The battery and turbine project refers to a system designed by CU Boulder students in which wind power is harnessed to generate electricity, powering components of an Antarctic research base. This report’s overall objective is to present a general outline of the proposed project to see whether further cost and time expenditures are worth investing into the actual build during the 2019 spring semester.

Through mainly online research, the team concluded that the entire project can be funded with about a $5500 budget, which would cover the cost of the turbine, batteries, battery housing, and wiring connections. This figure reflects the lowest possible cost after ruling out several other options (including different battery types and sizes of turbines) that each had at least one flaw, therefore not allowing for successful completion of project requirements as outlined further in other sections.

If achieved, the project will benefit Antarctic researchers by providing a long-term solution to power generation while permitting recovery of the batteries to avoid environmental pollution.

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Risks to Turbine System........Page 10  Appendix.........................Page 20
**Introduction**

Global warming continues to represent an ongoing issue that plagues the entire globe. Ecosystems around the world have been impacted by the effects of a warming climate while negative consequences rapidly multiply. The poles of the Earth experience these side effects, which take the form of melting sea ice, glaciers, and permafrost (Scambos, 2016). In particular, glaciers in the Amundsen Sea Embayment located in the Antarctic region, including the Thwaites Glacier, are losing mass at an alarming rate.

In response to this phenomenon, the Thwaites-Amundsen Regional Survey and Network (TARSAN) has installed a series of stations along glaciers in this region to monitor and record data and observations of both oceanic and atmospheric conditions over the course of two years (Pettit & Heywood, n.d.). The stations, called Atmosphere-Ice-Ocean multi-sensor remote autonomous stations (AMIGOS), will assist researchers from the TARSAN organization by providing real-time information regarding any changes that may occur with, or surrounding, the glaciers they are placed on. Using the data, scientists can construct accurate ice sheet, climate, and mass-loss models to further understand the processes that contribute to the degradation of the Antarctic glacial shelves.

**Project Overview**

On an AMIGOS-III station located on the Thwaites Glacier, researchers drill narrow holes that extend deep into the glacial body. The “bore holes” span about 8-10 inches in diameter and often reach over 6000 feet in depth (Pettit & Heywood, n.d.). In order to obtain current footage of ice layers within the Thwaites Glacier itself, the Colorado Space Grant Consortium (COSGC) team, located in Boulder, CO, is designing a pressure vessel that will be lowered by a crane into the bore hole. The contraption takes the form of a six-inch diameter aluminum tube with all of the necessary electronics, camera, and lights fitted inside that will allow for continuous video recording until the bottom of the bore hole is reached. At the same time, the team is programming two CR1000x data loggers wired to eight thermistors that will obtain temperature data throughout the venture down the bore hole. These two systems will be powered by a custom battery and turbine system, the overarching focus of this investigation.

Collectively, the turbine that powers this system would ideally generate 3-5 watts of continuous power to about 400 amp-hours of sealed lead acid gel
cell batteries. Gel cell batteries are preferred to liquid acid as they maintain cycling efficiency in low temperature conditions whereas the latter tends to falter. Likewise, gel cells can be oriented in a variety of ways without losing efficiency, further suiting them to our application. The system must function in low-temperature surface conditions averaging around -50°C while generating and supplying power if wind speeds fall below the Antarctic average of about 19 ft/s (Natural Resources Canada, 2017). At the same time, if wind speeds accelerate without warning, such as during storms, the turbine must not overcharge and blow the gel batteries.

**System Requirements**

<table>
<thead>
<tr>
<th>Turbine</th>
<th>Batteries</th>
<th>Tubes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generates 3-5 continuous watts of power</td>
<td>Sealed lead acid gel cell</td>
<td>House all batteries with sealed hatch</td>
</tr>
<tr>
<td>Powers 400 amp-hours of batteries</td>
<td>400 total amp hours of charge</td>
<td>Wide enough to support a rack/extraction method</td>
</tr>
<tr>
<td>Detach method to prevent overcharging of batteries</td>
<td>Maintain cycling efficiency in the cold</td>
<td>Tubes themselves extractable</td>
</tr>
<tr>
<td>Weather/Cold/Ice resistant</td>
<td>Wired together so that all are sufficiently charging</td>
<td>Sturdy/Weather/Cold resistant</td>
</tr>
</tbody>
</table>

The chart provides the general requirements of the system and its main components. Withstanding the cold is a key factor for each of the components to sufficiently function in Antarctica. However, other requirements (such as the 3-5-watt output of turbine) are subject to change and could alter which options would be more effective as the team moves forward with the project.

**Design of Turbine**

**Overview**

Our proposed turbine design that will fulfill the requirements of the project is a stacked and staggered vertical savonious model (see Figure 1 below). The design features two semicircular halves of a hollow tube split down the center and attached by an overlapping gap. The turbine is comprised of two of these units stacked on top of each other in a perpendicular fashion so that a wind scoop is located at each 90-degree segment, increasing efficiency by providing wind-power access at four points rather than two.
The design is built on a vertical axis, which assists in providing continuous rotational torque to the shaft in varying wind directions and speeds, as opposed to a traditional horizontal axis turbine that relies on blade aerodynamics and lift (Krivcov, Vladimir, & Krivospitski, 2011). The lack of blades additionally eliminates the risk of blade damage or failure that is caused by variable conditions and low temperature effects on materials. Blades that extend outwards could become warped or crack in extreme conditions which could compromise their aerodynamic capability. Furthermore, the inherent risk of ice forming on the turbine will pose less of a threat as the entire aerodynamic effectiveness of the system is not as crucially affected as with a horizontal form. Moreover, implementing a gap between the two scoops of the lower and upper segments increases efficiency in terms of the airflow (figure 6) (Jaohindy, Garde, & Bastide, n.d.). As air enters the scoops, it applies a force which is translated to the circular motion of the shaft. The gap provides an avenue for the “used” air to escape more quickly, thus allowing “new” rapidly-moving air to take its place and continue the turbine rotation (Krivcov, Vladimir, & Krivospitski, 2011).

### Turbine Dimensions

The figures below represent a series of virtual tests conducted on various sizes of turbines. They display the power and torque curves for those different sizes as well as the power curves for differing wind speeds.

<table>
<thead>
<tr>
<th>Size</th>
<th>Radius (mm)</th>
<th>Height (mm)</th>
<th>Gap (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tiny</td>
<td>70</td>
<td>260</td>
<td>20</td>
</tr>
<tr>
<td>Small</td>
<td>90</td>
<td>320</td>
<td>40</td>
</tr>
<tr>
<td>Medium</td>
<td>110</td>
<td>380</td>
<td>60</td>
</tr>
<tr>
<td>Big</td>
<td>130</td>
<td>440</td>
<td>80</td>
</tr>
<tr>
<td>Huge</td>
<td>150</td>
<td>500</td>
<td>100</td>
</tr>
</tbody>
</table>

*Figure 1: SolidWorks Sketch of Turbine Model from top, level, and bottom angles*

*Figure 2: Table of Turbine Sizes*
**Figure 3:** Graph of Power Output vs. Different Wind Speeds  
(Power increases as wind speeds increase)

**Figure 4:** Graph of Power Output vs. Size of Turbine  
(Largest turbine has highest peak power)
As seen in figures 3, 4 and 5, the largest turbine design would produce the greatest amount of power but would also require the largest amount of force to start spinning (Pieterjan, 2017). This raises the question whether it is worth utilizing the larger turbine and implementing a self-start system using some of its own produced power or resorting to a smaller turbine and settling for less power produced without a self-start. The self-start could function by applying forward power to the turbine through a separate motor for a short period of time, starting the revolutions. Then the

**Figure 5: Graph of Torque vs. Size of Turbine**
(Largest turbine requires largest magnitude of torque to begin spinning)

**Figure 6: Model showing Dimension Specifics of Largest Turbine**
motor would shut off and the shaft would then spin due to the wind power, correspondingly spinning the generator and creating charge. Unfortunately, none of the smaller models can produce sufficient power to cross the required 3-5 continuous watt output as noted by figure 3. Thus, the largest turbine remains the most viable option moving forward if this goal is steadfast. Figure 2 includes all tested turbine dimensions.

The size of the turbine similarly affects how fast it spins (revolutions per minute). The largest turbine will spin the slowest (the least angular velocity) while the smallest turbine will spin the fastest (greatest angular velocity). However, the larger turbine will spin with greater torque, thus rotating a larger shaft that can be converted to a faster spinning smaller shaft via gears and a gearbox located in a nacelle (a gearbox housing) on the bottom of the turbine (Pieterjan, 2017). Figure 7 depicts an example of a real vertical axis turbine with attached gearbox located in a nacelle. The smaller turbines will not need a gearbox as they are solely capable of spinning smaller shafts. Again, the size of the turbine will determine the revolutions per minute (RPM) and the size of the vertical axel, correspondingly deciding the need for a gearbox conversion before linking to the generator.

The disengagement capabilities when utilizing a gearbox represents another positive aspect. In the same way a car enters neutral gear, the turbine gearbox could detach the spinning shaft gear from the generator during times such as storms when the risk of overcharging is most imminent. This would allow for the addition of a necessary fail-safe to keep the batteries and the entire system safe from overcharging. Nonetheless, including a gearbox does presents further challenges in the form of more moving parts. In the extreme cold, minimizing the amount of interacting parts decreases the risk of those parts fusing together due to freezing moisture, warping, or rupturing entirely due to increased brittleness. Moreover, the gears and connections will all require lubrication, another setback due to cold temperatures that will be discussed later in this investigation. Applying a heater to the inside or outside of the gearbox could help reduce these potential fail points, yet would siphon more of the generated power away from the batteries themselves in order to power it.
Despite generating power with a slower moving shaft, removing the idea of a gearbox for even the larger turbine may prove advantageous by eliminating many of the associated risk factors mentioned above. However, if the 3-5-watt output goal is lowered, a smaller turbine or even a series of smaller turbines may function the best in the Antarctic setting because the forces needed to start them would be reduced while the transfer of power to the shafts would not require a gearbox. To reiterate, more moving parts will yield more conflict.

Machining of the turbine itself will be conducted in one of the labs on the CU campus. The team will obtain certification to utilize the tools inside the labs and thus, the only cost would be for the material itself. Team members would put in the labor hours and the labs are free to use after classes and certification have been obtained.

**Turbine Bearing**

One of the key points of failure resides in the bearing system that the spinning turbine rests on as it rotates. Not only does the bearing need to be large to fully support the larger turbines, it needs to function either with “extreme cold” or “arctic” specialized lubrication or without lubricants at all. Lubricated bearings tend to cost significantly less, yet they often utilize grease to reduce the friction between the ball bearings. The cold climate poses a significant risk to the use of this form of lubrication as any increase in the grease viscosity would cause a dramatic spike in the friction levels, drastically lowering the efficiency of the turbine. Even with models that take advantage of certain lubrications that are designed to withstand the cold, the system still remains at risk (“Bearing the Cold,” 2013).

**Lubricated Bearings**

Traditional lubricated bearings feature a metal housing and steel ball-bearings that run through the housings as the bearing rotates. If the project team decides to go forth with a traditional lubricated bearing, members must carefully consider both the viscosity and viscosity index (VI) of the lubricant they are using. When the temperature drops, viscosity increases (the substance becomes “thicker” and less runny) due to the slowing of particles that make up the matter (“Bearing the Cold,” 2013). Because of this fact, the team must find a material with a perfect balance between too thick and too thin. If the material is not viscous enough, it will not create enough of a space between the bearing walls and the balls themselves, ultimately causing wearing and excess friction. On the other hand, if the material exhibits a higher viscosity, it will not efficiently flow back into the needed areas of friction. After each rotation of the
bearing, the space between the balls and the frame that holds them expends the lubricant outside of the area. When it comes time to move again, the lubricant must be able to seep back into those spaces in time for the next rotation. A material with too high of viscosity would not re-lubricate the areas in time, leading to lubricant starvation causing wearing and friction as well (Gonzalez, 2017).

Furthermore, VI accounts for the resilience of the materials under different temperature exposures. A high VI yields a lower variability to extreme cold or heat, meaning that the characteristics of the substance remain consistent. A low VI indicates that the material and its qualities shift drastically based on the temperature it is used in. The goal of the team would be to pinpoint a lubricant with a high VI that additionally resides toward the middle or lower ends of the viscosity spectrum, compensating for the fact that even high VI materials see a small increase in viscosity when exposed to the cold.

**Types of Lubrication**

Bearings can be lubricated with different kinds of material based on application. Potential lubricant candidates include petroleum-based, synthetic hydrocarbons, and silicones (“Bearing the Cold,” 2013). Petroleum-based oils are the easiest and cheapest to manufacture, yet they already display a higher viscosity at room temperature that will increase as the temperature plummets. Synthetic hydrocarbons dwell on the more expensive side and are made in alternative temperature variants and exhibit lower room-temperature viscosity. They function in a more homogenized manner with upgraded flow and spread. Silicones perform well in a wide range of applications with an associated range of costs. They come packaged with an added benefit of being hydrophobic, an extremely useful characteristic in the Antarctic where moisture accumulates due to temperature differences between surfaces and air (Canadian Wind Energy Association, 2017). The constantly turning bearing and the friction generated releases heat, thus hydrophobic lubricants would help repel the potential moisture build up. Of this third category, nitride rubber or fluorosilicate materials stand out as the top two options for low temperature utilization (Gonzalez, 2017).

**Unlubricated Bearings**

Another valid and less risky option than using generic bearings and lubricant would require using ceramic bearings. These products tend to cost vastly more than their...
average counterparts due to the fact that they are able to run completely “dry” (meaning without any lubrication) (“Full Ceramic Bearings,” n.d.). On Amazon, a four-pack of traditional 3/4-inch ball bearings costs about $13 (“Amazon Ball Bearing,” n.d.) while a single 3/4-inch ceramic ball bearing costs over $115 (“Amazon-Ceramic Ball Bearing,” n.d.). The exorbitant price disparity only exponentiates as the size of the bearings increase. The added price tag, however, presents a multitude of added benefits.

These bearings offer extremely low levels of friction because ceramic is a porous material, unlike steel (“Full Ceramic Bearings,” n.d.). These bearing housings do not require lubrication as the ceramic material of both housing and balls acts as a smooth, glass-like surface with a very low coefficient of friction. Most importantly, the lack of lubrication altogether allows them to function without the risk of the cold temperature affecting their lubricant performance. Ceramic additionally displays better thermal properties than traditional steel balls, yielding less heat release and decreasing moisture attraction to the bearing, therefore avoiding other conflicts. Ceramic bearings withstand more strongly against corrosion and can be cleaned using regular tap water. According to the product website, some ceramic bearing models can even operate at temperatures down to -80°C (“Full Ceramic Bearings,” n.d.).

**Ball vs. Ceramic Bearings**

The last bearing design specification revolves around the type of actual bearing located inside the bearing housing. The two most appropriate types for this project’s applications are the traditional ball bearing and the roller bearing.

The ball bearing design features two rings that serve as the frame which hold the balls at an equal distant apart. The balls, within their framework, then slide along the outer ring and create the rotating movement as they support the load of whatever the objects are that need spinning. When speaking of oiled bearings, the friction caused between the balls and their two-ring framework demands lubrication to suppress. Roller bearings, instead of capitalizing on spherical bearings, implement cylindrical units embedded within the inner components of the rotator frame (Gonzalez, 2017). Similar to the ball bearings, these cylinders are kept equidistant apart through placement along two frames. Yet, these bearings possess a higher radial load capacity, meaning they can withstand higher external pressures and still operate with efficiency. The load is distributed over a larger area because instead of a single point of contact between the tip of a sphere and the housing, the roller bearings contact the outer frame over an entire line of space.
Depending on the size of the final design, if the turbine’s mass presents a higher load on the bearing system underneath, roller bearings may appear as the most effective solution. Accurately gauging which type of bearing to use will require further testing.

**Risks to Turbine System**

**Icing**

In cold and snow-prone environments such as the Antarctic region, icing of integral components could lead to several issues including inefficiencies within the system and possible failure. Icing of the turbine blades, which are constantly exposed to the open elements, would add mass to the overall entity while misshaping the wind flow over the scoops, ultimately causing a setback in power production. To counteract this occurrence, the team decided to construct a vertical-axis turbine to minimize the effects of iced blades, as the lift and rotation of vertical blades do not fully depend on air flow direction, in contrast to horizontal axis turbines (Krivcov, Vladimir, & Krivospitski, 2011). However, the added ice will still slow the vertical turbine by making it heavier and less aerodynamic. To remove the ice, a low-power heating system, such as one found on the rear windshield of a car, could serve this purpose. The turbine could use some of its own produced power to generate heat through a series of thin black wires fitted in a net-like-fashion over the surface of the turbine, similar to those found on windshields of cars. This would decrease the adhesion force of the ice to the surface and result in fewer forming ice chunks.

The scoops of the turbine could additionally be painted black to absorb as much heat during daylight hours as possible to avoid water from freezing to the surface (Canadian Wind Energy Association, 2017). Still, these two solutions may cause further problems as moisture in the air gravitates towards sources of heat due to the temperature disparity between warm surface and cold air. The warmer the turbine surface, the higher the likelihood of water attaching, freezing, and growing into ice (Gonzales, 2017). The key solution would be to coat the entire surface in hydrophobic material in order to resist any moisture from adhering (see figure 9) (Canadian Wind Energy Association, 2017). Without this base of adhesion, other water molecules could no longer attach to the existing water on the surface, reducing the

![Figure 9: Water Behavior on a Hydrophobic Surface](image)
likelihood of larger ice crystals forming on the turbine surface.

**Cold Temperature**

Without a doubt, the relentless sub-freezing temperature similarly poses a threat to the materials used in the construction of the entire system. Aluminum serves as a suitable element that can be readily purchased at reasonable costs and will not warp, crack, or shatter under the given conditions. Other composite materials may function well for this application too, especially ones with structural integrity that are light weight and resilient against temperature. Lightweight materials remain crucial to this project’s application as reduced weight of the turbine reduces the force of friction within the supporting bearing and allows the turbine to spin faster even during lower wind speeds.

**Storms**

Weather in the Antarctic presents another adverse factor to consider when designing this project. The consistently shifting wind conditions is exponentiated with the arrival of storms that causes speeds to drastically increase over a very short amount of time (Skinner, 2012). If the turbine continues to run throughout these conditions, there exists a higher probability of overcharging batteries due to the faster rotation of the turbine, leading to a quicker generation of power. To counteract the impact of the frequent storms, the gearbox could be serviced to break the electrical connections between the spinning turbine shaft and the generator. This kill switch could attach to a wind speed sensor and would activate when the speed crossed a certain maximum threshold. The sensor could additionally attach to the turbine and measure its output, communicating a red-flag signal if generation of power exceeded certain limits.

The flaws of this design would center around the mechanical risks. Even if electrically detaching the turbine would secure the batteries and electrical components, it would still be spinning too fast for too long: the bearings, shaft, and other features would be at risk of damage due to over-rotation at too great of speeds. To solve this issue, the turbine system could similarly include an electrical or mechanical system to slow the rotation to a desired speed. While an electrical-friction system would suck power from the turbine generation itself, a mechanical implementation would allow for slowing of the turbine without using excess charge. This system could take the form a rubber ring or some added material placed around the base of the turbine so that the added resistance would slow the rotation.
**Heat Generated from Turbine**

As moving parts of the system continue to rotate, the contact between different elements creates friction that, in turn, is expended as heat. As mentioned in previous sections of this investigation, differences in temperature between warmer surfaces and cold air could lead to moisture accumulation, which poses a risk of possible formation of ice crystals. The freezing moisture critically impacts the bearing system as unwanted chunks of ice embedded in the rotating ball bearing frame would lead to excess friction and damage. Neutralizing this threat requires limiting of the turbine’s power output and using low-friction materials so that it cannot generate sufficient heat to attract moisture and snow. Further laboratory testing of this concept is needed to determine the exact threshold heat levels that yield moisture accumulation.

**Design of Battery System**

**Overview**

The battery system associated with this project requires 400-amp hours of stored power sealed within lead-iron gel-cell batteries (valve regulation lead acid batteries). The system must also survive the low-temperature conditions without losing a significant amount of charge and cycling efficiency due to the cold. The batteries are installed on metal frames, which are then lowered into a series of tubes and sealed with a hatch. In the future, after the snow levels have risen, research teams in Antarctica can successfully recover the batteries for re-use and to avoid pollution. The tops of the hatches should still be visible or very near the surface so minimal digging is required to locate and retrieve the batteries.

**Tubes**

The general layout of the system includes 3-4 aluminum tubes 10-12 feet in height that each contain a framework of wired gel-cell batteries. These frames can easily lower into the mouths of the tubes, which are then sealed with a user-friendly hatch that can be easily reopened when the batteries need to be recovered. Ideally, the outer diameter of the tubes would span a maximum of six inches. PVC was initially considered as an option to hold the batteries but proved unrealistic due to the high potential risk of the material becoming brittle and shattering because of the extreme cold. Most minimum temperature ratings approve PVC tubing down to 0°C when carrying fluid, yet most rating systems do not account for temperatures lower than that and do not provide data for fluid-less applications such as this one.
Consideration of environmental pollution must be kept in mind, too, as differing materials will affect the surrounding ecosystem in different ways, especially if the tubing remains in the snow after the batteries have been removed. Aluminum fares well in this realm because when it is exposed to air, it forms an oxide layer on its surface that promotes high resistance to corrosion and weathering (The Environmental Literacy Council, 2015). Therefore, the tubing will not rapidly decay when placed in the snow pack and will not pollute the surrounding environment.

The cost of 20-25 feet of tubing unquestionably affects the project budget. Hollow aluminum tubing, although sturdy, effective in variant climates, and light weight, places an enormous price tag on the allocated funds. Depending on material, size availability, and metal provider, an 11’ 7” outer diameter and 6” inner diameter (0.5” thick) tube costs between $1100 and $1200, according to quotes provided by companies such as Metal Supermarkets located in Wheat Ridge, CO (Metal Supermarkets, n.d.). This same company estimates a 6” outer diameter and 5.5” inner diameter (0.25” thick), 12’ aluminum tube at about $700. These numbers reflect the cost after inquiring about college and student-project discounts.

Because this company is located nearby, the team can save on shipping costs by purchasing and picking up from the store itself, making this metal provider a cost-effective option. However, transporting 12’ aluminum tubing to the team’s work site proves a challenge and would cost even more to ship to Antarctica. A solution would involve purchasing the tubes and transporting them via a rented U-Haul or other large-vehicle to the local team site, followed by a fee to ship them to Antarctica with the other components of the project, totaling about $500 (According to Mr. Scambos). The team must proceed with this option because the only want to save money would be shipping the tubes directly to Antarctica, a service which Metal Supermarkets and other sellers do not fulfill (Metal Supermarkets, n.d.). If the metal providers could ship internationally, the team could instead purchase one 6’ length of tubing and construct the battery system surrounding this sample. Then, the team would ship the components to Antarctica and assemble them into the larger tubes at the AMIGOS site itself.

Originally, the team researched larger tubes such as the first one above in order to fit two batteries side-by-side within the diameter of the tube, thus reducing the amount of overall tubing length needed to save money. However, after extensive research into different types of gel batteries, every model
required over a 6’’ outer diameter to fit two side-by-side. In response, the team suggests utilizing a 6’’ outer diameter tube with a 5.5’’ inner diameter that can fit one battery stacked on top of the other.

Another less expensive option would utilize hollow square aluminum tubing. This tubing can be found online and in stores. Online Metals, a website for purchasing products such as these, values a 5’’ outer height and 4.5’’ inner height (0.25’’ wall thickness), 8’ section of square tubing at $230 (Online Metals, n.d.). This option will allow for easier fit of rectangular shaped batteries and will reduce cost. However, the AMIGOS site may exploit the tubes for other applications beyond housing the batteries. Therefore, it is uncertain as of now whether moving forward with cheaper and more effective square tubing is possible.

**Batteries**

**Battery Type and Count**

The most viable battery option is the Power Star 12V VRLA lead-acid gel-cell battery that has a capacity of nine amp-hours, seen in figure 10. The battery dimensions are as follows: 2.56’’ width, 3.66’’ length, and 5.94’’ height (Big Time Battery, 2017). The batteries fall into the deep cycle class, meaning they can fully recharge and discharge as needed unlike common starter batteries. This characteristic further benefits the project as the turbine continuously recharges the system while charge constantly gets consumed by electrical components on the AMIGOS system.

With nine amp-hours provided by each unit, 45 batteries would suffice in crossing the 400 amp-hour collective requirement. Each battery, placed horizontally inside the tube (dimensions shown in figure 11), will span a length of about six inches, allowing for two per foot of tubing. In total, housing all 45 batteries would demand about 23 feet of aluminum tube, achieved through implementing two separate 12-foot segments.
Battery Wiring and Rack

Further investigation into the wiring of the batteries is required to determine which wiring diagram best suits the application. The team needs to ensure that the turbine can successfully power all the batteries linked together, whether that means splitting the units into smaller wired groups or collectively charging all as a single entity. The former may work more effectivity as the turbine’s power can charge 4-5 batteries at a time and then rotate onto other groups while the charge from the first group is expended. The turbine most likely will not output sufficient power to continuously maintain power in all 45 batteries at the same time. The team will apply a charge controller in between the turbine and battery components to evenly distribute power as needed.

The battery rack presents another challenge for this particular application. Its primary job would be holding the batteries in a certain orientation within the tubes while shelving all the units for easy extraction later. Due to the specific dimension requirements of this project, the rack requires necessary custom modeling and fine-tuned construction of a working solution. Some racks can be found online (VRLA Battery Racks, n.d.), yet these would need heavy re-modification to suit this project. The rack needs to be designed to snugly store all batteries and needs to be sturdy enough to support the weight of all 24 units it holds when removing the entire bundle with a crane upon extraction. Each battery will be placed on the rack with its terminals facing the same direction for ease of wiring and connectivity to surrounding units.

Summary and Alternative Options

Altogether, a 400-amp heavy-duty charge controller, the metal to construct two battery racks, and wiring and soldering material will cost about $500. In addition, each Power Star battery costs about $30, totaling to about $1350 for all 45 batteries. 24 feet of aluminum tubing will cost an additional $1400 dollars, totaling up this component of the overall project to roughly $3500 with an added $250 for extra expenses.

The team researched other options for the battery system, but all included a setback that made the above option the highlighted choice. One option featured a Battery Mart gel-cell battery which held 31 amp-hours of charge but required an 8.5” inner diameter tube to fit (Friednietz, n.d.). A German company called Sonnenschein likewise produces gel-cells, but the sizes that fit our needs cost well over our desired budget at about $90-$100 per only 10 amp-hours. Traditional AGM (absorbed glass mat) non-gel batteries were also noted as options due to their increased size availability and lower prices, yet their significantly faster degradation of cycling efficiency
would deem them insufficient for this cold-climate application.

Testing

Turbine Performance

The CU Boulder Experimental Aerodynamics Laboratory houses wind tunnels for testing projects such as this one. If the lab permits the team to utilize their space, the team could test the turbine rotation in similar Antarctic wind scenarios. At the same time, the team should test the system against low temperatures. One way to complete this test would be installing the bearing of the turbine itself on a motor inside a cooler filled with dry ice. The bearing would spin continuous for a set amount of time, so the team could see if the moisture and freezing temperatures of the environment would affect the functionality of the component. Weights could be added to the top of the bearing on a platform to mimic the load of the actual turbine as well. If needed, the team could test the final system at the National Ice Core building if permitted to do so, depending on facility availability during the time the team needs to test.

Battery Performance

Before purchasing all 45 Power Star batteries, the team should first buy a single unit and test the effects of cold environments on its cycling efficiency. Preparation would include developing a temporary cold climate inside of a cooler and testing with an electrical cycle load. If the single battery performs without significant power or cycling reduction, the team can continue in purchasing the rest of the units for additional testing. The COSGC has a cold chamber on campus that the team can exploit to test the batteries.

Overall, extensive testing of both systems combined is required to fully validate many of the conclusions reached in this investigation. The team will have to purchase minimal amounts of parts and test the effects of cold on each to ensure that long-term exposure to Antarctic elements will not disrupt the system after implementation.

Conclusion

The final proposed design of the turbine will feature two savonious models stacked and staggered. The dimensions incorporate a 150mm radius, 100mm gap, and 500mm height. The turbine will most likely revolve on a ceramic ball-bearing of either spherical or cylindrical bearing type, as determined by further testing. It will charge a series of 45 gel cell batteries that will in turn supply power to equipment and machinery on the base as needed. The batteries will be housed in two 12’ aluminum tubes, stacked on racks.
within the tubes for ease of retrieval after the project is terminated. The total cost of the battery system revolves around $3500. The turbine and bearing should not cost more than $1500 including parts and machinery according to information regarding bearing costs and other aluminum turbine designs (desert turbine website). Thus, the entire project, ideally, can be completed with a $5500 budget (see appendix).

If successfully approved, tested, and completed, the project components will be sent to Antarctica where they will be integrated into the Thwaites Glacier research base. The power generated and stored within this system will assist in driving various components located on the base such as the thermistor systems utilized in recording other atmospheric and surface data. Environmental research and conservation represent key areas of study that stand between a natural Earth and a permanent human footprint. The CU Boulder Colorado Space Grant Consortium team hopes to assist the Antarctic researchers with their environmental work to better understand the rapidly changing world, helping to fight climate change in the long run.

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https://earthobservatory.nasa.gov/blogs/fromthefield/2012/02/14/antarctic-storms/


**Figures:**

Figure 1 retrieved from: SolidWorks Design and Testing

Figure 2 retrieved from: SolidWorks Design and Testing

Figure 3 retrieved from: SolidWorks Design and Testing

Figure 4 retrieved from: SolidWorks Design and Testing

Figure 5 retrieved from: SolidWorks Design and Testing

Figure 6 retrieved from: SolidWorks Design and Testing

Figure 7 retrieved from: http://www.desertpowerinc.com/pacwind.m

Figure 8 retrieved from: https://www.vxb.com/Fidget-HandSpinnerFullCeramic-Bearing-NylonCagp/fullceramic-608-zro2-nylon-ca.htm

Figure 9 retrieved from: https://www.geek.com/geekcetera/watchhoweirdly-water-behaves-on-hydrophobicsurfaces-1600379/

Figure 10 retrieved from: https://www.bigtimebattery.com/store/12v-9ah-high-temperaturebattery.html?gclid=Cj0KCQiAlXfBRCpARIsAKvManwW4USxL4haHHf7xt-

Figure 11 retrieved from: https://www.desmos.com/calculator
# Appendix

## Budget Chart Summary

<table>
<thead>
<tr>
<th>Project Component</th>
<th>Option 1</th>
<th>Option 2</th>
<th>Option 3</th>
<th>Final Option/Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbine Shell</td>
<td>Large Aluminum $&lt; 750</td>
<td>Small Aluminum $&lt; 500</td>
<td>Large Aluminum $&lt; 750</td>
<td></td>
</tr>
<tr>
<td>Turbine Bearing</td>
<td>Ceramic Unlubricated $&lt; 750</td>
<td>Traditional Lubricated $&lt; 200</td>
<td>Either Ball or Roller Bearings</td>
<td>Ceramic Unlubricated $&lt; 750</td>
</tr>
<tr>
<td>Batteries</td>
<td>Power Star $&lt; 1350</td>
<td>Battery Mart (not viable)</td>
<td>Traditional AGM Battery (not viable)</td>
<td>Power Star x 45 $&lt; 1350</td>
</tr>
<tr>
<td>Battery Tubes</td>
<td>Aluminum Round x 24’ $&lt; 1400</td>
<td>Aluminum Square (contingent) $&lt; 700</td>
<td>Aluminum Round x 24’ $&lt; 1400</td>
<td></td>
</tr>
<tr>
<td>Battery Racks</td>
<td>400 Amp Heavy Duty Charge Controller/Metal Racks/Wires $&lt; 500</td>
<td></td>
<td></td>
<td>$&lt; 500</td>
</tr>
<tr>
<td>Wiring</td>
<td>Extra costs of manufacturing/selection of different system options</td>
<td></td>
<td></td>
<td>$&lt; 250</td>
</tr>
<tr>
<td>Charge Controller</td>
<td>Turbine and Tubes $&lt; 500</td>
<td></td>
<td></td>
<td>$&lt; 500</td>
</tr>
<tr>
<td>Other Expenses</td>
<td></td>
<td></td>
<td></td>
<td>TOTAL $&lt; 5500</td>
</tr>
</tbody>
</table>

The budget sheet includes price estimates for all parts of the project based on observations of existing systems and research on varying material cost. Contingent on which options the team choses to move forward with, the budget could increase or decrease if more materials are needed or expended. As of the options chosen above, the project should be completed with $5500 or less.