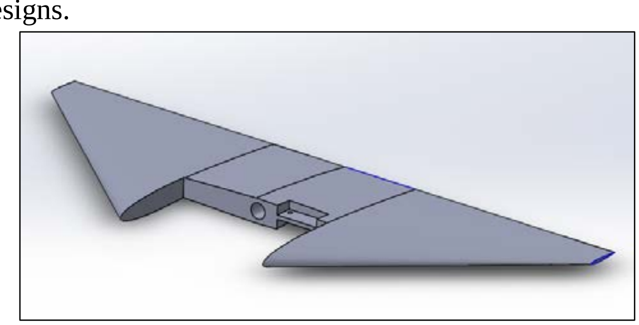

Figure 17: Tailfin Design

The vertical stabilizer was designed to fit within the contest prescribed size envelope and such that a sufficient moment would be created for yaw stabilization. The design was created in SolidWorks utilizing an NACA-0009 symmetric airfoil and can be seen in **Figure 17**. The NACA-0009 was chosen not only for its symmetrical properties but also for its smooth coefficient of lift and drag slopes, signifying the airfoil will not tend to overcompensate for small deflections.

The vertical stabilizer was also designed to utilize the maximum amount of area possible, spanning forty-five centimeters from top to bottom, and nine centimeters from the back of the generator housing. Since nine centimeters is not a particularly large chord for an airfoil, the vertical stabilizer was designed to hang over the generator housing by about eight centimeters, giving the airfoil an effective chord of about seventeen centimeters total.

The vertical stabilizer is comprised of a single piece of 1/8” Aluminum plate which acts as a backbone and an attachment point for the stabilizer, and two 3D printed sections that form the NACA-0009 airfoil around the aluminum. The aluminum plate was considered because it would supply a strong and stable attachment point that wouldn’t be comparable with a simple 3D printed mount. The 3D printed airfoil was used because it was a lighter alternative to a completely aluminum airfoil.

4.4.5 Rotor Hub Design

The rotor was taken off a RC helicopter rotor and implemented into our hub, as seen in **Figure 18**. The main benefit of the rotor was its ability to collectively pitch the blades. The rotor consists of three forks which grip the root of the blade. An eighth inch bolt is also inserted into the fork through the blade root to keep it fixed while operational. Initial optimum pitch was set using the analysis done with XTurb-PSU and then further refined with wind tunnel testing. The pitch was adjusted throughout testing in order to obtain maximum power at varying wind speeds.

Figure18: Rotor Hub

Pitching is also used to maintain a constant power once the rated power has been reached and the pitching mechanism allows for the turbine to brake when required. Braking is done by pitching the blades to such an angle that the lift generated on the blade causes the blade to want to spin backwards. There is a one-way bearing in the shaft that prevents the blades from spinning backwards and effectively stops the turbine.

The optimum pitch values are implemented into the Arduino control code which then relays the signal to a servo motor behind the rotor. The servo arm is connected to the end of rotor. When the servo arm pitches as determined by the Arduino, the rotor also pitches and forces all three blades simultaneously to the optimum or desired pitch angle.

4.4.6 Generator & Structure

4.4.6.1 Generator Design

The generator was designed first to ensure an adequate amount of power could be produced. Then the structure and housing were designed around the generator to ensure it fit within the housing and the structure had an adequate factor of safety to support it. The 3-stage axial flux generator design used in past years' turbines has performed well and worked reliably in testing and competition. This year, the goal was to reduce the cut-in wind speed without sacrificing power production while decreasing the voltage and increasing current, to delay reaching the 48V limit.

In order to accomplish the lower cut-in, the coil to magnet ratio was reduced from 9:12 to 6:8 so it would require less torque to spin. We then used an Excel code to determine how much power could be produced at an RPM. The code requires the input of number and strength of magnets, the number and dimensions of the coils, as well as the spacing between the coils and magnets. This code outputs the voltage and current produced at different angular velocities.

We decided to use the same magnets used in previous designs because they performed well and if we used fewer of them per rotor, we knew the generator would require less torque to spin. These are disc magnets that are 3/16" thick with a ½" diameter made from Neodymium-52.

The team read a research paper[11] that stated if the inner diameter of the coils had the same dimensions as the magnets then the most magnetic flux passed through the coils, which should theoretically produce the most power. The magnet dimensions were determined first so the coil inner diameter was set at 0.5", which left determining the coil thickness and outer diameter, and wire gage. Using the excel code described above, the team determined that the optimal coil thickness and outer diameter to produce the maximum amount of power was 0.3" and 1.2" respectively. The team used the maximum current calculated in the excel code to determine the smallest possible wire to use, which was 26 gage. The wire gage and coil dimensions were used to determine that each coil requires 300 turns.

4.4.6.2 Generator Testing

To confirm the generator performed as predicted in section 3.4.5.1, the team used a MagtrolModel 6400 dynamometer, shown in **Figure 19**, to calculate the power input into the generator and then the measured power produced by the generator. The team used the values generated in this testing to determine whether the generator's performance was acceptable or if changes to the design were needed. This data was also used to match the generator's RPM and torque required with the angular velocity and torque produced by the blades. A couple of stator designs were tested with the same rotor design to determine what design performed best in terms of power produced and compatibility with the electrical system. These can be seen in **Figure 20**.

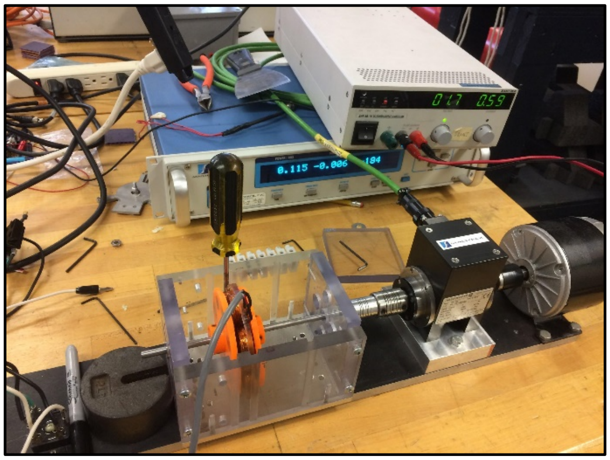

Figure 19, Dynamometer Test Stand

Figure 20: Two Generations of Stators

The first stator design, as described in section 3.4.7.1, had an inner diameter of 0.5", thickness of .3", and 300 turns with 26 gage wire. This was the new stator design that theoretically could produce more power than previous year's generators. The second stator design had an inner diameter of 0.25" with the same thickness, number of turns, and wire gage as the new design. This second design was similar to the designs used by previous teams and was tested to validate the theory that the coil inner diameter and magnet diameter should be equal to maximize power production. The load for each stator was equal to the resistance between two of the output plugs, 11 Ω and 8 Ω for the large and small inner diameters, respectively. All other stator and testing variables were held constant so only the coil inner diameter would affect the results.

Data was taken in intervals of 200 RPM between 0 and 2400 RPM. The angular velocity and torque were measured on the dynamometer and were used to calculate the power input to the shaft. The voltage and current produced were measured on the variable load and were used to calculate the power produced by the generator. The results are shown in **Figures 21-24.**

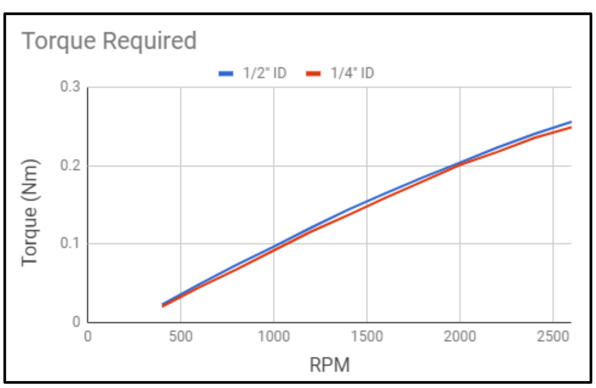

Figure 21: Torque vs RPM

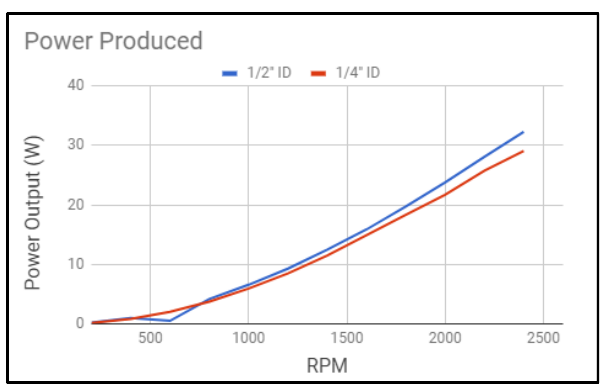

Figure 22: Power vs RPM

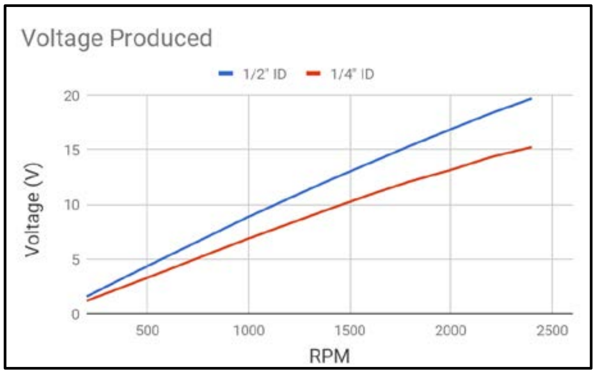

Figure 23: Voltage vs RPM

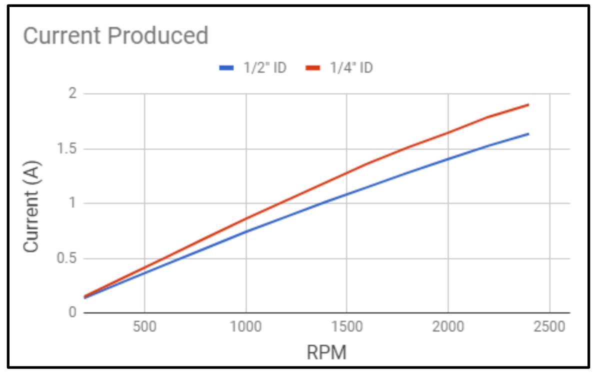

Figure 24: Current vs RPM

The testing yielded results that were used when determining the stator design with 0.5” inner diameter was the best choice based upon power and current production. As seen in figure xx, the large inner diameter stator produced more power compared to the little inner diameter stator. Although it only produced a couple more watts at the higher RPM, this difference will be increased by a factor of three when three stages are used in the final generator, making it significant. The large inner diameter stator also produced more voltage and less current compared to the small inner diameter stator, as seen in figure xx. The electrical team was consulted to determine whether more current or voltage was preferable for the electrical system. Due to the high losses associated with higher current systems, the electrical team’s preference was the large inner diameter stator. This design produced the most power of the two tested but also produced more voltage, which means the 48V limit would most likely be reached at higher wind speeds.

4.4.6.3 Structure Design

The generator structure and housing serve to support the generator shaft so it can spin freely, secure the stators so they cannot move and touch the rotors, as well as shield the generator from the elements. These components were designed in SolidWorks and after the generator itself was designed to ensure the generator would fit properly and can support the necessary loads.

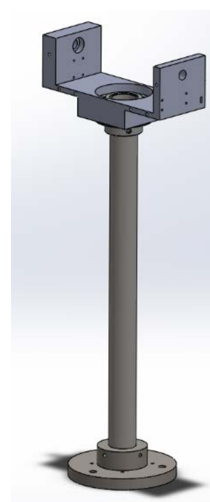

Figure 25: Test Turbine Structure and Housing

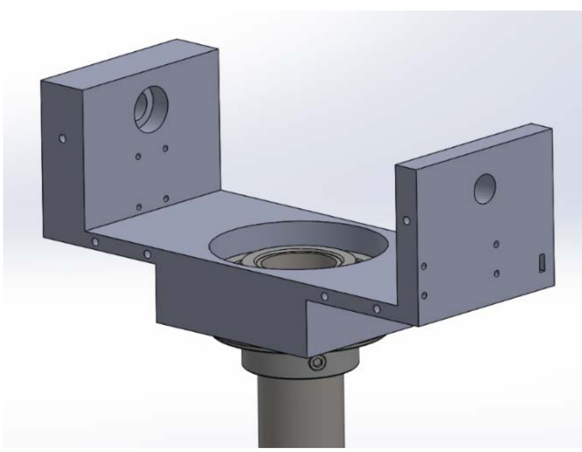

Figure 26: Test Turbine Housing

The generator structure is comprised of three components, the generator platform and two uprights as shown in **Figure 26**. The platform serves to connect the generator structure to the tower via the yaw bearing as well as provide structure to connect the uprights. The platform has to be long enough for the generator to fit between the uprights. The uprights on either end of the platform serve to contain the shaft bearings and support the tailfin and pitch servo. The uprights have to be tall enough so the rotors do not hit the platform when rotating. This structure also supports the housing via screws in the sides of the platform and uprights. The housing is comprised of two parts, the top and bottom. The bottom portion of the housing connects to the front upright and platform. There are three sets of eyelets on the sides of the housing that hold the stators in place so they do not move and rub against the rotors. The top of the housing connects to the back upright and the bottom housing. This section of the housing only serves to enclose the generator from the elements and has no structural purpose.

The yaw system of the turbine consists of a bearing and the tail fin connected to the back of the nacelle. The bearing connects the tower to the nacelle, allowing it to spin when the wind direction changes. The tail fin and bearing ensure the turbine is pointed directly into the wind by creating a correcting torque that pushes the tail back to the correct orientation if it deviates. This yaw system is critical to the turbine's performance because the blades cap the most energy when they are perpendicular to the flow.

4.6.4 Structural Analysis

SolidWorks finite element analysis (FEA) was used to evaluate the test turbine's structural integrity with the intent to validate the design and provide information about the operational limits. The structural components include the generator structure, the tower, and the baseplate. The analysis was run separately on each of the components to ensure their individual integrity. If each component is deemed acceptable separate from the other components, it can be assumed when assembled, the components will perform similarly. Conservative loads were used in all simulations to ensure the operational limits were higher than actually predicted.

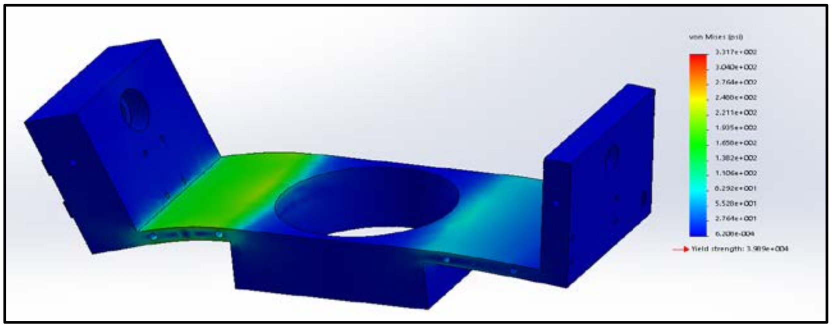

Figure 27: FEA Analysis of Test Turbine Housing

The forces used when evaluating the generator structure were found by calculating the force pushing against the blades at a wind speed of 20 m/s with a flat plate assumption and weighing the blade and shaft system. The design absorbs the force pushing against the turbine in the back upright. As seen in **Figure 27**, the part is most stressed in the housing connection holes closer to the back upright. The lowest factor of safety given this part is constructed from 6061-T6 aluminum is 120. This means this part can withstand much higher forces than are generated at wind speeds of 20 m/s.

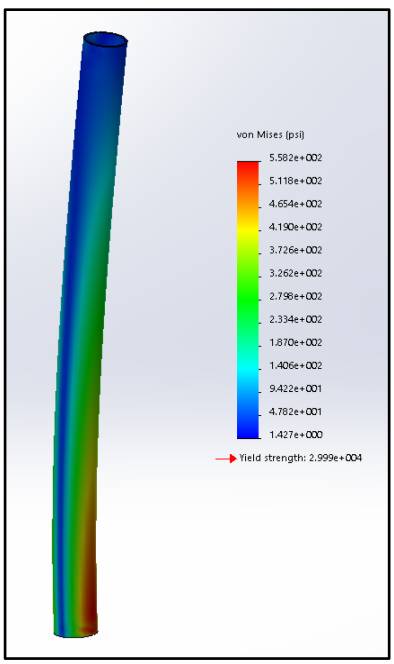

Figure 28: FEA Analysis of Test Turbine Tower

The tower, as shown in **Figure 28**, must withstand the forces generated by the wind pushing against the turbine and the weight of the nacelle. The baseplate anchors the bottom of the tower to the tunnel, causing the most stress to be generated in the bottom of the tower on the side opposite the incoming wind. The tower is made from 304 stainless steel, giving it a factor of safety of 53. This means the tower will be able to withstand significantly higher forces than the generated by 20 m/s wind but will fail before the generator structure.

The baseplate, shown in **Figure 29**, must withstand the torque generated by the tower and anchor the turbine to the tunnel via three screws. The baseplate was designed to the CWC's requirements with additional support material around the tower hold to better support the torque generated by the tower. The greatest stresses are generated in the tower support material on the side opposite of the wind direction. Given the material is 4041 steel, the factor of safety is 392,

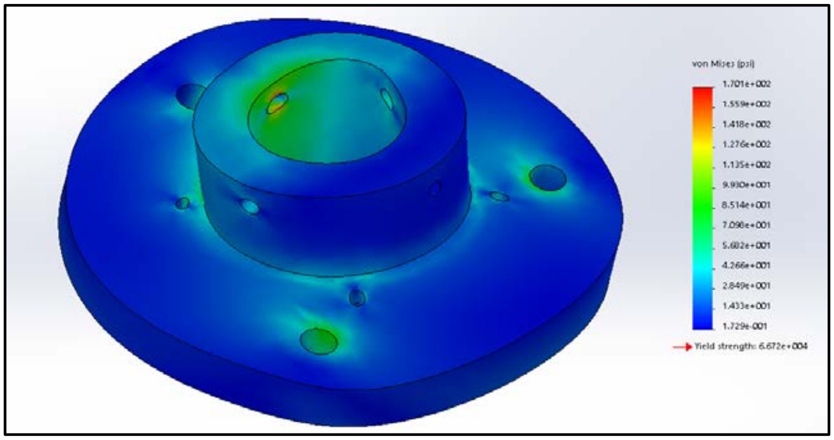

Figure 29: FEA Analysis of Test Turbine Base Plate

higher than the generator structure and tower. This means the baseplate will most likely not be the first component to fail.

Since the turbine structure's lowest factor of safety is 53 at a wind speed of 20 m/s, the structure will most likely not be the first component to fail. The blades or pitching mechanism will be more likely to fail at these higher wind speeds. This is assuming the system is operating normally. If the system becomes unbalanced, causing vibrations, the structure may then experience fatigue and could fail at lower operating conditions than predicted above.

4.4.6.4 Construction

Standard machining practices were used to construct the turbine's structure, including the baseplate, tower, generator platform, and uprights and tail fin. 3D printing was used to construct the generator housing and generator rotors. The stators were constructed by 3D printing a positive mold of the stator, which was used to create a rubber negative mold. This rubber negative mold was then used to cast the final stator with the wired coils, as seen in figure xx.

Figure 30: Construction Materials for Generator Stators

4.4.7 Control and Load Design

4.4.7.1 Load Design

The load for the test turbine is a single passive 50 Ω wire wound carbon resistor. The 50 Ω resistance was determined by using the mechanical power curve of the turbine. The power is directly proportional to the cubic of the rotor speed. Since 11 m/s is the rated wind speed in the competition, the rated power is determined to be about 50 W. The rated rotor speed is about 1650 RPM according to the design TSR of 3.5. The optimal resistance would be $RL = \frac{V_{max}^2}{P}$ where V_{max} is the competition's maximum allowable voltage (48V).

4.4.7.2 Control Circuit

The test turbine is controlled by an Arduino "micro" processor. The Arduino controls pitching of the blades which allows us to find the maximum power output at a given wind speed. The Arduino is also responsible for controlling the rated speed and power for wind speeds above 11 m/s while allowing the system to meet the competitions braking requirements. The first part of the control circuit consists of a Schottky diode bridge rectifier, which converts the AC phases of the generator into a common DC power signal. The DC is then processed through the control circuit which goes to the load via the point of common coupling (PCC). This system is shown in **Figure 31**.

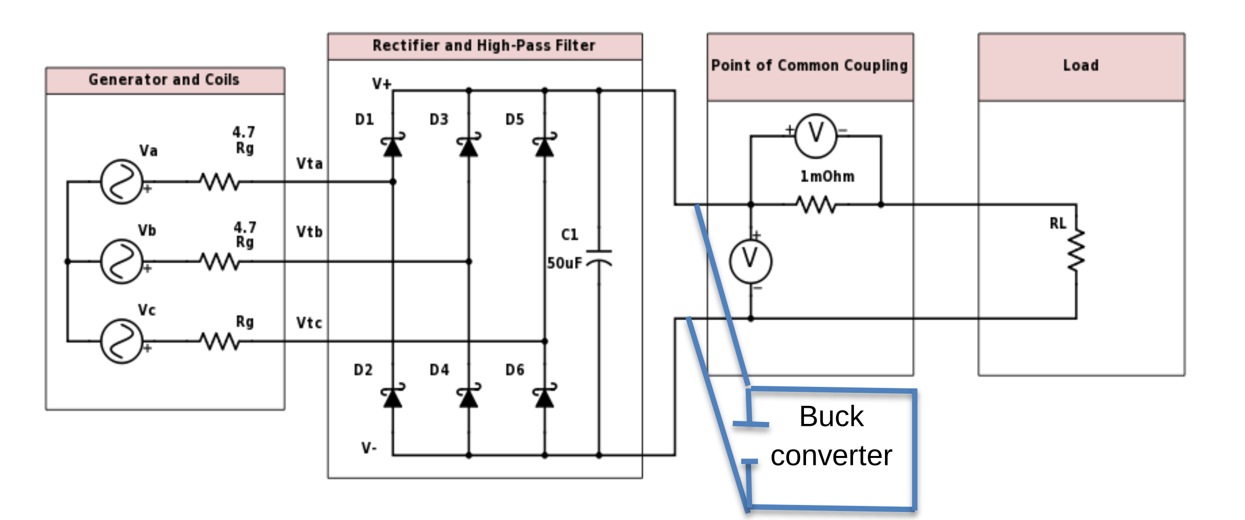

Figure 31: Control Circuit and Load Diagram

The Arduino controls a servo mounted at the rotor. The servo allows for active pitching of the blades to either optimize or control the power generated by the turbine. The servo allows for the blades to be pre-set to a low pitch angle (angle from the plane of rotation to the average chord is large). Once the blades start to rotate, a voltage is generated and sent across the load through the PCC. After 8V has been generated, the Arduino and servo have enough power to be used. The Arduino then pitches to the optimal pitch angle at the inferred wind speed resulting in a large increase in voltage and current produced. As the wind speed changes, the blades are incrementally pitched to obtain maximum power up until 11 m/s. Above 11 m/s, the power and rotor speed are kept constant by pitching back into the wind.

In addition to pitch control, a buck converter is used to maintain or further maximize power, depending on the given task. Furthermore, in cases that the turbine is producing more than the competition's voltage limit of 48V, the buck converter would step down the voltage to a desirable value. This is especially useful in the durability task, where 5V needs to be maintained across the competition provided variable load. The drop in voltage is directly related to the duty cycle of the buck converter’s switch. The buck converter is composed of an inductor, diode, MOSFET, gate driver, capacitor and the 50 Ω resistor that lies inside of the load box. Figure ## below shows the buck converter that lies before the PCC. To find the optimal values of each of the components of the converter, a simulation of the system was run with various initial voltage and duty ratio conditions. This component is mainly used for the durability test to maintain the required constant 5 V.

Incorporation of Storage Unit

In the durability section of the test, the Maxwell Technologies’ 16-V small cell ultracapacitor is connected across the input voltage of the buck converter as seen in **Figure 32.** The rectifier converts the AC voltage coming out of the generator to DC voltage, accessible by the other electrical components. Due to the 16V limit of the ultracapacitor, active pitching of the blades will be utilized to limit the voltage. The charge of the capacitor is a function of a change in voltage. Therefore a change in pitch can charge and discharge the capacitor as needed. In cases of low resistance and low wind speeds, the ultracapacitor discharges to maintain the 5V required for the Arduino. The Arduino then will set the duty cycle in a way such that the voltage across the load is maintained at 5V. In cases of high resistance and high wind speeds, the ultracapacitor will be charged to prevent the rotor from spinning out of control.

4.4.7.3 Control Logic

The system utilizes the Arduino microprocessor to send signals to a servo that control blade pitch and the MOSFET of the buck converter. Data collected on the optimal startup pitch and optimal pitch angles given a specific wind speed are included in the code uploaded to the Arduino. Before the turbine cuts-in, the blades are set to the optimal startup pitch angle to produce power as quickly as possible. The servo requires 8 V to function, which is the minimum voltage required for the system to be fully operational.

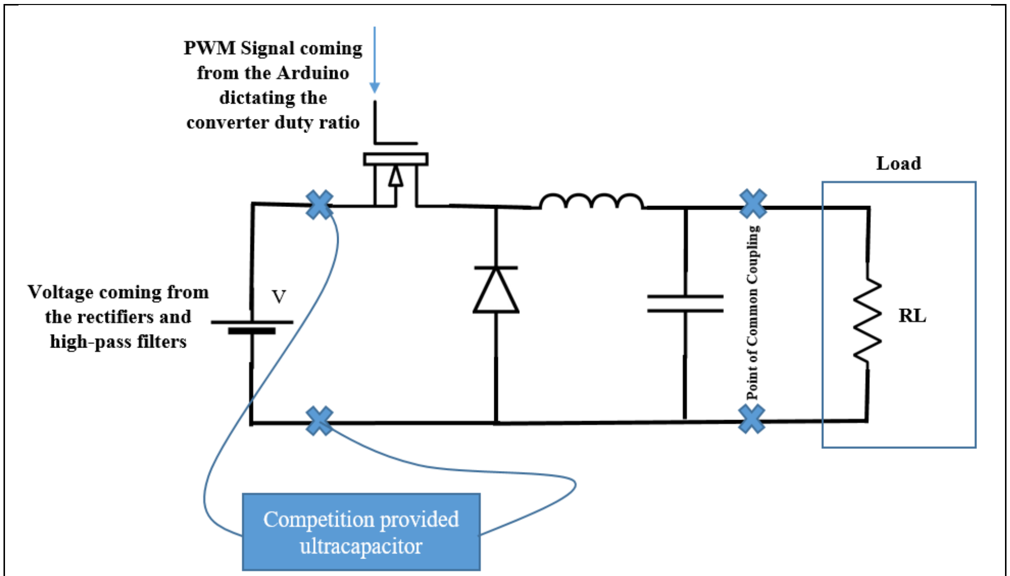

Figure 32: Control Circuit Buck Converter

Voltage data collected from testing at given wind speeds are used in conjunction with a voltage reading from the Arduino to deduce the wind speed in the tunnel at any given moment. The system then looks through a table of the optimal pitch angles at this given wind speed and sends this information to the servo to alter the blade pitch to the specified angle. This process repeats until voltage reaches a critical level of 44V, giving a small buffer for competition limits. When voltage reaches this threshold, the buck converter duty cycle regulates the output voltage. Given an input voltage, the necessary duty cycle is calculated and corresponding pulse width modulation (PWM) pulse sent from the Arduino to the MOSFET. This stabilizes output voltage at the threshold and prevents incremental increases in the voltage past competition requirements.

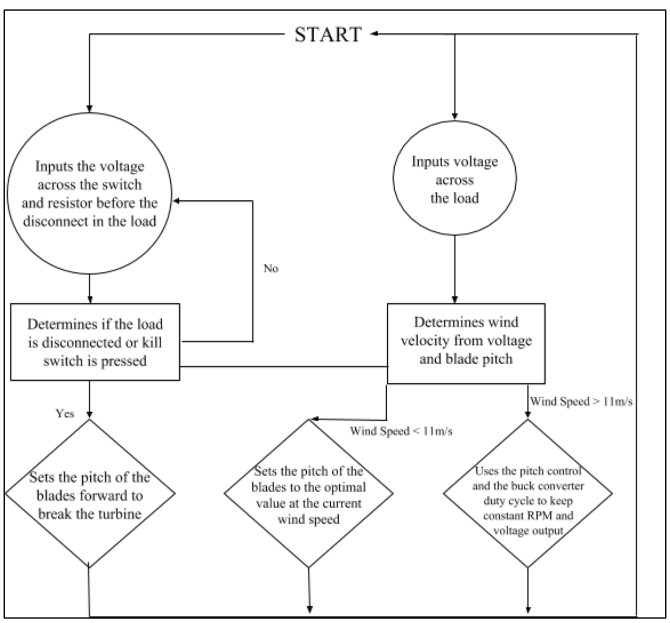

Figure 33:Control Flow Chart, Normal Operation

The system is equipped with two safety modes that stop the turbine from spinning. The first is a kill switch, as shown in **Figure 33**, that indicates to the Arduino to pitch the blades completely out of the wind to prevent further power output. Additionally, the system continually reads the voltage drop across the load. If the Arduino senses this to be zero, it deduces that there must be no current running through it. This indicates a disconnect, causing the Arduino to pitch the blades to the stopping pitch to prevent any further power production.

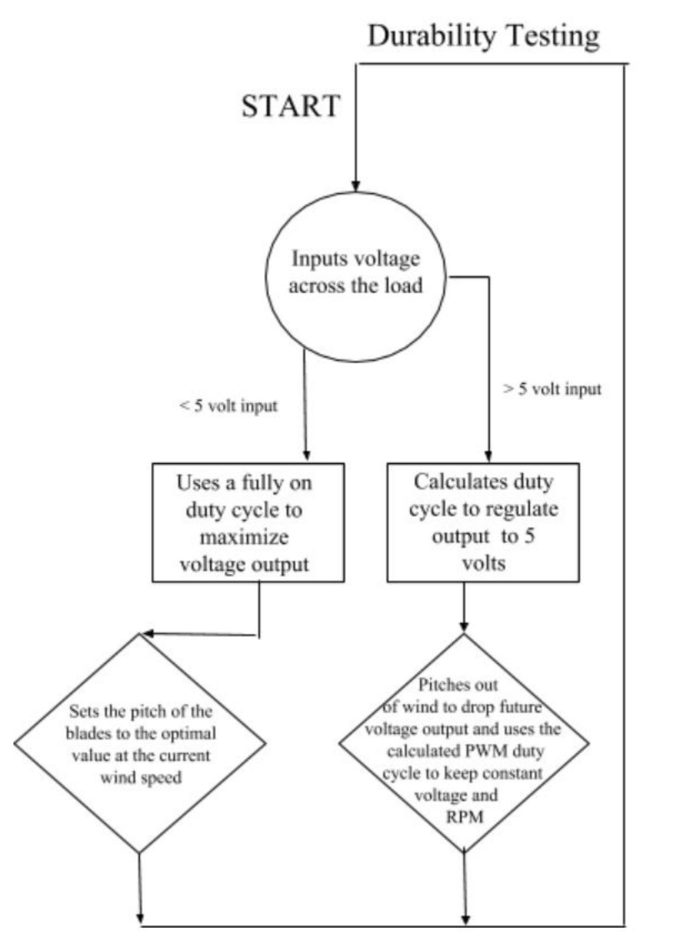

Figure 34: Durability Testing Control Flow Chart

During the durability portion of the turbine testing, new code is implemented which can be seen in **Figure 34**. Voltage is regulated in the same way using the buck converter and PWM; however, the maximum allowable voltage is restricted to 5V to refrain from damaging the storage unit and to regulate the voltage drop across the load. A significant portion of the ultracapacitor is not charged so it can act as an additional sink given the case of excess power output in the remainder of the durability test. After the charging portion is finished, the buck converter steps down the input voltage to a consistent 5V. If the turbine does not produce enough power for this 5V requirement at the given wind speed, the ultracapacitor discharges and supplements the power input. If too much power is produced, the system begins to pitch the blades out of the wind to prevent the ultracapacitor from overcharging with the excess power.

4.4.8 Performance Testing

For the test turbine to score as high as possible, it is critical to complete preliminary testing to find the optimum operating conditions. For a given wind speed, these conditions include load resistance and angle of attack. To find the conditions that produce the most power, we ran tests in our wind tunnel at constant wind speeds, with arbitrary load values, and swept through varying angles of pitch. **Figure 35** shows these conditions that produce the most power for a given wind speed. We also did testing to find the optimal start-up angle of attack, which cuts-in by 2.5 m/s and produces 8 volts by 5 m/s, allowing us to then pitch to the optimal conditions described above. The cut-in data is shown in **Figure 36**.

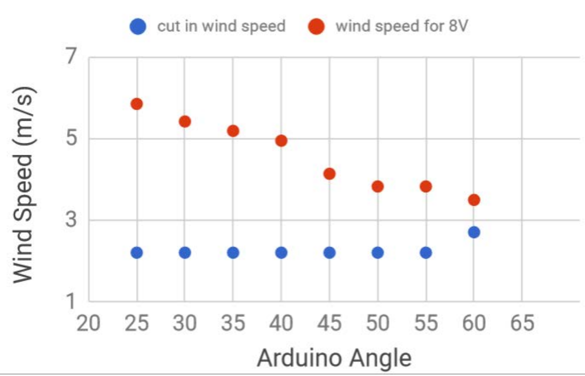

Figure 35: Optimized Cut-in Pitch Angle

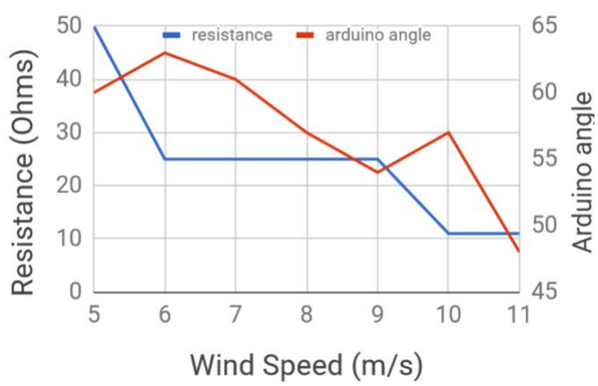

Figure 36: Optimization for Power Testing

5. Conclusion

Green Lights has described a promising investment opportunity in the business plan, deployment strategy and technical design. The company's innovative, portable lighting system is powered through wind energy and will improve upon the current diesel lighting systems. Our customers' will save money since they'll no longer have to purchase fuel and will create a safer working environment because the wind turbine is much quieter compared to a diesel generator. With the help of a $777,600 investment in exchange for a 19% stake, Green Lights is ready to take a market share of the currently archaic portable lighting industry. This investment will allow us to start replacing the current generator systems with a wind-powered system, furthering the renewable energy initiative. The fundamental essence of the company's public appeal and brand loyalty is its application of wind turbines. Our 43% ROI in 3 years is an achievable and promising opportunity and will only be possible with the help of your investment. Thank you.

6. References

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Appendices

Cash Flows

	Cash Flow Forecast Years 1-3													
	Prepared By:	Company Name:	NOTE: To only view the annual total side-by-side, highlight columns C through N and right-click. Then select "Hide". Use the same procedure to Hide columns P through AA. To show them again, highlight columns B, O and AB, right-click and select "Unhide".											
	Parth Patel	Green Lights												
	Year 1 Totals	**July**	**August**	**September**	**October**	**November**	**December**	**January**	**February**	**March**	**April**	**May**	**June**	**Year 2 Totals**
Beginning Balance		$ 56,576	$ 63,876	$ 70,529	$ 73,735	$ 81,748	$ 89,762	$ 92,967	$ 100,981	$ 108,994	$ 112,200	$ 120,213	$ 128,227	
Cash Inflows														
Cash Sales	**$ 122,400**	11,220	11,220	11,220	11,220	11,220	11,220	11,220	11,220	11,220	11,220	11,220	11,220	**$ 134,640**
Accounts Receivable	**$ 248,200**	23,800	24,820	26,180	26,180	26,180	26,180	26,180	26,180	26,180	26,180	26,180	26,180	**$ 310,420**
Total Cash Inflows	**$ 370,600**	$ 35,020	$ 36,040	$ 37,400	$ 37,400	$ 37,400	$ 37,400	$ 37,400	$ 37,400	$ 37,400	$ 37,400	$ 37,400	$ 37,400	**$ 445,060**
Cash Outflows														
Investing Activities														
New Fixed Asset Purchases	$ -	-	-	-	-	-	-	-	-	-	-	-	-	$ -
Additional Inventory	$ -													$ -
Cost of Goods Sold	**$ 183,297**	16,663	18,330	18,330	18,330	18,330	18,330	18,330	18,330	18,330	18,330	18,330	18,330	**$ 218,290**
Operating Activities														
Operating Expenses	**$ 36,390**	3,130	3,130	3,130	3,130	3,130	3,130	3,130	3,130	3,130	3,130	3,130	3,130	**$ 37,555**
Payroll	**$ 81,834**	7,889	7,889	7,889	7,889	7,889	7,889	7,889	7,889	7,889	7,889	7,889	7,889	**$ 94,664**
Taxes	**$ 17,886**	-	-	4,808	-	-	4,808	-	-	4,808	-	-	4,808	
Financing Activities														
Loan Payments	$ -	-	-	-	-	-	-	-	-	-	-	-	-	$ -
Owners Distribution	$ -													$ -
Line of Credit Interest	$ **384**	38	38	38	38	38	38	38	38	38	38	38	38	**$ 461**
Line of Credit Repayments	$ -													$ -
Dividends Paid	$ -													$ -
Total Cash Outflows	**$ 319,791**	$ 27,720	$ 29,386	$ 34,195	$ 29,386	$ 29,386	$ 34,195	$ 29,386	$ 29,386	$ 34,195	$ 29,386	$ 29,386	$ 34,195	**$ 350,971**
Net Cash Flows	**$ 50,809**	$ 7,300	$ 6,654	$ 3,205	$ 8,014	$ 8,014	$ 3,205	$ 8,014	$ 8,014	$ 3,205	$ 8,014	$ 8,014	$ 3,205	**$ 94,089**
Operating Cash Balance		$ 63,876	$ 70,529	$ 73,735	$ 81,748	$ 89,762	$ 92,967	$ 100,981	$ 108,994	$ 112,200	$ 120,213	$ 128,227	$ 131,432	
Line of Credit Drawdown	**$ 5,767**	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Ending Cash Balance		$ 63,876	$ 70,529	$ 73,735	$ 81,748	$ 89,762	$ 92,967	$ 100,981	$ 108,994	$ 112,200	$ 120,213	$ 128,227	$ 131,432	
Line of Credit Balance		**$ 5,767**	**$ 5,767**	**$ 5,767**	**$ 5,767**	**$ 5,767**	**$ 5,767**	**$ 5,767**	**$ 5,767**	**$ 5,767**	**$ 5,767**	**$ 5,767**	**$ 5,767**	

July	August	September	October	November	December	January	February	March	April	May	June	Year 3 Totals
$ 131,432	$ 138,101	$ 144,059	$ 147,040	$ 154,494	$ 161,947	$ 164,929	$ 172,383	$ 179,836	$ 182,818	$ 190,271	$ 197,725	
12,342	12,342	12,342	12,342	12,342	12,342	12,342	12,342	12,342	12,342	12,342	12,342	**$ 148,104**
26,180	27,302	28,798	28,798	28,798	28,798	28,798	28,798	28,798	28,798	28,798	28,798	**$ 341,462**
38,522	39,644	41,140	41,140	41,140	41,140	41,140	41,140	41,140	41,140	41,140	41,140	**$ 489,566**
-	-	-	-	-	-	-	-	-	-	-	-	$ -
												$ -
18,330	20,163	20,163	20,163	20,163	20,163	20,163	20,163	20,163	20,163	20,163	20,163	**$ 240,119**
3,230	3,230	3,230	3,230	3,230	3,230	3,230	3,230	3,230	3,230	3,230	3,230	**$ 38,759**
10,255	10,255	10,255	10,255	10,255	10,255	10,255	10,255	10,255	10,255	10,255	10,255	**$ 123,064**
-	-	4,472	-	-	4,472	-	-	4,472	-	-	4,472	**$ 17,889**
-	-	-	-	-	-	-	-	-	-	-	-	$ -
												$ -
38	38	38	38	38	38	38	38	38	38	38	38	**$ 461**
												$ -
												$ -
$ 31,853	$ 33,686	$ 38,159	$ 33,686	$ 33,686	$ 38,159	$ 33,686	$ 33,686	$ 38,159	$ 33,686	$ 33,686	$ 38,159	**$ 420,292**
$ 6,669	$ 5,958	$ 2,981	$ 7,454	$ 7,454	$ 2,981	$ 7,454	$ 7,454	$ 2,981	$ 7,454	$ 7,454	$ 2,981	**$ 69,274**
$ 138,101	$ 144,059	$ 147,040	$ 154,494	$ 161,947	$ 164,929	$ 172,383	$ 179,836	$ 182,818	$ 190,271	$ 197,725	$ 200,706	
$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
$ 138,101	$ 144,059	$ 147,040	$ 154,494	$ 161,947	$ 164,929	$ 172,383	$ 179,836	$ 182,818	$ 190,271	$ 197,725	$ 200,706	
$ 5,767	**$ 5,767**	**$ 5,767**	**$ 5,767**	**$ 5,767**	**$ 5,767**	**$ 5,767**	**$ 5,767**	**$ 5,767**	**$ 5,767**	**$ 5,767**	**$ 5,767**	