EXOCO Farms Business Plan & Test Turbine Technical Report

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EXOCO FARMS

CALIFORNIA STATE UNIVERSITY – MARITIME ACADEMY

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Executive Summary

EXOCO Farms is an offshore aquaculture operation that is dedicated to delivering the highest quality fish to consumers in an environmentally sustainable way. Once launched, we will be the only offshore aquaculture farm in the world to utilize wind energy to significantly reduce greenhouse gas emissions. EXOCO Farms has formulated a sustainable model for utilizing the world's natural fisheries because, according to current projections, wild fish resources are faced with the threat of complete collapse. We specialize in the production of cobia. This species is ideal for offshore aquaculture because it possesses a fast growth rate and is extremely versatile in terms of how it can be prepared. EXOCO is branding itself as a premium product that will be sold directly to chefs, and wholesalers.

Our firm is partnering with the industry leader in offshore aquaculture technology, InnovaSea, to create a farm that can produce 420,000 fish every thirteen months. Located in the Gulf of Mexico, EXOCO Farms is the first firm to attempt this kind of operation in the United States. By utilizing the wind turbine generated power, EXOCO Farms differentiates its product from the competition by producing fish while limiting our greenhouse gas emissions.

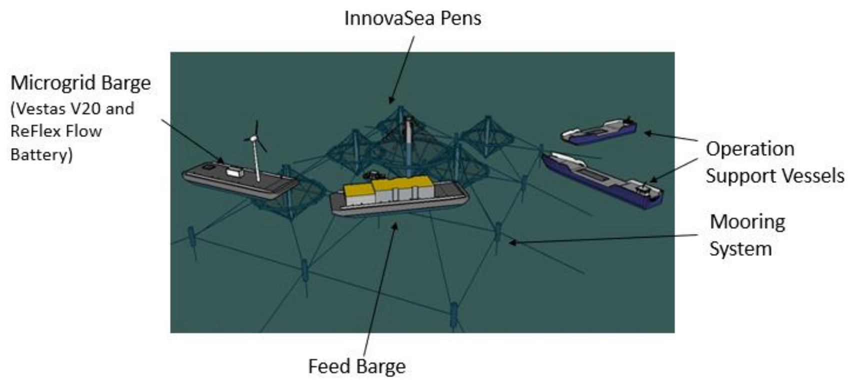


Figure 1-1 Diagram of EXOCO Farms proposed operations.

EXOCO Farms consists of a microgrid barge that floats a Vestas V20 wind turbine and UniEnergy Technologies ReFlex battery, six InnovaSea pens, two operation support vessels and a feed barge that stores fish food, monitoring equipment and provides living quarters. Figure 1-1 is a 3D rendering of the EXOCO Farms operation. We believe that the increase in marketability of our product due to using wind energy to power our operation will enable us to brand our cobia fish as a premium product.

The test turbine is modeled as a scaled-down version of a Vestas V20, the wind turbine used on the microgrid barge. The rated power of a Vestas V20 is 120 kW, while rated power for the test turbine is approximately 40 W at 3000 rpm. The market turbine and test turbine are both fixed-pitch machines that utilize aerodynamic stall to maintain rated power at high wind speeds. The test turbine autonomously controls a buck-boost DC/DC converter to track maximum power for wind speeds within 5 and 11 m/s. The load used in during this application is a 6-V lead-acid battery. In winds of 11 to 20 m/s, the system employs a complementary control algorithm in order to control rotor speed and maintain rated power while simultaneously charging a capacitive storage element and delivering a steady 5 V, via a secondary DC/DC converter, to a variable load resistor. While operating in this mode, the system is designed to accommodate fluctuating load demands and wind speeds. Additionally, the turbine is capable of stopping on demand or in the case of load disconnect. The test turbine, the AC/DC rectifier and the two DC/DC converters were entirely manufactured by the student engineering team and tested in our campus wind tunnel.

Chapter 1: Business Plan

1.1 Business Overview

EXOCO Farms is an offshore aquaculture operation that is dedicated to delivering the highest quality fish to consumers in an environmentally sustainable way. Once launched, we will be the only offshore aquaculture farm in the world to utilize wind energy and significantly reduce greenhouse gas emissions. The name EXOCO is derived from the scientific name for the flying fish, Exocoetidae, which embodies our company's marriage of wind energy and aquaculture. EXOCO is more than just a name; it shows consumers that the fish they eat were produced with environmental sustainability in mind.

EXOCO Farms has decided to operate further offshore for several important reasons. First, fish can grow and develop in their natural habitat which ultimately creates a higher value product for harvest. Secondly, moving offshore allows us to tap into the stronger winds that are present out at sea. This will help ensure that our wind turbine is able to generate as much power as possible to provide the maximum value to our firm. Additionally, moving further offshore minimizes the potential for fecal pollution, an inevitable byproduct of fish farming, to reach coastal waters. It also allows provides plenty of space for expansion as EXOCO Farms prepares to ramp up production.

We specialize in the production of cobia. This species is ideal for offshore aquaculture because it possesses a fast growth rate and is extremely versatile in terms of how it can be prepared. Our business model relies on selling our cobia to wholesalers and directly to restaurants. By forming partnerships with local seafood providers, we gain a competitive advantage because we are selling more environmentally friendly fish to the market. EXOCO Farms can achieve economies of scale with this model by specializing in the production of one fish.

Our vision is to provide our customers with sustainable fish at an affordable price. With the world's fisheries in a state of collapse, and a fishing industry that is two to three times larger than what the seas can sustainably support, EXOCO Farms will aid in satisfying the world's demand for fish without causing any further damage to natural fish populations [1]. All signs indicate that aquaculture will be the future of fish production. EXOCO Farms is positioning itself to become an industry leader once the aquaculture industry takes off. Our value proposition is that our cobia fish are of the highest quality and are also environmentally friendly.

There are serious issues facing the world's natural fisheries and our customers can rest easy knowing that they are not contributing to global warming or depleting the world's fisheries. We believe that the combination of quality, price and sustainability makes EXOCO Farm's cobia a value proposition that consumers can't beat.

1.2 Market Opportunity

The world's natural supply of fish is in an alarming state of decline. According to National Geographic, most of the world's seafood populations may completely disappear by 2048 [2]. Twenty-nine percent of seafood species that humans consume have already been wiped out. If this pattern continues, we will completely lose the ability to sustainably harvest most commercially viable fish species in about 30 years [2]. These losses have major impacts on the ocean's ecology and will have detrimental effects in the future. Additionally, the United Nations released findings that 80% of the world's fisheries are now fully exploited or overexploited, and that the maximum wild capture for fisheries has likely been reached [3]. Currently, our methods are unsustainable and the world will inevitably look to aquaculture as the solution for meeting the demand for seafood. Since aquaculture is presently underutilized when compared with natural capture, we believe that now is an excellent time to enter this industry because it is likely on the brink of significant growth.

According to the U.K.'s Waste and Action Resources Programme, farmed fish had a net tonnage of 41 million metric tons in 2005 [4]. By 2050, that number is expected to rise to approximately 140 million metric tons, a 241% increase over the next three decades. In addition to the expected growth in aquaculture production, the world's population is predicted to grow from 7.3 billion to 9.7 billion people by 2050 [5]. This will create huge demand for protein, especially as people become more affluent throughout the world. Furthermore, there is an important environmental cost associated with the production of certain types of protein. Some types emit substantially more CO_2 than others. For example, producing one kilogram of lamb produces 39.2 kg of CO_2, which is roughly the same amount as driving a car 90 miles, while producing 1 kg of beef releases nearly 27 kg of CO_2. Farmed fish, on the other hand, emit a little under 12 kg of CO_2 per kg of meat [6]. This is significant because as climate change intensifies, many consumers will consider changing their eating habits in order to reduce their carbon footprint. The Food and Agriculture Organization of the United Nations predicts aquaculture will produce virtually two thirds of global fish consumption by 2030 [7].

1.2.1 Advantages of Wind Energy and Moving Offshore

With all these statistics, it is reasonable to wonder why aquaculture is not more prevalent. First, farming large amounts of fish in one area will generate sizeable amounts of fecal matter. Currents and tides can sweep these excrements to nearby coastlines, polluting their shores [8]. It is safe to assume that nobody wants to live in an area contaminated by fish fecal matter. There are many offshore aquaculture businesses in various places around the world. However, the United States has historically kept offshore aquaculture illegal. As of 2016, the U.S. federal government is accepting applications for offshore aquaculture permits in the Gulf of Mexico. Additionally, offshore aquaculture farms can be an eyesore for local coastal communities. People are as resistant to offshore aquaculture being in their backyard as they are to the installment of land-based wind farms.

As mentioned previously in Section 1.1, moving operations further offshore provides a means of circumventing these issues. There are numerous other advantages associated with harvesting fish further offshore. First, it lessens the environmental impact since fecal matter falls to the seafloor where it decomposes, rather than polluting [7]. Secondly, fish farmed in open ocean nets experience a magnitude of health-boosting effects. A fish's flesh quality improves significantly since the consistent swell exposure provides a flow of fresh water in the pens [9]. By increasing the flesh quality, EXOCO Farms can sell farmed fish for a higher price. Additionally, moving offshore eliminates the availability of space concern so as the business expands, the open ocean gives us room to expand with additional pens.

1.2.2 Why Wind?

In terms of harnessing wind energy to power our operations, moving farther offshore provides stronger winds. The seas have some of the best wind resources available and EXOCO Farms plans to make use of them. This strategy has multiple benefits. First, a year-long study determined that a hybrid system utilizing wind energy and solar panels at sea has the potential to be the most cost-effective system [10]. This study showed that a typical fish farm releases approximately 120,000 kg of CO_2 per year. However, the study estimates that by using a combination of solar panels and wind turbines, in addition to a backup diesel generator, aquaculture farms can cut their CO_2 emissions by approximately 50% while saving 16% in fuel costs [11]. As a startup, EXOCO Farms has yet to achieve this result, but upon expanding we are confident that these numbers will hold true for our operation as well. Second, this strategy allows us to eliminate diesel as a primary source of energy. Our farm would require approximately 11,539 gallons of diesel fuel without a wind turbine (see Section 1.6.4). With the wind turbine and a 500 kWh battery, fuel consumption is curbed by approximately 800 gallons of fuel per year. While the wind turbine is an extremely expensive investment, it does help save on yearly fuel costs and allows EXOCO Farms to be more environmentally friendly than any other fish farm on the market.

1.2.3 Justification of Wind Turbine

Our marketing strategy is to brand our fish as a premium product that is completely sustainable. Many environmentally conscious consumers are willing to pay higher prices for sustainably sourced products, such as grass fed beef [12]. Since EXOCO Farms cobia are considered a premium product, we will charge a higher price than competitors. Products from EXOCO Farms sell for $15 more than those of Open Blue Cobia, our main competitor. Our wind turbine is the reason we believe we'll be able to price our cobia higher than the competition. As seen in Section 1.4.4, our turbine does not save us money on energy production compared to using just diesel. However, using wind energy still makes sense from a marketing perspective because it allows us to increase prices. We determined that we need to charge approximately 3.6% more per fish than the competition to pay for the wind turbine. In short, the turbine might not make sense from a cost perspective, but the increased marketing benefits make the turbine extremely valuable to EXOCO's value proposition because it allows us to charge more for our premium cobia fish.

1.2.4 Target Market

One of the strengths of raising cobia in the Gulf of Mexico is that it can be farmed year-round. Our cobia will mostly compete in higher end markets as it tastes very similar to tuna and can be grilled, sautéed, seared, and consumed raw. Many other high-end fish, like salmon, are only available at certain times of the year, providing EXOCO Farms with a competitive edge. Growing cobia year-round is ideal for chefs looking to construct a reliable menu. A survey showed that 94% of chefs have the disposition to substitute other fish with cobia [13]. Once a chef designs a popular dish using cobia, they can keep it on the menu all year because EXOCO Farms will have the fish they need in order to keep customers satisfied. EXOCO Farms plans on staggering fish pen use so that we can harvesting one pen every two months. This ensures a steady supply of cobia for our valued customers. Once chefs more broadly understand that cobia is an affordable substitute for the fish they're currently using, we expect demand will increase sharply.

Our wind turbine meets the desires of our target market in several ways. First, people do not want to purchase farmed fish in traditional land-based aquaculture operations because of the negative stigma associated with it [14]. Even though those fish are cleaned thoroughly and are completely safe to eat, the fact of the matter is that at one point the fish were swimming in their own excrement. That can be a major detraction for consumers. EXOCO Farms does not have this problem as our farms are offshore, an operational model made possible by the wind turbine. By utilizing renewable energy and reducing the need for transporting fuel over water, we can move further out to sea than any existing offshore aquaculture farm. Our competitor, Open Blue Cobia, is currently eight miles offshore Panama while EXOCO Farms is 33 miles off the coast of Texas. We can achieve this because we don't need to go out to the farm site as frequently to refill our fuel tanks as frequently as Open Blue. The turbine is a natural fit for an offshore aquaculture operation because it enhances the benefits of moving offshore in the first place. The farther out at sea the farm is located, the better the fish quality and the better the wind resource. The turbine also gives the added benefit of allowing us to market our product as the most sustainable on the market. Not only do we produce higher quality fish, but we're actively limiting our carbon footprint – it's a win-win.

1.2.5 Pricing

In terms of pricing, we have decided to sell our fish wholesale for $65 a fish, or $5.90 per pound. This is a premium price for cobia. Typically, this species will sell for anywhere between $40 and $50. We decided on this price because we want to price our fish as a premium environmentally sustainable product. There is very little that is fundamentally different about EXOCO Farm's cobia when compared to Open Blue Cobia's. Seeing as Open Blue sells their products for fifty dollars a fish, we want to create the brand perception that EXOCO fish are of higher quality and more environmentally friendly. This also delivers substantial value to the consumer. Part of the value that cobia brings to the table is that it is a high a quality fish with many more well-known commercially viable species but costs substantially less.

1.2.6 Permitting

The Gulf of Mexico has recently opened for offshore aquaculture. The Federal government is allowing up to 20 different aquaculture businesses to develop operations in the Gulf of Mexico [15]. Companies currently have a huge incentive to try to become one of the first local Gulf of Mexico aquaculture farmers since there is no competition. Our first step in developing our operation is to obtain all required permitting from federal bodies like NOAA and the U.S. Coast Guard. In 2016, NOAA laid out a streamlined permitting process for aquaculture in the Gulf of Mexico, making it by far the easiest area in the US to start this sort of operation [16].

1.2.7 Funding

EXOCO Farms plans to finance the venture using a five and ten-year loan plan. Lower costing equipment and supplies will be allocated on a five-year loan while the larger superstructures and heavy equipment will be categorized via a ten-year loan. In addition to loans, EXOCO Farms plans to apply for multiple grants. These grants will help reduce costs of the wind turbine, as well as startup expenses. We plan on applying for the Special Research Grants Program for Aquaculture Research, which is a government subsidy sponsored by the Department of Agriculture [17]. This grant allows us to request up to $300,000 and is designed for aquaculture businesses. Secondly, we plan to apply for the grant that Sea Pact offers. Sea Pact is a coalition of seafood distributors that donates up to $30,000 to small farms to help them get off the ground [18]. Applying for this grant will not only allow EXOCO Farms to reduce costs, but will also allow us to gain prospective distributors around the world. EXOCO Farms also plans on applying for NOAA's Small Business Innovation Research Program "SBIR". The SBIR program offered by NOAA allows small businesses to reach out for funding to explore innovative ideas. This program will allow us to apply for roughly $520,000 over the course of 30 months [19] [20]. NOAA also has created a grant called the National Marine Aquaculture Initiative. This grant is designed to help coastal communities create a sustainable seafood supply for promising fish species such as cobia by awarding up to $750,000 in financial assistance [21]. Another grant that EXOCO will apply for is the Saltonstall-Kennedy Grant, which donates up to $300,000 to fish farms in order to optimize their economic capacity and sustainable benefits [22]. Additionally, we will apply for the Fisheries Finance Program, which is a loan that is sponsored by NOAA. This program provides funding for up to 25 years with a maximum amount of $750,000 [20]. This will be an important loan to secure in addition to our bank loans because it will increase the total amount of capital that EXOCO Farms can borrow to start up our business. Finally, the most important grant that we will apply for is the Marine Fisheries Initiative, which is sponsored by NOAA. This grant promotes businesses who attempt to promote economic and social benefits with their designs and operations, specifically in the Gulf of Mexico. This grant does not have a set award ceiling, so EXOCO must negotiate carefully in order to maximize our potential benefit [20] [21]. Excluding the Marine Fisheries Initiative, EXOCO Farms has identified upwards of $2,650,000 in potential available funding in addition to bank loans to help finance our fish farm. This leaves us extremely optimistic about the economic potential that this operation and industry possesses.

1.3 Management Team

Figure 1-1 AKVA Feed Barge (AKVA GROUP, 2015)

The management team of EXOCO Farms is comprised of two parts. First, we have our administration staff. The administration staff is responsible for all business transactions, logistics, and overall management of the firm. The administration staff is located at a small office in Galveston, Texas and is onsite 9:00 am to 5:00 pm weekly. This ensures that any discrepancies can be taken care of in a timely manner, and that the offshore farm site gets the attention it needs in case of malfunction. Additionally, we keep a "weekend duty officer" on call 24/7 during the weekends in case of emergency.

Inside the office, EXOCO Farms administration staff is comprised of a Chief Executive Officer, Logistics and Purchasing Manager, Human Resources and Admin Manager, Sales and Marketing Executive, and Front Desk Manager. During our startup phase, many of our land-based operation positions will be multitasking between various jobs to keep costs down. The Chief Executive Officer will be responsible for the overall facilitation of the firm.

Our Logistics and Purchasing Manager is responsible for the direct sales and coordination of all feed, fingerlings, and harvesting procedures to and from the farm. They are essentially responsible for the transportation portion EXOCO Farms faces. Current operations only entail one Logistics and Purchasing Manager. In addition to the administration staff, the Human Resources and Admin Manager does all tasks relating to human resources, payroll, legal troubles, hiring management, etc. Lastly, a Sales and Marketing Executive in the office sells the cobia to restaurants and building customer relationships between wholesalers and restaurants.

Table 1-1 EXOCO Farms Employee salaries prior to benefits and taxes ([23] through [29])

Position	Salary	# of Workers
Chief Executive / Operating Officer	$ 137,051.00	1
Logistics / Purchasing Manager	$ 107,286.00	1
Barge Operator	$ 96,000.00	2
Marine Veterinarian (As needed/estimate)	$ 82,040.00	1
Human Resources and Admin Manager	$ 76,022.00	1
Marine Biologist	$ 70,800.00	1
Sales and Marketing Executive	$ 62,694.00	1
Accountant / Cashier	$ 55,202.00	1
Lead Diver	$ 54,782.00	2
Front Desk Manager	$ 45,866.00	1
General Fish and Seafood Farm Manager	$ 39,540.00	1
Aquaculture Technician	$ 35,000.00	8
Diver	$ 34,434.84	4
TOTAL	$ 1,395,804.36	25

Secondly, Exoco Farms employs two different groups of SeaStation staff to allow employees to have a work schedule of one week on, one week off. The SeaStation staff are responsible for the actual visitation on the farm. One group of SeaStation staff workers consists of one feed barge operator, one lead diver, two regular divers, and four aquaculture technicians.

While the administration team is responsible for maintaining partnerships and selling the product, the SeaStation staff are vital in making sure the fish are healthy and happy. Our current operation requires a feed barge operator to make sure that the fish are being adequately fed in specific time sensitive intervals, and any repairs and maintenance the feed barge requires.

The divers' responsibilities are mainly focused on the integrity of the pens. Once a day a lead diver, and two regular divers make rounds on each pen to check for wear and tear. If needed, the divers will carry out extensive repairs to ensure that the pens are not damaged. While they are mainly concerned about the pens, the divers will also collect information about fish sizes, and maintain watch over the fish stock. Collectively, the dive team works 26 weeks out of the year.

Lastly, EXOCO Farms SeaStation staff have eight Aquaculture Technicians who are responsible for the fish health. These Aquaculture Technicians have the huge responsibility of ensuring that our cobia are sufficiently fed and growing. If adjustments to feeding need to be arranged, they are the ones who make the call. Additionally, our Aquaculture Technicians perform all harvesting requirements and rotate out in crews of four per week. Annual salary for each employment position can be found in Table 1-1.

1.4 Development and Operations

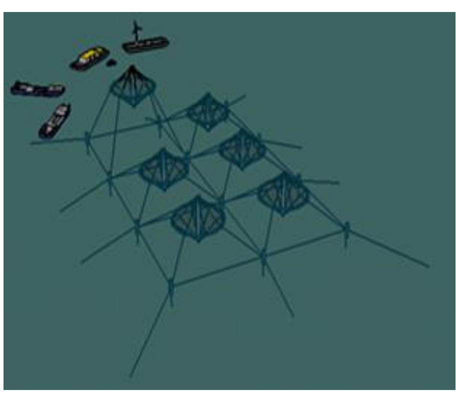


Figure 1-2 3D rendering of EXOCO Farms.

Located 33 nautical miles off the coast of Galveston, Texas, EXOCO Farms is working to become the premier offshore aquaculture farm in the United States. We will be deploying six 14,500 m^3 fish pens, constructed by a company called InnovaSea, with a total capacity of producing 420,000 cobia fish every thirteen months. Our six pens are connected to a feed barge purchased from AKVA that supplies the necessary food for the farm once a day. This barge is equipped with living quarters that can sustain a crew of eight employees. These eight employees will live at the farm in one week shifts before switching out with another crew. The main reason that we have week on-week off shifts is to reduce the amount of fuel necessary to go out to the pens every day. One of our service boats and the dive boat are used vessels sourced from a firm called Lee Felterman and

Associates. Our second service boat is also refurbished and sourced from Horizon Ship Brokers. Further information on all price quotations found in this report are available upon request, however the purchases mentioned in this section are shown in Figure 1-3.

We have deployed our turbine on a separately purchased used ocean barge, and this connects to the microgrid to power the various systems in the pen. The feeding system, mixes the feed with water to create a slush that is then injected into the pens. Due to the scale of our pens, the feed must be dispersed. The reason for this methodology is that it reduces the amount of feed wasted when compared with systems that use pressured gas to break the feed apart. InnovaSea design allows us to reduce the amount of feed wasted every year.

EXOCO Farms is utilizing InnovaSea SeaStation 14500 pens for several reasons. First, it is one of the most advanced aquaculture pens on the market. The pen has a pyramidal shaped net that surrounds a central column called the spar. The spar is the central column of each pen that gives the net its shape. This spar has the ability to rise and float in the waves in order to control the depth of the water that the cobia are kept at. Furthermore, when harvesting season arrives, the spar acts as a flotation device to help force the cobia to the surface. These nets are moored into the seabed to prevent them from drifting off. Each pen comes with its own video surveillance system to monitor the fish's health and living conditions. Additionally, the netting is made out of a copper alloy mesh that is resistant to predator attacks and corrosion from the sea [30]. This helps decrease risk of escape and natural external threats. We will need to hire two engineers from InnovaSea to assist the full setup and installation of our system's six pens [31].

Fingerlings are purchased 12 months before their harvest date so the first batch of 60,000 fingerlings must be purchased up front and then every other month for the first year. Then in the second year we will ramp up purchasing to 70,000 fingerlings at a time. The price of these fingerlings is reflected in Table 1-7. One fingerling costs $2.50, so for every fish produced, $2.50 can be subtracted from the profit margin.

Our operation will also include a purchase of an office space in Galveston, TX to serve as a base of operations. In addition to the SeaStation pens and offices, EXOCO Farms will acquire two service vessels and a dive boat. The two service vessels are included to help transport harvested fish, feed, and personnel to and from the farm. The function of the dive boat is to help assist the aquaculture technicians and divers to perform routine inspections. After the SeaStations have been installed, the next step will be to acquire the fish. We will source cobia fingerlings from the aquaculture institute at the University of Miami for approximately $2.50 per fingerling [31]. The University of Miami is located close to our farm which will reduce costs of transportation significantly as opposed to being in foreign waters. One of our largest operating costs is the feed which we are sourcing from a multinational corporation called Cargill. The cost of feed and delivery to our berth at Galveston is $1,452.27 per short ton delivery [32]. It is important to note that the cost of feed listed in the Figure 1-3 refers to a startup cost, and that the yearly price of feed consumed is substantially higher. For this figure, please refer to the financial projections below.

Startup Expenses		
Capital Equipment List		
InnovaSea Pens	$	3,600,000
Feed Barge	$	2,000,000
Turbine	$	240,000
Turbine Barge	$	200,000
Operation and Maintenance (Turbine)	$	4,200
Microgrid Controller	$	100,000
Moorings	$	5,000
Buoys/Markers	$	27,000
Boat 1	$	350,000
Boat 2	$	240,000
Dive Boat	$	80,000
Turbine Batteries	$	400,000
Operation and Maintenance (Battery)	$	8,000
Generator	$	33,023
Operation and Maintenance (Generator)	$	340
Slip	$	3,444
Office/Equipment	$	10,000
Company Car	$	31,600
Other		-
Total Capital Equipment	$	7,332,607
Location and Admin Expenses		
Rent & Related Costs	$	3,107
Utility deposits		1,000
Legal and accounting fees		36,000
Prepaid insurance		10,000
Other		-
Total Location and Admin Expenses	$	50,107
Opening Inventory		
Fingerlings	$	1,037,400
Feed	$	646,272
Vaccinations	$	100,000
Total Inventory	$	1,783,672
Advertising and Promotional Expenses		
Advertising	$	1,500
Travel/entertainment		1,000
Other/additional categories		-
Total Advertising/Promotional Expenses	$	2,500
Other Expenses		
Other expense 1	$	-
Other expense 2		-
Total Other Expenses	$	-
Reserve for Contingencies	$	10,000
Working Capital	$	-

Figure 1-3 Start-up Costs

1.4.1 Manufacturing Approach

EXOCO Farms has a unique approach to raising cobia so they are ready for the market. In a typical production process, an aquaculture farm raises cobia from an egg to maturity. This entails a startup period where cobia eggs are placed into a hatchery and raised into fingerlings. This operation takes approximately 75 days, and requires an onshore facility. To simplify our operation, we have decided to avoid investing in hatchery technology, and instead procure fingerlings from the University of Miami's existing cobia hatcheries.

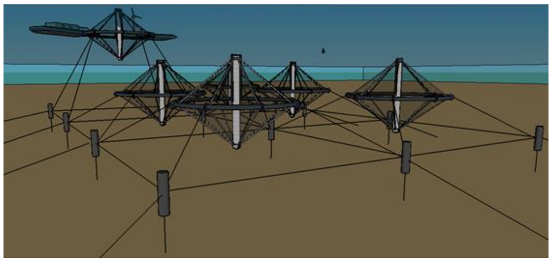


Figure 1-4 Six InnovaSea 14500-m^3 cages shown moored into the seabed, with one cage at sea level.

The SeaStation 14500 comes equipped with a smaller scale nursery net that is attached to the spar which has a substantially tighter mesh to restrict the cobia from escaping. After they outgrow the nursery phase, they are released into the larger pen where they will grow until harvest. Typically, cobia will reside in the nursery for approximately one month before being too large. Cobia will enter the nursery net at around 30 g and be released into the full net after weighing 120-150 g [33]. After twelve months of growth in the larger pen and achieving a weight of 11 lbs, the cobia are ready for harvest.

EXOCO Farms will use two separate service vessels to harvest cobia from the pens. Cobia will be sucked up a pipe to get it on the vessel. At this point they will be stunned and killed by a machine called the BAADER 101 which is included in the price of the SeaStation [31]. This is the most humane way to harvest large quantities of fish without subjecting them to physiological stress. Not only is this an ethical process for harvesting fish, it also produces higher quality fish flesh because the fishes muscles don't seize up from the stress during the harvesting process [31]. Once successfully processed, the fish are ready to be sold to restaurants and wholesalers.

1.4.2 Distribution

Once the cobia is fully grown it is ready for distribution to wholesalers. EXOCO Farms has elected to sell directly to wholesalers to simplify our operations as much as possible. Due to low consumer awareness, we believe that wholesalers are better positioned to find customers who demand our product. We will also be selling directly to restaurants in and around the Gulf of Mexico. For the chefs that we sell our fish to directly, we will utilize the USPS Priority Mail Express and the necessary packaging materials to ensure that the fish are delivered overnight, and of the highest quality.

1.4.3 Risk Assessment

When farming fish offshore there is a higher risk of losing fish from inclement weather. By utilizing InnovaSea's 14500 SeaStation we can mitigate the potential negative effects of large storms. The SeaStation is moored into the seabed, and is able to sink itself beneath the surface to avoid waves and winds from large storms. In the event of a hurricane, the feed barge, wind turbine, service vessels and the dive boat will be towed to shore so there is no risk to the equipment.

Another threat to the operation is the risk of cobia disease. There are various diseases that can wreak havoc on fish pen health. However, EXOCO Farms has invested in resources to avoid this outcome. We have a marine veterinarian and a marine biologist on staff to monitor cobia's health and take corrective action should the need arise. We have also invested in procuring the necessary vaccinations to mix with our feed to make our fish more resilient against disease [34]. Finally, the SeaStation system provided by InnovaSea has integrated features that help circulate water throughout the pen so that a fish never encounters the same water twice [31]. This helps reduce exposure to pathogens which ultimately reduces the risks of illness.

One of the major technical constraints facing EXOCO Farms is the size of the wind turbine. Our turbine has been specifically designed to power a farm of our size. This means that our turbine will not provide any additional benefit as we expand, and we would have to rely on diesel if we were to add more pens, or invest in a larger wind turbine. While we do not have restrictions on space, EXOCO Farms will have to carefully budget how the price of fuel will affect plans in the future. An additional technical constraint will be protecting the turbine during hurricanes. EXOCO Farms will have to pay for a tug to move the turbine-barge and feed barge to get them out of harm's way. During this time the farm will have to rely entirely on diesel to power its systems.

Our proposed concept for an offshore aquaculture farm is buildable. InnovaSea's pens have already been tested and proven to work well in these types of environments. Additionally, cobia thrive in climates ranging from 25 to 30°C [33]. The temperature of the water EXOCO Farms is entering complements what cobia prefer to live in. Furthermore, the aquaculture industry is lobbying to change regulations and make the offshore permitting process much easier [35].

1.4.4 Diesel Usage and Total Cost of Energy Analysis

EXOCO Farms prides itself on the use of our wind turbine because it allows us to significantly reduce the amount of diesel we use each year. Without the turbine, our estimates show that we would spend approximately $22,617 a year on fuel given cost of $1.96 per gallon of marine diesel oil. With the use of a 120 kW wind turbine and one 500 kWh battery, fuel costs drop to approximately $1,568 a year, resulting in a yearly savings of $21,049. We also analyzed the savings that could be achieved by adding a second 500 kWh battery but the additional capital cost was not justifiable.

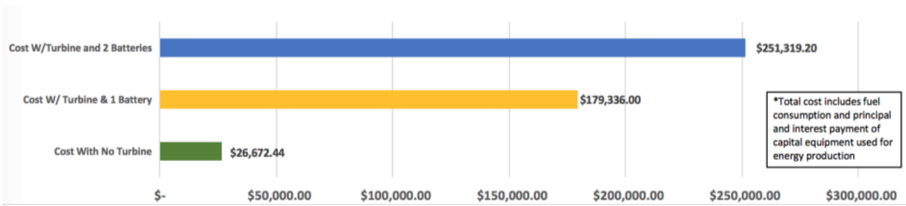


Figure 1-5 Total Cost of Power Generation per Year

We also analyzed the total cost of power generation per year for all three of the above-mentioned scenarios. Based on our numbers, the total cost of generating power is more expensive with the wind turbine than if we utilized traditional diesel. Our analysis on total cost examined the cost of fuel as well as the principal and interest payment of all capital equipment used for energy production per year. The expected cost of generating power for a year with just diesel was approximately $26,673. With a 120 kW wind turbine and a single 500 kWh battery, the cost was approximately $179,336.00. It costs EXOCO Farms an additional $152,664 a year to produce our required energy because the turbine and its related equipment are so expensive.

As such, we started to play with external factors such as the cost of diesel and a reasonable carbon tax to determine if a wind turbine could make financial sense in the future. If the price of marine diesel oil increased from $1.96 to $4.00 a gallon, the turbine starts to make more sense. At $4.00, the total cost of using just diesel changes from $26,672.44 to $54,424.00, a 104% increase. This makes the wind turbine more attractive, but still not quite enough to warrant investment strictly from a cost standpoint. We then examined what would happen to costs if the price of diesel increased to $4.00 a gallon and the government implemented a reasonable carbon tax of $50 per metric ton of CO_2 released. This did not change the findings much as it only increased the total cost of energy production for diesel from $54,424.00 to $55,480.00, or a 1.9% increase.

1.5 Financial Analysis

Table 1-2 through Table 1-7 show the pertinent information in respect to EXOCO Farms' financials. The two cash flow statements show all cash moving in and out of the operation over the first three years. The income statements show each of the ending net incomes/losses for the first three years. The balance sheet displays all of the assets, liabilities and equity in EXOCO Farms over the first three years. Lastly, it is important to note that with the period needed to grow cobia that no sales are made until February of the second year. It is for this reason that these six financial tables were provided.

EXOCO plans on taking out two separate commercial loans, both at an interest rate of 13%. The first of these will be paid out over 120 months, while the second commercial loan will be paid out over 60 months. The first commercial loan totals $7,286,600, which covers the InnovaSea pens, leasehold improvements, equipment, office equipment, vessels and company car. The second commercial loan totals $6,444,728 and includes pre-opening salaries and wages, construction management wages, turbine operation and maintenance, company phone plan, inventory, legal and accounting fees, start-up rent and rent deposits, start-up utilities and utility deposit, supplies, advertising and promotions, licenses and insurance, travel expenses and working capital.

The operating costs include multiple expenses that are incurred monthly. In all, the constant monthly operating expenses total $38,606. However, we also have a monthly interest payment on our loans, so operating expenses are roughly $210,000 per month for the first year. It is also important to note that the operating expenses increase from 3 to 5% annually, while payroll rises 3% each year, in order to account for inflation. The production ramp up is responsible for increasing cash sales from year 1 to 3.

Table 1-2 Cash Flow Year 1

	January	February	March	April	May	June	July	August	September	October	November	December	Totals
Beginning Balance	$ 6,000,000	$ 5,545,259	$ 5,090,518	$ 4,635,777	$ 4,181,036	$ 3,726,294	$ 3,271,553	$ 2,816,812	$ 2,362,071	$ 1,907,330	$ 1,452,589	$ 997,848	
Cash Inflows													
Cash Sales	-	-	-	-	-	-	-	-	-	-	-	-	$ -
Accounts Receivable	-	-	-	-	-	-	-	-	-	-	-	-	$ -
Total Cash Inflows	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Cash Outflows													
Cost of Goods Sold	-	-	-	-	-	-	-	-	-	-	-	-	$ -
Operating Activities													
Operating Expenses	38,606	38,606	38,606	38,606	38,606	38,606	38,606	38,606	38,606	38,606	38,606	38,606	$ 463,272
Payroll	160,701	160,701	160,701	160,701	160,701	160,701	160,701	160,701	160,701	160,701	160,701	160,701	$ 1,928,412
Total Cash Outflows	$ 454,741	$ 454,741	$ 454,741	$ 454,741	$ 454,741	$ 454,741	$ 454,741	$ 454,741	$ 454,741	$ 454,741	$ 454,741	$ 454,741	$ 5,456,893
Net Cash Flows	$ (454,741)	$ (454,741)	$ (454,741)	$ (454,741)	$ (454,741)	$ (454,741)	$ (454,741)	$ (454,741)	$ (454,741)	$ (454,741)	$ (454,741)	$ (454,741)	$ (5,456,893)
Operating Cash Balance	$ 5,545,259	$ 5,090,518	$ 4,635,777	$ 4,181,036	$ 3,726,294	$ 3,271,553	$ 2,816,812	$ 2,362,071	$ 1,907,330	$ 1,452,589	$ 997,848	$ 543,107	
Line of Credit Drawdown	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Ending Cash Balance	$ 5,545,259	$ 5,090,518	$ 4,635,777	$ 4,181,036	$ 3,726,294	$ 3,271,553	$ 2,816,812	$ 2,362,071	$ 1,907,330	$ 1,452,589	$ 997,848	$ 543,107	
Line of Credit Balance	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	

Table 1-3 Cash Flow Year 2

	Year 1 Totals	January	February	March	April	May	June	July	August	September	October	November	December	Year 2 Totals
Beginning Balance		$ 543,107	$ 81,360	$ 2,460,614	$ 1,652,687	$ 4,031,941	$ 3,570,194	$ 5,032,648	$ 4,570,902	$ 6,950,155	$ 6,137,311	$ 8,516,564	$ 8,054,818	
Cash Inflows														
Cash Sales	$ -	-	3,900,000	-	3,900,000	-	3,900,000	-	3,900,000	-	3,900,000	-	3,900,000	**$ 23,400,000**
Accounts Receivable	$ -	-	-	-	-	-	-	-	-	-	-	-	-	$ -
Total Cash Inflows	$ -	$ -	$ 3,900,000	$ -	$ 3,900,000	$ -	$ 3,900,000	$ -	$ 3,900,000	$ -	$ 3,900,000	$ -	$ 3,900,000	**$ 23,400,000**
Cash Outflows														
Cost of Goods Sold	$ -	-	1,059,000	-	1,059,000	-	1,059,000	-	1,059,000	-	1,059,000	-	1,059,000	**$ 6,354,000**
Operating Activities														
Operating Expenses	**$ 463,272**	40,224	40,224	40,224	40,224	40,224	40,224	40,224	40,224	40,224	40,224	40,224	40,224	**$ 482,690**
Payroll	**$ 1,928,412**	166,088	166,088	166,088	166,088	166,088	166,088	166,088	166,088	166,088	166,088	166,088	166,088	**$ 1,993,059**
Financing Activities														
Loan Payments	**$ 3,065,210**	255,434	255,434	255,434	255,434	255,434	255,434	255,434	255,434	255,434	255,434	255,434	255,434	**$ 3,065,210**
Total Cash Outflows	**$ 5,456,893**	$ 461,747	$ 1,520,747	$ 807,926	$ 1,520,747	$ 461,747	$ 2,437,546	$ 461,747	$ 1,520,747	$ 812,844	$ 1,520,747	$ 461,747	$ 2,442,625	**$ 14,430,914**
Net Cash Flows	**$ (5,456,893)**	$ (461,747)	$ 2,379,253	$ (807,926)	$ 2,379,253	$ (461,747)	$ 1,462,454	$ (461,747)	$ 2,379,253	$ (812,844)	$ 2,379,253	$ (461,747)	$ 1,457,375	**$ 8,969,086**
Operating Cash Balance		$ 81,360	$ 2,460,614	$ 1,652,687	$ 4,031,941	$ 3,570,194	$ 5,032,648	$ 4,570,902	$ 6,950,155	$ 6,137,311	$ 8,516,564	$ 8,054,818	$ 9,512,193	
Line of Credit Drawdown	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Ending Cash Balance		$ 81,360	$ 2,460,614	$ 1,652,687	$ 4,031,941	$ 3,570,194	$ 5,032,648	$ 4,570,902	$ 6,950,155	$ 6,137,311	$ 8,516,564	$ 8,054,818	$ 9,512,193	
Line of Credit Balance		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	

Table 1-4 Cash Flow Year 3

	January	February	March	April	May	June	July	August	September	October	November	December	Year 3 Totals
Beginning Balance	$ 9,512,193	$ 9,041,747	$ 11,885,800	$ 10,969,530	$ 13,813,583	$ 13,343,137	$ 15,075,713	$ 14,605,267	$ 17,449,320	$ 16,527,454	$ 19,371,507	$ 18,901,061	
Cash Inflows													
Cash Sales	-	4,550,000	-	4,550,000	-	4,550,000	-	4,550,000	-	4,550,000	-	4,550,000	**$ 27,300,000**
Accounts Receivable	-	-	-	-	-	-	-	-	-	-	-	-	$ -
Total Cash Inflows	-	4,550,000	-	4,550,000	-	4,550,000	-	4,550,000	-	4,550,000	-	4,550,000	**$ 27,300,000**
Cash Outflows													
Cost of Goods Sold	-	1,235,500	-	1,235,500	-	1,235,500	-	1,235,500	-	1,235,500	-	1,235,500	**$ 7,413,000**
Operating Activities													
Operating Expenses	41,914	41,914	41,914	41,914	41,914	41,914	41,914	41,914	41,914	41,914	41,914	41,914	**$ 502,967**
Payroll	173,098	173,098	173,098	173,098	173,098	173,098	173,098	173,098	173,098	173,098	173,098	173,098	**$ 2,077,181**
Financing Activities													
Loan Payments	255,434	255,434	255,434	255,434	255,434	255,434	255,434	255,434	255,434	255,434	255,434	255,434	**$ 3,065,210**
Total Cash Outflows	$ 470,446	$ 1,705,946	$ 916,270	$ 1,705,946	$ 470,446	$ 2,817,423	$ 470,446	$ 1,705,946	$ 921,867	$ 1,705,946	$ 470,446	$ 2,823,204	**$ 16,184,336**
Net Cash Flows	$ (470,446)	$ 2,844,054	$ (916,270)	$ 2,844,054	$ (470,446)	$ 1,732,577	$ (470,446)	$ 2,844,054	$ (921,867)	$ 2,844,054	$ (470,446)	$ 1,726,796	**$ 11,115,664**
Operating Cash Balance	$ 9,041,747	$ 11,885,800	$ 10,969,530	$ 13,813,583	$ 13,343,137	$ 15,075,713	$ 14,605,267	$ 17,449,320	$ 16,527,454	$ 19,371,507	$ 18,901,061	$ 20,627,857	
Line of Credit Drawdown	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Ending Cash Balance	$ 9,041,747	$ 11,885,800	$ 10,969,530	$ 13,813,583	$ 13,343,137	$ 15,075,713	$ 14,605,267	$ 17,449,320	$ 16,527,454	$ 19,371,507	$ 18,901,061	$ 20,627,857	
Line of Credit Balance	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	

Table 1-5 Income Statement Year 1

	January	February	March	April	May	June	July	August	September	October	November	December	Annual Totals
Revenue													
Aquaculture	-	-	-	-	-	-	-	-	-	-	-	-	$ -
Total Revenue	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Cost of Goods Sold													
Aquaculture	-	-	-	-	-	-	-	-	-	-	-	-	$ -
Total Cost of Goods Sold	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Gross Margin	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Payroll	$ 160,701	$ 160,701	$ 160,701	$ 160,701	$ 160,701	$ 160,701	$ 160,701	$ 160,701	$ 160,701	$ 160,701	$ 160,701	$ 160,701	$ 1,928,412
Operating Expenses													
Advertising	500	500	500	500	500	500	500	500	500	500	500	500	$ 6,000
Accounting and Legal Fees	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	$ 36,000
Utilities	500	500	500	500	500	500	500	500	500	500	500	500	$ 6,000
Office Rent/Berths	3,107	3,107	3,107	3,107	3,107	3,107	3,107	3,107	3,107	3,107	3,107	3,107	$ 37,284
Phone Plan	720	720	720	720	720	720	720	720	720	720	720	720	$ 8,640
Insurance	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	$ 240,000
Personnel Groceries	5,400	5,400	5,400	5,400	5,400	5,400	5,400	5,400	5,400	5,400	5,400	5,400	$ 64,800
Fuel	3,500	3,500	3,500	3,500	3,500	3,500	3,500	3,500	3,500	3,500	3,500	3,500	$ 42,000
Repairs and Maintenance	1,879	1,879	1,879	1,879	1,879	1,879	1,879	1,879	1,879	1,879	1,879	1,879	$ 22,548
Total Operating Expenses	$ 38,606	$ 38,606	$ 38,606	$ 38,606	$ 38,606	$ 38,606	$ 38,606	$ 38,606	$ 38,606	$ 38,606	$ 38,606	$ 38,606	$ 463,272
Income (Before Other Expenses)	$ (199,307)	$ (199,307)	$ (199,307)	$ (199,307)	$ (199,307)	$ (199,307)	$ (199,307)	$ (199,307)	$ (199,307)	$ (199,307)	$ (199,307)	$ (199,307)	$ (2,391,684)
Other Expenses													
Amortized Start-up Expenses	9,576	9,576	9,576	9,576	9,576	9,576	9,576	9,576	9,576	9,576	9,576	9,576	$ 114,909
Depreciation	31,010	31,010	31,010	31,010	31,010	31,010	31,010	31,010	31,010	31,010	31,010	31,010	$ 372,120
Interest													
Commercial Loan	78,938	78,615	78,288	77,957	77,623	77,285	76,944	76,599	76,250	75,898	75,541	75,181	$ 925,119
Commercial Loan 2	69,818	68,986	68,144	67,294	66,435	65,566	64,687	63,800	62,902	61,995	61,078	60,151	$ 780,856
Total Other Expenses	189,342	188,186	187,018	185,837	184,643	183,437	182,217	180,984	179,738	178,478	177,205	175,918	$ 2,193,004
Net Income Before Income Tax	$ (388,649)	$ (387,493)	$ (386,325)	$ (385,144)	$ (383,950)	$ (382,744)	$ (381,524)	$ (380,291)	$ (379,045)	$ (377,785)	$ (376,512)	$ (375,225)	$ (4,584,688)
Income Tax	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Net Profit/Loss	$ (388,649)	$ (387,493)	$ (386,325)	$ (385,144)	$ (383,950)	$ (382,744)	$ (381,524)	$ (380,291)	$ (379,045)	$ (377,785)	$ (376,512)	$ (375,225)	$ (4,584,688)

Table 1-6 Balance Sheet Years 1-3

ASSETS	2019	2020	2021
Current Assets			
Cash	543,107	9,512,193	20,627,857
Inventory	100,000	100,000	100,000
Prepaid Expenses	228,485	114,243	-
Other Initial Costs	1,333	667	-
Total Current Assets	$ 872,925	$ 9,727,102	$ 20,727,857
Fixed Assets			
Real Estate -- Buildings	3,600,000	3,600,000	3,600,000
Leasehold Improvements	3,000	3,000	3,000
Equipment	2,972,000	2,972,000	2,972,000
Furniture and Fixtures	10,000	10,000	10,000
Vehicles	680,000	680,000	680,000
Other	21,600	21,600	21,600
Total Fixed Assets	$ 7,286,600	$ 7,286,600	$ 7,286,600
(Less Accumulated Depreciation)	$ 372,120	$ 744,240	$ 1,116,360
Total Assets	$ 7,787,405	$ 16,269,462	$ 26,898,096
LIABILITIES & EQUITY			
Liabilities			
Commercial Loan Balance	6,906,158	6,473,202	5,980,485
Commercial Mortgage Balance	5,465,936	4,352,038	3,084,387
Total Liabilities	$ 12,372,094	$ 10,825,241	$ 9,064,872
Equity			
Retained Earnings	(4,584,688)	5,444,222	17,833,225
Total Equity	$ (4,584,688)	$ 5,444,222	$ 17,833,225
Total Liabilities and Equity	$ 7,787,405	$ 16,269,462	$ 26,898,096

Table 1-7 Income Statement Years 1-3

Revenue	2019		2020		2021	
Aquaculture	-		23,400,000		27,300,000	
Total Revenue	$ -	100%	$ 23,400,000	100%	$ 27,300,000	100%
Cost of Goods Sold						
Aquaculture	-		6,354,000		7,413,000	
Total Cost of Goods Sold	-	0%	6,354,000	27%	7,413,000	27%
Gross Margin	-	0%	17,046,000	73%	19,887,000	73%
Payroll	1,928,412		1,993,059		2,077,181	
Operating Expenses						
Advertising	6,000		6,180		6,365	
Accounting and Legal Fees	36,000		37,800		39,690	
Utilities	6,000		6,180		6,365	
Office Rent/Berths	37,284		38,403		39,555	
Phone Plan	8,640		8,899		9,166	
Insurance	240,000		252,000		264,600	
Personnel Groceries	64,800		66,744		68,746	
Fuel	42,000		43,260		44,558	
Repairs and Maintenance	22,548		23,224		23,921	
Total Operating Expenses	$ 463,272	0%	$ 482,690	2%	$ 502,967	2%
Income (Before Other Expenses)	$ (2,391,684)	0%	$ 14,570,251	62%	$ 17,306,852	63%
Other Expenses						
Amortized Start-up Expenses	114,909		114,909		114,909	
Depreciation	372,120		372,120		372,120	
Interest						
Commercial Loan	925,119		872,606		812,844	
Commercial Loan 2	780,856		645,751		491,997	
Total Other Expenses	$ 2,193,004	0%	$ 2,005,386	9%	$ 1,791,870	7%
Net Income Before Income Tax	$ (4,584,688)		$ 12,564,865		$ 15,514,982	
Income Tax	$ -		$ 2,535,955		$ 3,125,978	
Net Income/Loss	$ (4,584,688)	0%	$ 10,028,910	43%	$ 12,389,004	45%

1.6 Microgrid Design

1.6.1 Load Description and Microgrid Layout

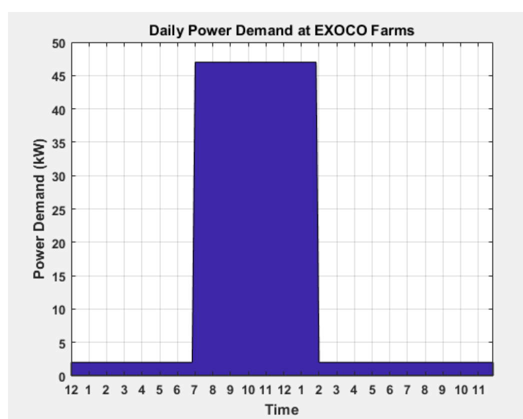


Figure 1-6 Plot of a daily power demand of EXOCO Farms.

Figure 1-6 is a plot showing the daily power demand at EXOCO Farms. The high energy consumption in the middle of the day is attributed to the fish feeding system. The fish are fed once and lasts approximately 6-7 hours per day [10]. The equipment used during the feeding process is an air compressor, pumps, and rotary valves. On the feed barge are silos that hold feed pellets. The feed pellets are moved from the feed barge to the fish pens via a pressurized air and fluid system. At the pens, there is a volute that funnels feed pellets into the water to feed the fish. When the fish are being fed, the power demand is approximately 47 kW for seven hours which equates to an energy demand of 329 kWh. The rest of the day, the base load of the aquaculture operation is 2 kW for monitoring, lights, cameras, hotel load on the feed barge, etc. for 17 hours which equates to 34 kWh. The total daily energy demand is 363 kWh. The total energy demand is a conservative estimate.

Today, most offshore aquaculture farms utilize diesel generators for power generation located either on the stationary feed barge or support vessels that travel daily to the offshore operation. The combination of the predictable daily energy demand and the potential to harness an abundant wind resource in an open ocean environment makes the offshore aquaculture electrical load suitable for a high penetration islanded microgrid which would have a properly sized wind turbine and a storage device, like a battery. During peak load (i.e. feeding the fish), the wind turbine can provide most of the power generation, and the battery can share the load when applicable. When the fish are not being fed, the wind turbine can store wind energy in the battery and be the main power generator for the instantaneous electrical load.

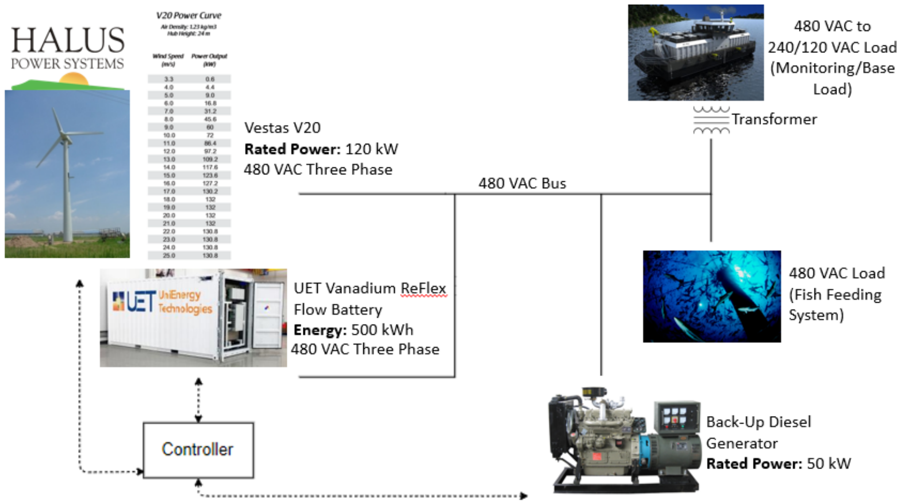


Figure 1-7 Microgrid electrical layout at EXOCO Farms.

Figure 1-7 is a depiction of the high penetration microgrid used at EXOCO Farms. There will be a wind turbine and battery, both would be sitting on a purchased used ocean barge. On the feed barge, there will be a back-up generator that will turn on only when the wind turbine is not producing any power and the battery is completely discharged. The microgrid will be a high penetration system with an advanced control system to autonomously direct load sharing to the appropriate energy resource. The control system chosen for the system is a Real Time Automation Controller (SEL-3530) from Schweitzer Energy Laboratories.

1.6.2 Wind Turbine Selection

We considered two wind turbine manufactures in the selection process for the wind turbine in the microgrid. The first was Northern Power Systems 60 kW and 100 kW wind turbines. The turbine has a 24 meter rotor, direct drive gearbox, and low cut-in wind speed. Northern Power Systems is a credible company with a track record of quality products and successful projects all over the world. Most notably, they have had successful projects in harsh environments like Alaska [36]. The cost of the NPS's turbines are approximately $2.50/W for a land-based installation [37]. The second manufacturer is Vestas. Approximately forty miles from CSU Maritime Academy in San Leandro, CA is Halus Power Systems. Halus Power Systems buys used Vestas V17, V19, V20, V27 and V39 wind turbines, remanufactures the WT's in-house, and resells them. In addition, Halus designs and manufactures many new wind turbine components including WT control systems. The cost of Halus' remanufactured wind turbines are approximately $2/W with a yearly operation and maintenance cost of $35/kW [38]. Ultimately, we chose to purchase a Vestas V20 from Halus Power Systems to use for the for the EXOCO microgrid. The Vestas V20 has a rated power of 120 kW, fixed pitch hub with a rotor diameter of 20 m and rotor height of 23 m. The rated speed is 13 m/s and cut-in wind speed is 4.5 m/s. The Vestas V20 was a workhorse machine from the early wind turbine market. The V20 was chosen because of its robust gearbox design and successful applications in harsh climates [38]. We had the opportunity to tour Halus Power Systems shop in San Leandro, CA and saw firsthand the remanufacture and refurbishment process. At $2/W, the turbine cost $240,000 and O&M cost is $4,200 (see Figure 1-3).

1.6.3 Battery Storage Selection

Due to the daily fluctuating electrical load and the goal of charging the battery when EXOCO Farms is not feeding, the most important characteristic of the battery was that the battery could be charged and discharged daily. The most common batteries available on the market today are lithium ion and lead acid batteries. However, both battery types have their limitations. Lithium ion batteries have a short life span when charged and discharged often, and typically have a rated number of cycles before the batteries need to be replaced. Deep cycle lead acid batteries have the capability to charge and discharge often but are limited in how deep the battery can be discharged. Deep cycle lead acid batteries can be discharged down to approximately 20% state of charge, but like lithium ion, their overall lifespan is compromised. For EXOCO Farms microgrid, we selected a vanadium redox flow battery from UniEnergy Technologies. Specifically, we selected a UniEnergy's ReFlex 500 kWh_{AC} battery. The ReFlex battery has a 20-year lifespan with an unlimited number of cycles. Also, the vanadium flow battery can charge and discharge down to 100% state of charge without compromising the lifespan of the battery [39]. The battery technology is enclosed in a twenty-foot shipping container making the housing ideal for the marine environment. The ReFlex battery outputs 480 VAC with its integrated AC to DC to AC inverter and has a roundtrip efficiency of approximately 70% [39]. Lastly, EXOCO Farms' electrical load fits nicely with a slow discharge of the ReFlex battery. For example, if the WT was not providing any energy and the ReFlex battery was the only energy source, the battery has the capability to discharge 64 kW_{AC} for eight hours. The maximum power demand of EXOCO Farms is approximately 47 kW for seven hours. At this discharge rate, we can maximize the full energy capacity of the battery, 500 kWh_{AC}. When a battery is discharged quickly, the efficiency of the battery decreases dramatically. In addition, at a maximum energy capacity of 500 kWh_{AC}, the ReFlex battery has the capability to provide energy for EXOCO Farms for approximately 1.25 days without relying on the back-up diesel generator. The cost of the ReFlex battery is between $600-800/kWh with a yearly O&M of 2% of initial cost per year [40]. At $800/kWh the battery costs $400,000 and the O&M is $2000 per year (see Figure 1-3).

1.6.4 EXOCO Microgrid Simulation Analysis

To simulate how often EXOCO Farms would need to run the back-up diesel generator, we used meteorological data taken from an offshore NOAA buoy in relative proximity to the proposed location of the EXOCO Farm. The data was take from station 42019 located in the Gulf of Mexico approximately 60 nautical miles south of Freeport, TX. For the simulation, we used a year's worth of data from the year 2016 with a data point taken every ten minutes. The data taken from buoy 42019 was date, time, and wind speed [41]. Using the wind speed data point taken every ten minutes, we were able to interpolate a power output for each data point from EXOCO's Vestas V20 using the wind turbines power curve. Then, we created an electrical load of EXOCO's Farms for the entire year by repeating Figure 1-6 every day for 365 days. Lastly, an algorithm was written in Matlab to calculate the net power of the farm at each data point: power from the wind turbine minus the electrical load demand. If the net power was positive, the wind turbine was producing enough energy to supply the farm and the excess energy would charge the ReFlex battery. If the net power was negative, then the battery would load share with the wind turbine. The algorithm started the battery at full charge, 500 $kWh_{AC.}$ A command was written in the algorithm that when the net power was negative, and the battery's state of charge was 10% charged, then the back-up diesel generator would start-up to supply the needed energy to the farm. An efficiency factor of 0.70 was applied to the energy going in and out of the battery to account for efficiency losses in storage and the conversion from AC to DC or DC to AC. Figure 1-9 is a plot showing the state of charge of the ReFlex battery for an entire year. In addition, Figure 1-8 is a plot showing the fuel consumption of the back-up diesel generator throughout the year. From this analysis, we found that the back-up diesel generator would need to run for 366 hours for the year, which approximately equates to 800 gallons of fuel. In terms of greenhouse gas emissions, burning 800 gallons of diesel fuel equates to approximately 8.12 metric tons of carbon dioxide released into the atmosphere. When compared to a hypothetical situation in which EXOCO Farms did not use a wind turbine or battery storage and only relied on a diesel generator, the farm would burn 11,539 gallons of diesel fuel which equates to 117 metric tons of carbon dioxide released into the atmosphere. The 11,539 gallons was calculated by interpolating a standard 50 kW diesel generator's fuel rate with the net power demand from the farm taken at ten minute intervals [42]. That is approximately a 93% percent reduction in CO_2 emissions. As a comparison, the average passenger vehicle emits approximately 4.7 tons of CO_2 per year [43]. Therefore, the EXOCO Farms would emit less than two passenger vehicle car's worth of $C0_2$ emission per year.

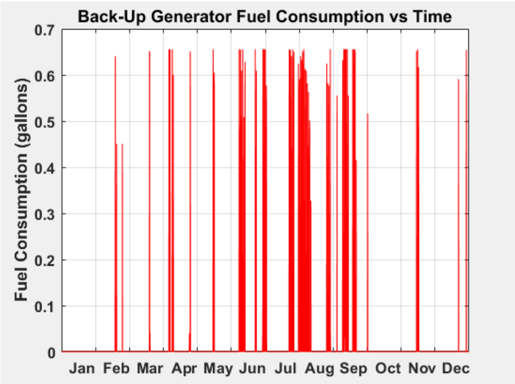


Figure 1-9 Plot showing fuel consumption of back-up diesel generator during microgrid simulations analysis.

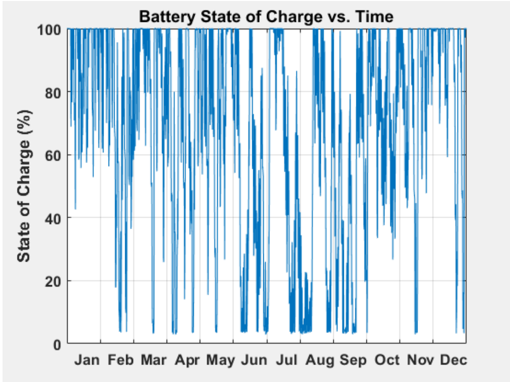


Figure 1-8 Plot showing ReFlex state of charge for a year during microgrid simulations analysis.

1.6.5 Barge Stability

The Vestas V20 wind turbine and the ReFlex battery will be placed on a large used ocean barge and float alongside EXOCO Farms. The barge will be moored to the sea floor with rope and chain moorings. Typically, offshore wind turbines that are floated use submersible or semi-submersible technology which float commercial wind turbines, 1 MW and greater. However, for EXOCO Farms, the Vestas V20 wind turbine is relatively light, approximately 11,979 kg, and relatively short, 24 m compared to wind turbines rated at above 1 MW. To validate this relatively novel plan, we performed a stability calculation of the wind turbine on the barge. For floating vessels or barges, a common analysis is to develop a static stability curve. A static stability curve is a plot that has angle of heel on the x-axis and the length of righting arm on the y-axis. The static stability curve determines the range of stability of the vessel. Once the righting arm becomes negative, the vessel will capsize. We chose a common size barge which is about 195' x 35' x 19'. Since the wind turbine has yawing capabilities, the worst-case scenario is when the barge will be heeling when the beam of the barge is equal to 35 feet. Because the Vestas V20 is approximately 1% the weight of an ocean barge, the center of gravity of the barge and wind turbine assembly is approximately in the same location if the wind turbine was not on the barge. Figure 1-10 is a plot showing the static stability curve for the barge and wind turbine assembly. The blue curve is the static stability curve of the barge without the wind turbine. As you can see, the righting arm of the righting moment is positive through 20 degrees of heel which means the barge will not capsize up to 20 degrees of heel. The red curve on the plot is a correction factor to include the thrust force applied to the

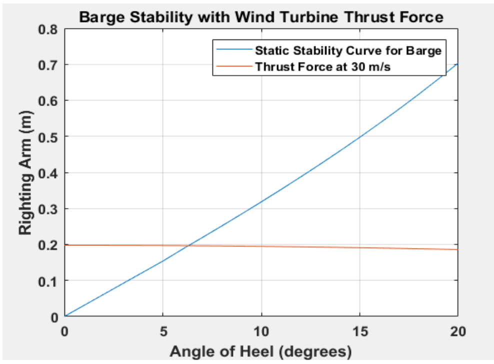


Figure 1-10 Plot of heeling righting arm vs angle of heel of barge.

wind turbine. When the thrust force from the tubular tower and the rotor were applied, both forces apply a moment to the barge. A drag coefficient of 0.7 was applied to the tower and a 0.889 thrust coefficient was applied to the rotor. The intersection point of the two curves show the angle of heel with the thrust moment applied to the barge. As you can see from the plot, the angle of heel is approximately two degrees. A similar situation is a crane on a barge. The safety standard for a crane lifting a heavy load is that the barge can't heel greater than fifteen degrees [44]. This was the safety standard chosen for this analysis.

Chapter 2: Technical Design

2.1 Test Turbine Related to Market Turbine

The test turbine is supposed to mimic a scaled down version of the Vestas V20, the market turbine. Table 2-1 outlines a comparison detailing the characteristics of the test turbine and the market turbine, a Vestas V20. In terms of rated power, our test turbine is approximately 1:3000 scale. The rated power of the test turbine is 40 W and the rated power of the Vestas V20 is 120 kW. Most notably, the hub design and control system are similar. Both the Vestas V20 and the test turbine utilize a stall controlled, fixed pitch design to shed power at high wind speeds. However, the Vestas V20 is fixed speed and the test turbine is variable speed [38]. The six volt load used by the test turbine during testing is similar to the Vestas V20 charging the 500 kWh ReFlex flow battery. However, during the durability task, the varying resistive load and storage element is an identical electrical layout to how our market turbine will be operating. Depending on the velocity of the wind, the Vestas V20 market turbine will be either providing power to the resistive load directly or will be sharing the electrical load with the storage element, the 58 Farad capacitor. Instead of the capacitor, the market turbine shares the power load with the ReFlex flow battery.

Table 2-1 Comparison of market turbine vs. test turbine

	Market Turbine (Vestas V20)	Test Turbine
Rated Power (W)	120,000	40
Control System	Stall Controlled, Fixed Pitch	Stall Controlled, Fixed Pitch
Generator	Induction	Synchronous
Number of Blades	Three	Three
Yaw System	Active	Passive
Tower	Tubular	Tubular
Blade Design	NACA 44	GOE 195
Blade Material	Reinforced Fiberglass	PLA Reinforced with Carbon Fiber
Brake Assembly	Hydraulic Actuation	Electrical
Rotor Axis	Horizontal	Horizontal
Wind Direction	Upwind	Upwind

2.2 Mechanical Design

2.2.1 Overview

Figure 2-1 is a picture of an exploded view of the entire assembly of the test turbine. The fixed hub was made from 6061 aluminum, pictured in Figure 2-2. The hub shaft was turned on a manual lathe. Then, the blade root attachments were machined with a Haas TM-1 vertical mill. The hub cone made from brass was manufactured on a Hass CNC lathe. The tower is made from a carbon fiber tubing (OD = 1.75", ID = 1.47") donated by an industry partner. The 6061 aluminum inserts at each end were machined on a manual lathe and single point threaded on a manual lathe. The inserts were bonded to the inside diameter of the carbon fiber tubing using EA 9394 epoxy. A bond line controller with a 0.007" tolerance was utilized to control the

Figure 2-1 Test turbine top assembly exploded view.

bond gap between the aluminum insert and the carbon fiber tubing. All parts manufactured by hand or using a CNC mill/lathe were done by students at the machine shop at CSU Maritime Academy. The aerodynamic nacelle and fairing were manufactured with a fused deposition modelling 3D printer.

2.2.2 Passive Yaw Assembly

The yaw design on the test turbine is a “free yaw” or passive yaw system that incorporates a bearing assembly and tail to direct the rotor axis into the wind. Figure 2-3 is a picture of the yaw bearing assembly. The shaft and sleeve are both made of 6061 Aluminum. The shaft was manually turned on a lathe. The internal threads attaching the yaw bearing assembly to the tower were cut using an internal boring bar and single point threaded. The sleeve was manufactured using a CNC vertical mill to ensure tight tolerances between the sleeve wall and bearing races. The bearing races were pressed into the sleeve using an arbor press. The two tapered roller bearings were pressed on the aluminum shaft with a press fit using an arbor press. The radial load capacity on the tapered roller bearings is 29.6 kN static load and the thrust load capacity is 34.5 kN static load [45]. At 20 m/s, the expected thrust force on the tower using a 0.7 thrust coefficient is 3.89 N and the expected thrust force on the rotor using a thrust coefficient of 0.889 is 34 N [46][47].

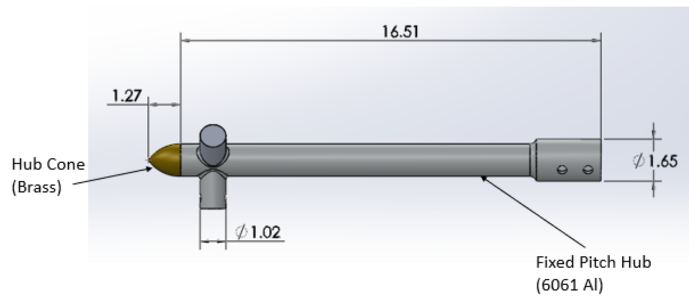


Figure 2-2 Fixed pitch hub detailing basic dimensions (cm) and material type.

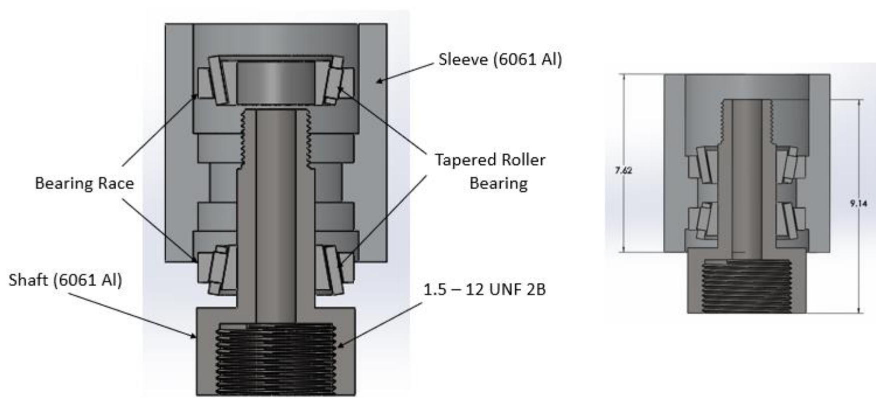


Figure 2-3 Bearing assembly detailing basic dimensions (cm) and material type.

2.2.3 Tail Analysis

The delta wing tail design was chosen due to its favorable aerodynamic characteristics and its developed research. Specifically, delta wings have a high stall angle which equates to a high restoring moment when the rotor has been turned away from the direction of the wind. The basic geometry of a delta wing is: r is the distance from the yaw axis to the center of pressure of the delta wing, c is the chord length, and b is the height of the wing. We employed the “pseudo-static,” to model a second order linear differential equation that describes the one degree of freedom equation of motion of the tail fin about the yaw axis where θ is the angle between the wind direction and the tail fin and φ is the wind direction [48]. For our purposes, the wind direction, φ, is equal to zero because the wind direction from the wind tunnel is always from the same direction and a fixed coordinate system was chosen. The natural frequency, ω_n, and the damping ratio, ζ, are defined Equations 2.1.

$$\omega_n = U_{wake}\sqrt{\frac{\rho r A K}{2I}} \quad , \quad \zeta = \sqrt{\frac{\rho r^3 A K}{8I}} \qquad 2.1$$

U_{wake} is defined as the wind speed experienced by the tail in the wake of the rotor, ρ is the air density, A is the tail fin area, K is defined by πb/c, and I is the inertia about the yaw axis that includes the tail fin, nacelle, yaw assembly, and tail boom. For the tail analysis, the following assumptions were made: all angles are assumed to be small, the drag is neglected, the frictional forces in the yaw assembly are neglected, the axial induction factor to calculate U_{wake} is 0.33 (Betz limit) and the tail fin's lift is linear with slope of K [48]. Our biggest design consideration for the tail design was that we wanted the rotor to turn back into the wind as quickly as possible. In turn, we wanted a high damping ratio. To have a high damping ratio, the length r is the largest contributor to the damping ratio value because it is a cubic function. Therefore, we wanted r to be as large as possible, but staying within the competition geometric design constraints. Figure 2-4 is a plot showing the solution to the first order linear differential equation in which the value of r was varied between 0.0562 to 0.169 m. The initial position of the tail was at an angle of 30 degrees and zero initial velocity. For our final tail design, we made the distance from the yaw axis to the center of pressure of the tail fin to be 15 cm and the tail dimensions we chose were c = 10 cm and b = 40 cm. For the tail material, we tested a thin sheet metal but observed the tail flapping at wind speeds up to 12 m/s. Therefore, we chose a stiffer material, 6061 Aluminum with a thickness of 1/8 inches.

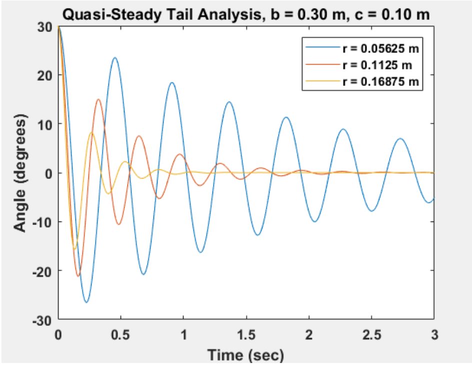


Figure 2-4 Quasi-steady tail analysis comparing various tail lengths.

2.3 Blade Design

2.3.1 Airfoil Features

The blade utilizes two airfoils, the GOE 195, and the GOE 430 [49][50]. The thinner airfoil at the tip, GOE195, is chosen for superior aerodynamics, and the thick airfoil at the root, GOE430, is chosen for strength and stiffness. The GOE 430 has a max thickness of 13.38% of the chord, and the GOE 195 has a max thickness of 8.60%. The PLA blades were 3D printed.

2.3.2 Blade Design Process

QBlade, an open source software, was used to design and run aerodynamic simulations for blades. The Reynolds Number used for this analysis was approximated to be 50,000 based on a tip speed ratio of 6.5 and wind speeds from 5-11 m/s and a chord 0.123 m. Airfoils were chosen from airfoiltools.com and lift/drag polars were platted in Q-Blade [51][52]. Looking at Figure 2-5 the GOE195 was 42.2 and occurred at a 7.5-degree angle of attack. Conversely the GOE 430 has lower lift/drag properties.

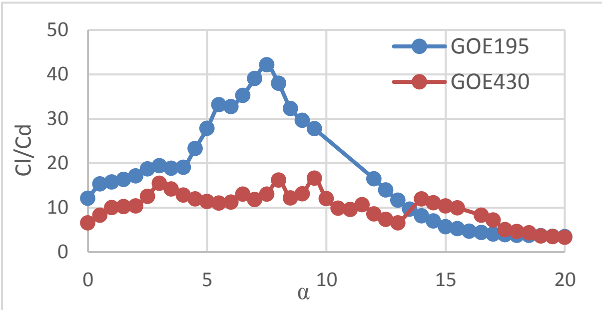


Figure 2-5 QBlade lift-to-drag ratio analysis plotted against angle of attack

Using a Schmitz optimization, blades were created using a variety of design tip-speed-ratios ($\lambda = \frac{\Omega R}{U}$, where Ω is the angular velocity of the blade, U is the velocity of the incoming wind, and R is the length along the blade) and angle of attack, α, in degrees [53]. The number of sections was set at 40, the radius of the rotor was 0.225m, and the radius of the hub was 0.01833m. By adjusting the design λ and α, an iterative process began which had a goal of designing a blade with high power at high wind speeds as well as a low cut in speed. Figure 2-6 shows the theoretical coefficient of power versus λ. As the design λ and α increase, the max power increases, the speed at which the max power is produced increases, and the physical dimensions of the blade decreases. For the λ=6.5, α=3.5 blades, the maximum C_p=0.42 occurs at λ=4.5. At 11 m/s and R = 0.225 m, this corresponds to 54 W and 2100 rpm. For the purposes of the report, we will use this case as our basis for all theoretical analyses. The blade description is detailed in Table 2-2.

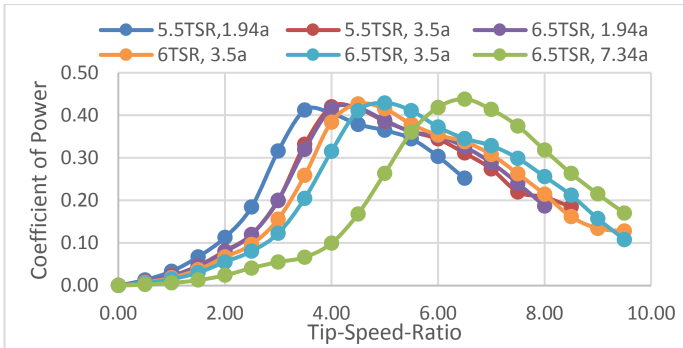


Figure 2-6 Coefficient of power vs tip-speed-ratio comparison

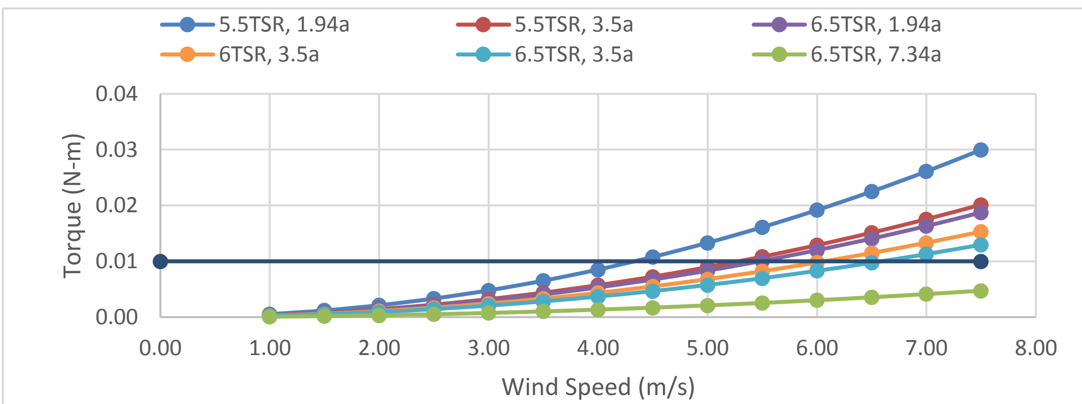


Figure 2-7 Torque vs wind speed at start-up comparison ($\Omega = 0$)

Table 2-2 Blade Design Description

Distance From Root (m)	Chord (m)	Pitch Angle (deg)	Airfoil
0.018	0.048	37.898	GOE430
0.039	0.047	24.229	Blend
0.060	0.038	16.581	Blend
0.080	0.031	12.041	GOE195
0.101	0.026	9.112	GOE195
0.122	0.022	7.088	GOE195
0.142	0.019	5.613	GOE195
0.163	0.017	4.493	GOE195
0.184	0.015	3.616	GOE195
0.204	0.013	2.910	GOE195

2.3.3 Blade Manufacturing

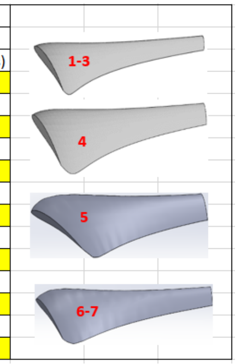
Blades were 3D printed using a MakerBot Replicator+ and PLA filament. They were oriented with the leading edge on the bed, with a slight tilt so that the tip of the blade was just off the bed. This was done to reduce curling of the blade during the printing process. Once the blades were printed, they were sanded to remove any discrepancies, then epoxied. We also explored a carbon fiber wrapping to increase blade stiffness and strength, and may apply the carbon fiber process to the final blade set.

2.3.4 Testing and Iterations

The blade detailed in Table 2-2 and several other blade designs were manufactured to empirically determine their power and start-up characteristics. The biggest problem we faced during the blade design process was overcoming the cogging torque of the generator. We performed an experimental test and determined the cogging torque was about 0.01 Nm. Using trends shown in Figure 2-7, several iterations of blades were designed and tested with the goal of optimizing maximum power and low start-up. Refer to Table 2-3 for blade descriptions and results. Blade iteration seven is our latest blade design and appears to be a balance between optimizing power and low start-up. However, for the purposes of this report, iteration one was used for all theoretical analyses.

Table 2-3 Blade Iterations

	Blade Design				Test Results	
Iteration	Root Chord (mm)	Tip Chord (mm)	Root Pitch (Deg)	Tip Pitch (Deg)	Power (W)	Start-Up Speed (m/s)
1	48.26	12.19	37.90	2.33	43.2	6.6
2	48.26	12.19	44.40	8.83	25.8	5.5
3	48.26	12.19	41.40	5.83	33.2	6.1
4	72.39	22.86	41.97	4.93	31.7	4.5
5	72.39	22.86	53.97	4.93	29.3	3.5
6	64.52	16.51	52.06	3.89	31.3	6
7	64.52	16.51	47.06	3.89	41.5	5.5



2.3.5 Blade Loading

Upon selecting a blade design, a Matlab script to evaluate mechanical blade loads was written. QBlade was used to generate a matrix of chord length, airfoil thickness, camber measurements and flapwise force at 40 radial sections spanning from root to tip. Flapwise force distributions were examined for the entire 6-20 m/s power curve using QBlade simulations, with the worst-case scenario occurring at peak power at 11 m/s wind speed. While performing tensile tests on a universal testing machine on our campus, 3D printed PLA having density 1.25 g/cm^3 [54] was observed to have a Young's modulus of 2.1 GPa and yield strength of 34.5 MPa. This information was used to approximate area and second moment of inertia at each cross section [55]. Then integrations were preformed to determine mass to the tip, shear force and bending moment at each blade section. Centripetal acceleration and axial force were found using the maximum anticipated rotor speed of 3300 rpm*. Bending moment was used to calculate bending stress and axial force was used to calculate axial stresses seen in Figure 2-9. Euler-Bernoulli

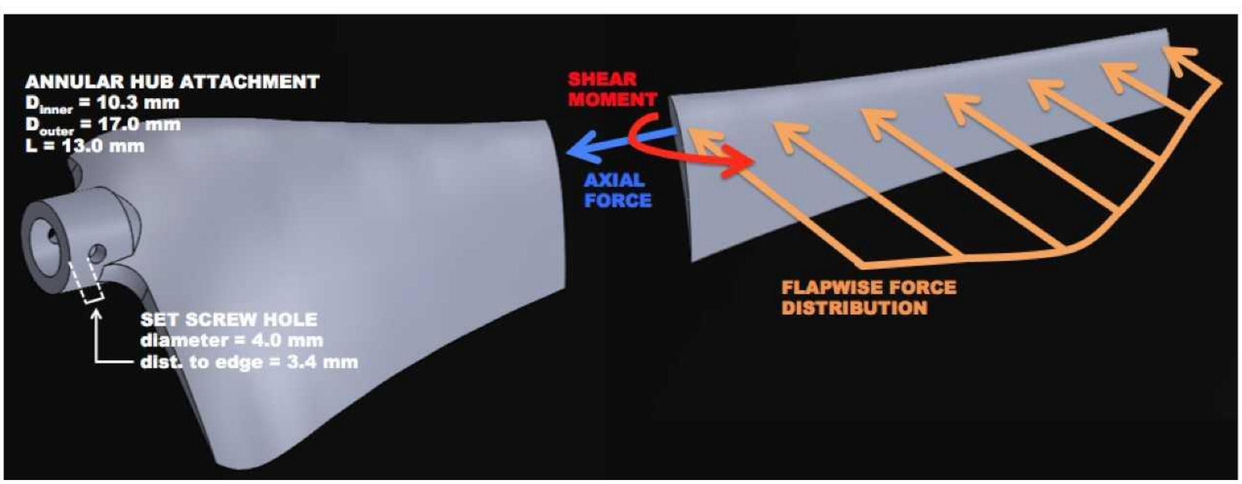


Figure 2-8 FBD of load terminology described in this section.

beam theory is used to determine blade deflection, however this simple analysis fails to account for blade twist; which should actually strengthen the beam (Figure 2-9, right). Analysis results indicate blade bending stress as the primary failure mode, with the safety factor dipping as low as 2.3 half way between the blade root and tip. However, the blades exhibit significantly less deflection than suggested by this analysis since centrifugal stiffening effects are ignored. In practice, we've observed that wrapping the blade in carbon fiber and epoxy resin nullifies the predicted 8-mm tip deflection by providing extra flexural stiffness.

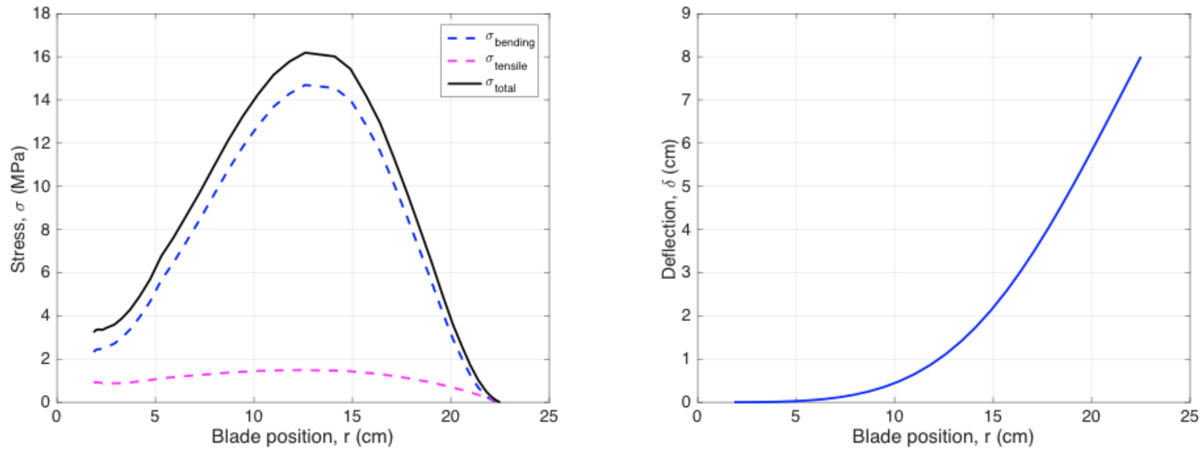


Figure 2-9 (left) Stress distribution along length of blade (right) Blade deflection along length of blade.

Using the 151.3-N axial force found to be acting at the blade root, we analyzed three additional stresses: tensile stress in the root attachment, and the bearing (compressive) and tear-out (shear) stresses presented by the setscrew hole. As indicated in Figure 2-8, the bearing stress at the setscrew provides a secondary failure mode, with a safety factor of 3.0.

***** Although QBlade simulations indicate a maximum rotor speed of ~2200 rpm while producing rated power at 11 m/s, max. speed actually occurred around 3300 rpm during testing (refer to section 2.6).

2.4 Electronics

2.4.1 Motor Selection

During the motor selection process, we wanted the following three characteristics in our generator: low cogging torque (magnetic forces between the permanent magnets of the rotor and stator slots) to maximize start-up at low wind speeds during the cut-in wind speed task, a voltage constant between 3.50-4.50 V/krpm to obtain a range of 4-15 V at speeds between 1000-3500 rpm, and low armature resistance to reduce power loss in the armature at high current applications. Using the criteria listed above, we purchased two three-phase brushless DC motors: ElectroCraft RapidPower 23 and an Applied Motion BL100-H03-I delta connected, 8 pole. Table 2-4 shows the highlighted specifications for each motor. The cogging torque was measured using weights to simulate the force and the lever arm was the distance between the line of action of the weights (force) and the rotational axis. Although the ElectroCraft 23 had considerable less cogging torque, the Applied Motion BL100-H03-I was ultimately selected due to its low

Table 2-4 Motor Comparison

	ElectroCraft RP 23	Applied Motion BL100-H03-I
Voltage Constant (V/krpm)	3.4	4.6
Armature Resistance (ohms)	0.88	0.18
Cogging Torque (Nm)	0.00318	0.01034

armature resistance. After selecting the Applied Motion BL100-H03-I, we used a dynamometer to measure open circuit voltage at various speeds and current at various resistive loads.

2.4.2 Performance Analysis

The first step in the design of the turbine's power system was a performance analysis. A range of operating conditions were developed by combining theoretical models of the electrical power system and aerodynamic power. Two primary objectives are targeted in this analysis. First, a range of operating conditions were determined, allowing design of the electronics for a set of extreme circumstances. Second, characteristic optimal power curves were defined as a function of rotor speed and wind speed. These curves provide a model for our control system to target as well as a theoretical marker for the evaluation of our testing data.

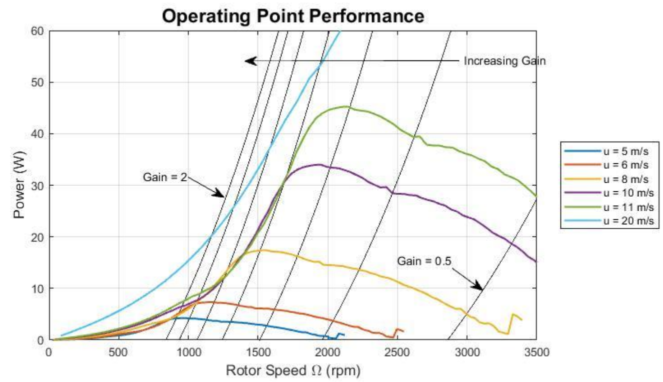


Figure 2-10 Electronic power curves superimposed over aerodynamic power curves which correspond to blade iteration 1 seen in section 0.

Once a viable blade design has been identified, C_p – TSR data is taken from QBlade and dimensionalized to create power curves as a function of rotor speed for each integer wind speed between 5 m/s and 20 m/s. MATLAB was used to generate curves and plots. A subset of the resulting power curves can be seen in Figure 2-10. The turbine's characteristic power curve (Figure 2-11) was generated by taking the maximum power point from each of the power curves from 5 m/s to 11 m/s. Power was capped at the peak value corresponding to the rated speed of 11 m/s. Figure 2-11 also shows rotor speed as a function of wind speed to illustrate that the rotor speed will be reduced at higher wind speeds to cap power.

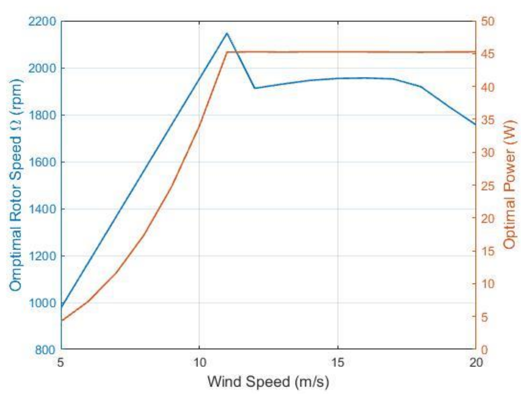


Figure 2-11 Power and rotor speed as a function of wind speed for blade iteration 1 as seen in section 0.

A DC/DC buck-boost converter (BBC) is utilized as the hardware mechanism of control of the turbine. The BBC controls the turbine by applying a gain to the input voltage from the turbine. Voltage gain is defined as the ratio of the voltage out of the BBC to the voltage in. It is important to note that this in/out convention is defined with respect to the BBC as it will be used throughout this text. Concepts related to the electronic system will be discussed further in later sections. An algebraic model of the electronic system was created, which included the generator output, BBC, load, and parasitic losses. Figure 2-12 shows a graphical depiction of the electrical characteristics of the major system components. Equation set 2.2 shows the final equation used to generate the electronic power curves. Individual curves for the electronic system were generated with voltage gain (G) as the varying parameter. These were superimposed over the aerodynamic power curves (Figure 2-10). Each intersection of the two power curve types represents a theoretical operating point. The electric power system required this initial step, mainly to determine the viability of a load and size the components of the BBC. Later in the design process this performance analysis helped determine aspects of the control theory. A purely resistive load was first considered and subsequently rejected in this analysis process.

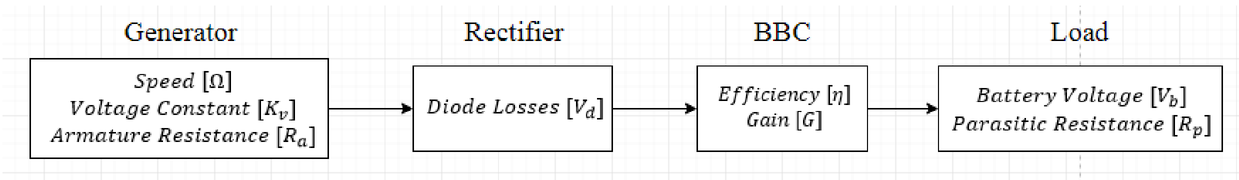


Figure 2-12 Electrical characteristics of major systems components.

$$V_{in} = \frac{\Omega}{K_v} - V_d - I_{in}R_a \qquad\qquad I_{in} = \frac{\frac{\Omega}{K_v} - V_d - \frac{1}{G}V_b}{\frac{\eta}{G^2}R_p + R_a} \qquad\qquad 2.2$$

A 6-V battery was chosen as the final load for our system and modeled as a voltage source in series with a small resistor. This load model resulted in electrical power curves with little curvature, with only one intersection occurring with each aero power curve. Better continuity with the business plan system is another desirable result of using a battery as a load. A 6V load required BBC voltage gains ranging from 0.5 to 2 to cover all of the peak power points of the aero curves from 5 to 11 m/s wind speeds in addition to regulated power operating points on the higher wind speed curves. Keeping the expected gain band in this range keeps the BBC efficiency in an optimal range and maintains the possibility of utilizing extreme voltage gains to control dramatic system changes. Multiple iterations of this performance analysis process were done in conjunction with testing and hardware modification.

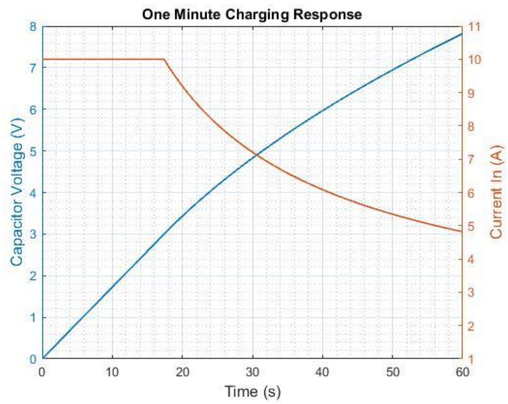


Figure 2-13 Current and voltage of 58F storage capacitor over minute of charging.

Capacitive load used in the durability task introduces a new dynamic to the system. In the charging phase, current will have to be optimized to deliver max power to the capacitor. A simple numerical model of the capacitor was created to ascertain the charging potential of the capacitor under optimal conditions. This model follows the basic equations that define the voltage change in an ideal capacitor. The model consists of a voltage source delivering constant power of 40 W to a capacitor in series with a resistor with the current capped at 10 A. The results of a one minute charging sequence are shown in Figure 2-13. This basic analysis was done to determine the current and voltage characteristics.

2.4.3 Power Electronics

The turbine's electrical system consists of 3 major components; a generator, rectifier, DC/DC converter of buck boost architecture () and a load. The active component is the buck-boost converter (BBC) which applies a gain (G) to the input voltage (V_{in}) from the turbine to the load. An inverse gain (1/G) is applied to the input current (I_{in}) from the generator. Since the load voltage remains relatively

Table 2-5 Component sizing for buck boost circuits.

	BBC #1	BBC #2
Output Capacitor	141 µF	122 µF
Input Capacitor	100 µF	100 µF
Inductor	220 µH	180 µH
Max Current	6.5 A	8.5 A

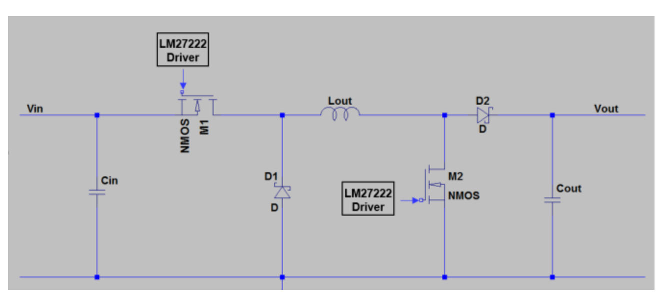
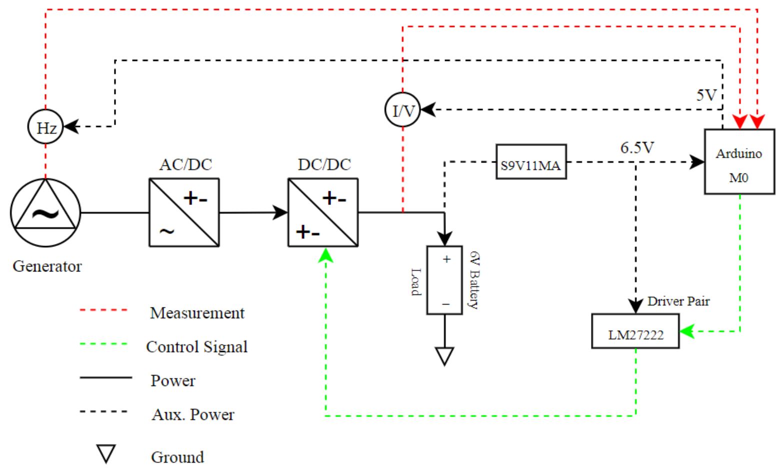


Figure 2-14 Schematic of a basic buck boost circuit.



constant at 6 volts, influencing a voltage gain with the BBC has the effect of changing V_{in} and thus the rotor speed of the turbine. An Arduino M0 microcontroller is used to automate the BBC gain for the purpose of tracking max power points and regulating power when necessary. A diagram of the electronic system can be seen in Figure 2-15. The operating principals of BBC circuits are well understood and can be found from a variety of sources [56].

Figure 2-15 Diagram of turbine power system for standard testing conditions.

A BBC utilizes fast switching MOSFETs (M1, M2) to induce a ripple current and ripple voltage across the output. The average of these ripple signals is the output voltage (V_{out}) and current (I_{out}) to the load. An inductor (L_{out}) and capacitor (C_{out}) facilitate this ripple dynamic and must be sized to fit the operating conditions of the system. A set of operating conditions was taken from the performance analysis in section 2.4.2 and used to calculate component sizing. The chosen operating conditions represent the most extreme expected gain values at the highest power conditions. Literature on component sizing from Texas Instruments (TI) was used to obtain sizing equations for L_{out} and C_{out} [57]. The TI literature also provided equations for calculating an input filter capacitor and peak instantaneous current. Performance analysis calculations provided maximum expected currents and voltages at the input and output of the BBC to facilitate proper selection of other components such as diodes, MOSFETS, and conductors. This theoretical sizing process was combined with testing data in multiple iterations.

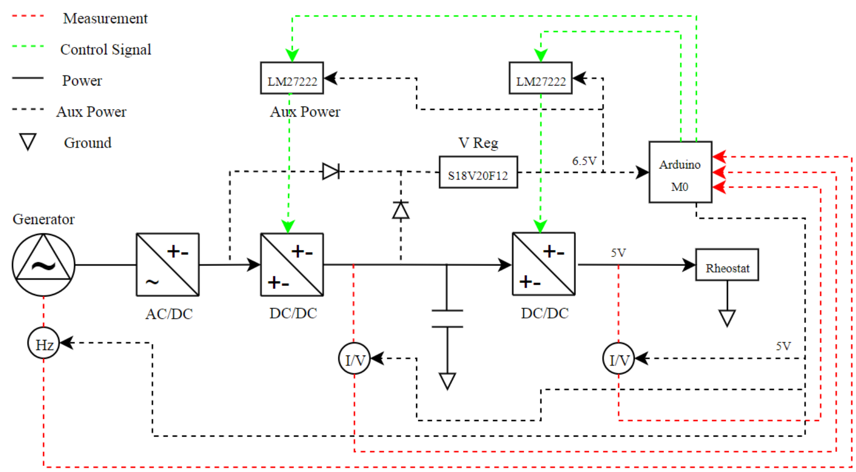


Figure 2-16 Diagram of system for durability task.

Another important consideration for component selection is available power sources. Since our system is designed to operate at relatively low voltages, MOSFET gate drivers with an appropriate supply voltage are needed. LM27222 drivers were chosen for their low supply voltage and high current design. FQP30N06L N-channel MOSFETs were chosen for their low threshold voltage and low on resistance. Due to high currents, it was necessary to minimize parasitic voltage losses to optimize efficiency and heat management. 20TQ045 Schottky diodes were chosen for the BBC and 19TQ015 Schottky diodes were chosen for the rectifier. Both have low forward voltage drops and are capable of handling the expected reverse voltages. See Table 2-5 for sizes of the capacitors and the inductor. Ceramic capacitors with an X7R dielectric were chosen for their temperature stability under fast switching conditions. A cylindrical inductor with a 20 Amp average current rating was chosen to provide a large factor of safety. Again, test results were used to verify these calculations and make design iterations.

Design of a second system was necessary for the durability task (Figure 2-16). Our main BBC will be used to regulate power to the capacitor during charging and discharging. A separate BBC is placed between the 58F storage capacitor and the variable load to maintain a constant 5V using an additional control loop. The same component sizing process was used to select capacitor and inductor sizes for the second BBC. In this process, the highest power operating condition was considered to size the components. See Table 2-5 for capacitor and inductor sizes for the second BBC. Since there is no power source in the load during the durability test, a power supply system to the controls is necessary. This is achieved by providing a dual supply to a small switching converter. If the capacitor is uncharged and the turbine is spinning, it will provide power to the control system. If the capacitor is charged and the wind speed drops dramatically the large storage capacitor will can maintain power to the control system. The diodes ensure that the voltage regulator supplying power to the auxiliary systems receives power from the highest voltage source.

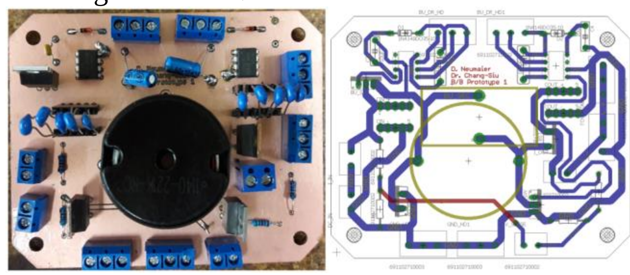


Figure 2-17 BBC circuit PCB board model and actual prototype board after fabrication.

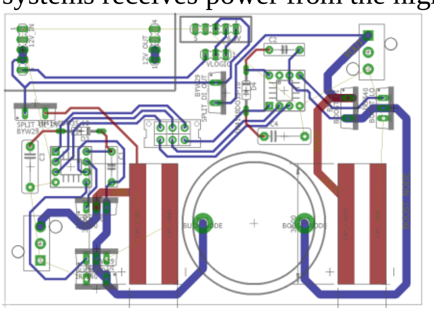


Figure 2-18 Board model of final BBC circuit.

Hardware design was done with the open source design software known as Eagle. A schematic was generated with all components symbolically represented. Each schematic symbol is associated with a simple two-dimensional model that accurately represents its physical footprint and connection layout. A .brd file, which is attached to the schematic, contains all of the component models. The physical board was laid out in this file by arranging all components in a desired pattern. Eagle then generates a g-code file to cut all of the conductor traces, pads, and holes. The resulting circuit PCB is routed into a two-sided, copper clad PCB blank with a small PCB router produced by Other Machine Company (now Bantam Tools). The rectifier, board, BBC board, and other supporting connection header boards were fabricated with this method. A .brd file of one of our prototype BBC circuits can be seen next to the actual board in Figure 2-17. All board cutting, soldering and fabrication was done at CSU Maritime Academy by students with the help of faculty advisors.

Testing played a crucial role in the design iteration process of the electronics. One principal problem that was consistently encountered was transient inductive noise in the ground node caused by high frequency switching of relatively high currents. Parasitic inductance in the MOSFET switches and conductor paths was a primary cause of this problem. To mitigate the noise, the entire top and bottom plane of unused copper was grounded to absorb noise and serve as a type of shielding. In addition, distance between components was minimized in the final version (Figure 2-18). Fast switching at high currents also had an adverse effect on aluminum poly and electrolytic capacitors, which caused excessive overheating. Ceramic capacitors where chosen to mitigate this problem. In the current BBC prototype efficiencies, between 85 and 95 percent have been achieved in the normal operating gain band which are consistent with commercially available switching regulators.

2.5 Controls

Microcontroller selection occurred after preliminary control code was implemented in testing. Of the three microcontrollers initially considered for use, the Arduino M0 was chosen because it exhibited the lowest power draw during testing. Automation of the power electronics is achieved using a control code algorithm written in the Arduino IDE that dictates how and when to modulate PWM signals administered to the BBC drivers. Depending on which CWC testing conditions the system experiences, the algorithm automatically engages the appropriate control mode. Requisite measurements and feedback logic governing these modes – as well as the conditions needed to trigger them – are shown in Figure 2-19. The system measures rotor speed, Ω, with the generator's integrated Hall effect sensor, while BBC conditioned power outputs P, I_{load} and V_{load}, are obtained using INA219 shunt-type, combined voltage-current sensors from TI. The block enclosed by green dashes automates the circuit described in Figure 2-15 during all five Competition tasks. An additional control algorithm – shown as the block enclosed by red dashes – is used in the durability task to charge the Competition capacitive load and maintain 5-V output from the second BBC shown in Figure 2-16.

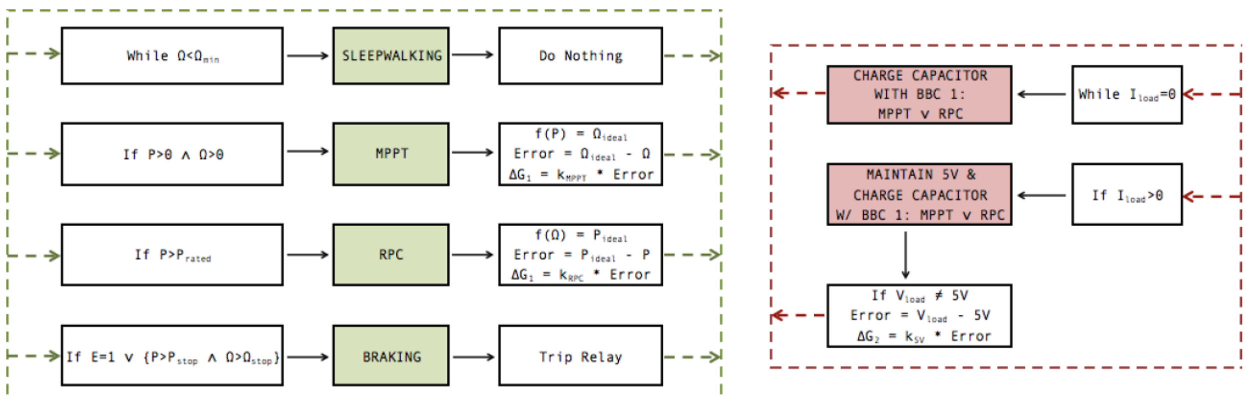


Figure 2-19 Logic flow for control code algorithm. MPPT refers to maximizing power point tracking between wind speeds 5-11 m/s and RPC refers to rated power control for wind speeds above 11 m/s.

2.6 Testing

Cal Maritime's ME program is highly specialized. Extensive training and practical experience is emphasized in hands on fabrication, troubleshooting, and operations in industrial settings. For this reason testing played a significant role in validation of our theoretical designs. All testing was done in our open loop wind tunnel which was constructed by the 2015-2016 Cal Maritime CWC team (Figure 2-20). The wind tunnel has a 3' x 3' cross section in the test area and is capable of achieving airflows up to 13 m/s. Wind speed in the tunnel is measured by a pitot tube and pressure transducer and monitored through a LabVIEW program. At the very beginning of our design process we ran Cal Maritime's 2017 CWC turbine system to develop an understanding of how the system worked. During this process we tested 2 different load configurations to verify results of the initial stages of our performance analysis. When our first design iteration of the turbine was ready for testing the 2017 BBC version controlled power to verify aerodynamic power curves while our new BBC was fabricated. Our initial objective was to build on the legacy knowledge of past CWC experiences while adding our unique designs to meet the fresh challenges presented.

Figure 2-20 CSU Maritime CWC wind tunnel.

Each viable blade design iteration was tested in our wind tunnel to verify the power curves developed in the performance analysis step. Experimental data points were determined by running the tunnel at constant wind speed and varying BBC gain. The results from iteration 1 superimposed over the theoretical power curves are shown in Figure 2-21.

Actual power delivered by many of the blade iterations saw a significant power reduction compared to theoretical predictions. There are many sources of power loss that can account for the discrepancy. Mechanical losses from the generators cogging torque and friction contribute to power losses, especially at lower wind speeds. Aerodynamic losses, particularly from the large frontal area of the nacelle, are another source of loss. Finally, voltage losses from resistive components in the electronics as well as efficiency loss in the BBC contribute to power loss. There is also a large speed discrepancy between the theoretical performance model and testing data. Rotor speeds reached as high as 1.5 times projected speeds. The source of this discrepancy is unknown and has been seen by prior CWC teams as well. Increased rotor speed and input voltage were accounted for in the final circuit design. In preliminary testing of our latest blades, peak power was within 85% of the theoretical model at rated wind speed. At higher wind speeds, voltage drops represent the bulk of power losses. Shunt resistors used to measure current dissipated significant power. The value of the shunt resistors was reduced to optimize power loss. The data shown is the power measured to the load.

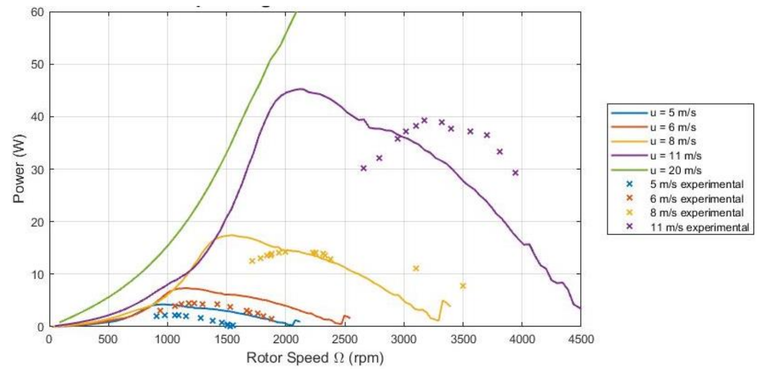


Figure 2-21 Testing data for blade iteration 1 superimposed on theoretical aerodynamic curves.

Other tests were conducted to examine various system conditions. Startup speed of each blade iteration was tested in an effort to meet the competition criteria. Stress testing for the BBC and rectifier was done at high power conditions to ensure necessary component durability. A few catastrophic failures of diodes, capacitors and MOSFETs were experienced and ultimately led to component upgrades that improved efficiency. Diode improvements alone led to loss mitigation of up to 7 W under high power conditions.

Testing for the durability task was undertaken after the rest of the system was rigorously proven. Initially, the 58 °F storage capacitor was attached directly to the DC end of the rectifier to observe its effect of the turbine’s speed. In this test we found the large load of the discharged capacitor did not completely stop the turbine. Next, we attached the capacitor on the output side of the primary BBC. Under rated wind speed we manually controlled the gain of the BBC to maximize the power delivered to the system. Gain was varied over the course of one minute charging runs to optimize input current to the capacitor. Capacitor testing was instrumental in developing a control scheme for the durability test and ensuring that the electronic system would produce the conditions needed to control the turbine in the durability task.

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