2024 Northern Arizona University Collegiate Wind Competition Project Development Sub Team

Conceptual Design Report Template

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Project Sponsor: US Department of Energy and The National Renewable Energy Library

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DISCLAIMER

This report was prepared by students as part of a university course requirement. While considerable effort has been put into the project, it is not the work of licensed engineers and has not undergone the extensive verification that is common in the profession. The information, data, conclusions, and content of this report should not be relied on or utilized without thorough, independent testing and verification. University faculty members may have been associated with this project as advisors, sponsors, or course instructors, but as such they are not responsible for the accuracy of results or conclusions.

EXECUTIVE SUMMARY

The U.S. Department of Energy's (DOE) Wind Energy Technologies Office's (WETO) Collegiate Wind Competition (CWC) welcomes 35 interdisciplinary teams of undergraduate students from a variety of notable universities across the nation to compete in four contests. Northern Arizona University WindJax's are split into 2 sub-teams: Turbine Design and Project Development. The nature of this report will focus on the Project Development team as they are tasked to research wind resource data, transmission infrastructure, and environmental factors to create a site plan and financial analysis for a hypothetical offshore wind farm. Some key factors the team will need to consider are physical site characteristics, infrastructure, turbine selection, ports, transmission, grid integration, environmental and wildlife impacts, and the coexistence between the residence and the turbines.

New to this year, the CWC encourages students to incorporate offshore wind energy generation as a feature to a hybrid power plant. This allows students to consider development and operation opportunities for grid benefits, alternative forms of market participation and mutual agreements, and a vast array of technological solutions.

At the time of writing this report, Northern Arizona University WindJax's Project Development team has progressed through the phase 1 selection and is preparing to be evaluated for the phase 2 cycle which ends at the end of Fall 2023. The team also accomplished an in-depth analysis of customer and engineering requirements, mathematical modeling that was backed by a literature review, and concept generations and evaluations that was determined by engineering calculations, failure modes and effect analysis, initial prototype, and a specified leasing area. The results of each analysis were checked and verified through the faculty advisor. The Project development team's next step is to complete another iteration of the prototype model of the hypothetical offshore wind farm and further the team's financial analysis.

This report will discuss the team's efforts in designing, analyzing, and modeling an offshore wind farm based off Lake Michigan. Lease block size, population and environmental impacts, current utility and transmission infrastructure support, turbine selection, and anchor design are several key factors that will be explored through this report to determine the ideal farm size and layout, financial report, and power output.

1 BACKGROUND

The Project Development goal, as laid out by The Department of Energy – the project sponsor – is to create a fully-fledged plan for a hypothetical offshore wind farm to participate in the 2024 Collegiate Wind Competition. With this, The Department of Energy (DOE) has communicated how the team will be scored compared to the other 35 competing university teams via the competition rulebook [1]. This competition gives applicable experience to engineers entering the field into project development and management. Applying hypothetical site development plans towards this project will address real world research questions that could potentially help wildlife habitability and migration, environmental protection, and the growing demand for clean energy. To this end, the Project Development team will need to evaluate site data, electrical grid data, and existing technology data to create a site development and maintenance plan. Alongside this, the team will need to analyze finances and prove that the hypothetical wind farm would be realistic. Further detail in the expectations of the DOE are as follows:

- Physical site characterization like assessing freshwater icing challenges, soft bed lakebed sediments, shallow bedrocks, and/or heavy metals in sediments.
- Consideration of access to infrastructure or ports, accounting for vessel constrictions
- Supply chain needs to manufacture, transport, install, and maintain equipment.
- Electric grid interconnection and integration, accessible electric power network and handling power capacities
- Accounting for no impact in wildlife and environment, migration, fish ecology, aquatic resources, etc.
- Assessing coexistence with residents and tribes in the U.S. and Canada
- Incorporate offshore wind energy generation as part of a hybrid power plant for development and operation in ancillary grid benefits.
- Market participation offtake agreements and multi technology solutions

1.1 Project Description

In this year's Collegiate Wind Competition (CWC24), 35 teams will be selected to compete for a greater engineering career pathway to be implemented towards knowledge of wind energy's potential clean energy future. The competition is divided into four contests and three phases: Turbine Design, Turbine Testing, Project Development, and Connection Creation. The first phase happens when all 35 teams have submitted their motivations in entering the competition. Phase two requires 12 teams to perform in reports and videos of how well they achieved competition objectives in the four contests. The third phase is the final where the team has performed and met industry standards along with completing a final report.

1.2 Client Deliverables

The Project Development team is required by the client submit two reports: one for the midyear and one for the final semester of the 486C course. The midyear report, a client deliverable due at the end of the first semester of capstone, focuses on team's progress in developing a draft of a hypothetical wind farm, and analysis of site data. The final report focuses on all aspects of the finalized design of the wind farm, including finalized choice in technology and its placement, data analysis, electrical transmission lines and connections to the electrical grid. For the purposes of ME476C, the Project Development sub team is focusing heavily on the midyear report, while preparing to pursue the final report.

1.3 Success Metrics

The success of this project accounts for key aspects of a wind farm siting and the activities relating to project development. Understanding how wind resource data is calculated, estimating performance, project economics, bathymetry, environmental issues, transportation constraints, transmission design, permitting requirements, turbine technology, and performance variables (e.g., wakes, turbine availability, and site-specific losses). Understanding these long-year key aspects are crucial to deliver customer requirements and engineering requirements like incorporating one other generation, storage, or end-use technology that can be added to the offshore wind turbine system (hybrid). Concluding the cost of energy is also important to also compensate a 20-year life expectancy. Getting involved with communities (connection creation) is also important for us to consider getting the right amount of info.

2 REQUIREMENTS

In order to ensure that the team meets the expectations of the client, a thorough breakdown of the client's desires and engineering measurements to meet them is required. The team did this by creating a House of Quality (HoQ) or Quality Function Deployment (QFD). This allows the team to understand how important each engineering standard is to the overall project from the consideration of the client/customer wants. These engineering requirements will help the team to quantify different aspects of design and pick the best design overall for the client. The Project Development team found eleven customer requirements and created twelve related engineering requirements. These requirements have undergone changes since their creation, and will continue to undergo changes as the team learns more. This section contains the most up-to-date version.

2.1 Customer Requirements (CRs)

The Department of Energy supplied their expectations via the Collegiate Wind Competition 2024 Phase 2-3 Rules Document [1]. This document was used to define the customer requirements. Few of these requirements have quantities associated with them, and so the team will need to rely on research of current wind turbine power plants to guide the project.

The requirements from The Department of Energy largely include selections for the team's hypothetical power plant, and justification for those selections. The team must select technology to be used and a site for the offshore wind farm in the great lakes. The technology selection is for existing technologies and designs of offshore wind turbines, anchor systems, energy transmission lines, and one other generation, storage, or end use technology. The site selection refers to the location of the offshore farm, both the decision on the lake, it resides in as well as the exact location within that lake. To support and inform these selections The Department of Energy also requires a development and technical integration plan, which informs how the power plant would be installed, harm mitigation strategies for affected ecosystems, which would ensure that the power plant is not causing undue stress to endangered species or fragile ecosystems nearby, and a financing plan, which includes annual costs, cost of energy and flow analysis, and market incentives to prove that the proposed power plant is profitable. Additional customer requirements include a 20-year lifespan for the power plant, an analysis of community impact, and a bid for a potential lease spot.

2.2 Engineering Requirements (ERs)

The team created engineering requirements guided by the needs of the customer requirements. As the client did not specify many values, the Project Development team is using values as indicated by the team's advisor, Dr David Willy, and turbine data as a starting point. Some of these values are expected to change as the team becomes more acquainted with the data. These requirements include several types of data, including bathymetry (water depth) in meters, wind speed in meters per second, weather data in which the team will focus on extreme weather events for high wind speeds as well as frequency that the lake is expected to be frozen yearly, species migration paths and shipping routes in which the team will review mapped square kilometers in reference to potential plant sites with the goal of being completely outside those zones. The team included further data for the engineering requirements that include community usage measured in population monthly usage with a goal of less than 100 people, power grid data measured in distance from power plant to substation with a goal of less than 80 km, and finally state and country policies. A notable change from the last submission of the Engineering Requirements is the addition of operational expenditures and capital expenditures. These additions will help better reflect the monetary requirements from the client. The final engineering requirements utilize all the prior mentioned data. These requirements are plant power output with the minimum goal of 150 MW, levelized cost of energy measured in dollars per kilowatt-hour, and area of leasing block measured in square kilometers. Typical development plans are given leasing blocks, but The Great Lakes do not as of yet have any such blocks.

2.3 House of Quality (HoQ)

For ease of viewing, the benchmarking "room" is separated into Figure 2.3.1, below. The benchmarking is covered further in Section 3.1 . The ratings given to each benchmarking are the team's assessment of how well each group met this year's customer requirements.

Benchmarking and competitive evaluation (1: low, 5: high)		
NAU 2022	NAU 2023	Pennsylvania State University's (PSU) 2023
5	4	5
5	3	5
4	3	5
4	4	5
1	1	1
4	3	4
5	4	3
5	3	5
5	3	5
5	4	5
4	4	4

Figure 2.3.1: House of Quality Benchmarking Room

The next page contains the CWC24 Project development House of Quality in Figure 2.3.2. Each engineering requirement was given a rating of how well it relates to the customer requirement. A rating of zero is unrelated, a rating of one is a weak relation, a rating of five is a moderate relation and a rating of nine is a strong relation to the customer requirement. From this, some simple math is done to see which of the engineering requirements scored highest, and therefore determine what the team needs to focus on in more depth. The highest rated requirements are the capital expenditures and port infrastructure. The percentages of importance from this House of Quality inform later sections and decisions made for design.

The correlation between engineering requirements was deemed by the team to be unimportant, and so has been removed for this report.

1: low, 5: high Customer importance rating (for full competion points)	Engineering Requirements (How's) → Customer Requirements - (What's) ↓	Area of Leasing Block (km^2)	Levelized Cost of Energy ($/kWhr)	Capital Expenditures ($)	Operational Expenditures ($/year)	Farm Power Output (150 MW)	Wind Data (85-140m height)	Bathymetry Data (m)	Weather Data (WindSpeed max for 100yr storm, and frequency below freezing)	Port Infrastructure (area of port, machinery available)	State/Country Policies	Species Migration Paths (km^2 mapped)	Shipping Routes (mapped)	Power Grid Utility Line Connections (<80km to plant)	Community Usage Data (<100 people in area monthly)
	Desired direction of improvement (↑,0,↓)	↑	↓	↓	↓	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
5	20 year lifespan	0	0	0	0	0	5	5	9	5	5	0	0	0	1
5	Siting Selection	9	0	9	0	0	9	9	9	9	5	9	9	5	9
5	Technology Selection (Turbine, Anchor, Energy Transmission)	5	9	9	9	9	9	9	5	9	5	5	0	5	0
5	Development and Technical Integration Plans	9	5	9	5	5	1	0	0	9	9	5	9	9	5
5	One other generation, storage, or end-use technology	5	5	5	5	5	0	9	5	5	5	5	1	5	1
4	Harm mitigation strategies for affected ecosystems	9	0	5	5	0	5	5	1	0	5	9	5	0	1
3	Local Community Impact	1	1	0	1	5	0	1	1	5	5	1	5	5	9
5	Financing Plan - annual costs, market incentives, etc	5	9	9	9	9	5	0	0	5	1	0	1	1	1
4	Cost of Energy and cash flow analysis	1	9	9	9	5	5	0	0	5	5	0	0	5	0
3	Annual Energy Production	5	1	0	0	9	9	1	5	0	0	1	0	0	0
5	Bid for potential Lease Block	9	9	9	5	5	5	0	0	5	5	0	0	1	0
	Technical importance score	228	179	261	179	155	165	138	122	225	205	134	135	140	116
	Importance %	10%	8%	11%	8%	7%	7%	6%	5%	9%	9%	6%	6%	6%	5%
	Priorities rank	**2**	**5**	**1**	**5**	**8**	**6**	**6**	**8**	**1**	**2**	**5**	**3**	**9**	**14**

Figure 2.3.2: House of Quality

3 Research Within Your Design Space

3.1 Benchmarking

To satisfy the requirements that are set by the DOE, the Project Development team will reference Pennsylvania State University's (PSU) 2023 performance are they were second overall and first in the project development category. The team can utilize this reference for the structure of the analyses and selection consideration. The team will also reference Northern Arizona University (NAU) 2022 submission for their second overall ranking. The team can utilize NAU's 2022 report as a basic outline in order to improve upon the areas that did not exceed in their respected category.

To revolutionize this year offshore wind farm, the Project Development team has examined three components of the system on a power plant level to determine which components can be altered to consider different state-of-the-art features. Those three plant features will be the utilization of current power plants that are retiring within close proximity of the Great Lakes, optimization of power generated based on the turbine parameters, and an ice preventative design.

The importance of considering retiring plants is to lower cost and time spent on the development of the plant. This will also allow the team to interconnect with the preexisting infrastructure that is providing energy to major cities. The goal of this project is to generate as much power as possible while keeping other components low such as the levelized cost of energy (LCOE). This is directly related to the wind turbine based on the number of turbines, hub height, farm spacing, and distance from shore. Considering these factors will ensure the team's design meets the client's parameters. Lastly, ice is an environmental factor that is still being researched to date. Being that both Great Lakes are susceptible to freezing conditions, the team is focused on designing a turbine tower and anchor system that is capable of surviving these conditions.

Sections 3.2 and 3.3 are provided to show the team's literature research of the power plants state-of-the-art feature on a sub level basis that is then followed by a mathematical analysis to justify the relevance of the design.

3.2 Literature Review

3.2.1 Site Selection – Alexander Longoria

The purpose of an in-depth analysis for Site Selection is to determine which of the Great Lakes is the ideal location for the offshore wind farm. To further explain, this section will go over some of the references used to help the team make that decision.

"Global Great Lakes: Lake Superior and Lake Michigan" [2]
Reference 2 is an online resource that is backed by the University of Minnesota Duluth's Large Lake Observatory. This source will be used to understand the numerical characteristics of the great Lakes such as the area, volume, population, and retention time of the water.

"Protecting Michigan's Inland Lake: A Guide for Local Government" [3]
Reference 3 is a guidebook published by michigan.gov titled. This guidebook was drafted to help citizens and officials understand the benefits of the inland lakes, the regulations that govern them, and the opportunities for locals to help protect these lakes.

“Lake Superior Shoreland Lot Development Requirements” [4]
Reference 4 coincides with rules and regulations from reference 2. This document focuses on the site plan standards that were derived by the corrosive properties of the water and the undercuts of the rocks from the waves. These references will be used to understand the laws and requirements of building infrastructure within the lakes.

“Investment cost and view damage cost of siting an offshore wind farm: A spatial analysis of Lake Michigan” [5]
Reference 5 will give the team a detailed understanding of the factors that are considered when estimating the initial costs of an offshore wind farm. This article provides the team with all the necessary equations to solve variables such as the Willingness to Pay, Annual View Damage Cost, and the Net Present Value View Damage Cost based on the distance the turbine is from the shoreline.

“Lake Michigan and Lake Superior” [6]
Reference 6 will be coming from the same online resource, greatlakes.guide. Adhering to the Lake Michigan and Lake Superior tabs, the author goes into depth about some of the current problems each lake is facing and how the community benefits from the lakes.

“Border Flows: A Century of the Candain-American Water Relationship” [7]
Reference 7 is a downloadable pdf book that discusses the relationship of Canada and the United States in regards the water resources and distribution. This book is an important read if the team chooses to consider Lake Superior for the location of the offshore wind farm. Approximately ¼ of Lake Superior is Canadian territory and the other ¾ is American territory. With that being said, if the team decides to populate turbine on the Canadian side, it would be important to understand the history of the two neighboring countries in order to maintain mutual alliance.

“Cape Spin: An American Power Struggle” [8]
Reference 8 is a documentary film about Americans first ever proposed offshore wind farm, Cape Wind. In this film, they talk about the 10-year struggle Jim Gordon faced because of his 130 wind turbine proposal. The team will be able to utilize this documentary to understand some of the negative backlash received in order to prevent ethical issues within the community.

“Great Lakes Wind Energy Challenges and Opportunities Assessment” [9]
Reference 9 is a document published by NREL. From this resource, the team will be able to find relevant graphs and information directly related to this year's project. In terms of site selection, this document will drive a lot of the decision and research questions for the provided data about wind resource data, bathymetry data, and levelized cost of energy.

3.2.2 Turbine Selection and Furow Farm – Sam Russell

Integral to wind power plant output is the turbine that is used. Consideration needs to be given to turbines height, rotor and tower size, optimum spacing requirements, cost, and assembly needs. The following references provide guidance on how best to choose a turbine, as well as provide various turbine specifications.

"Offshore Wind: A Comprehensive Guide to Successful Offshore Wind Farm Installation" [10]
This source, as suggested by the title, is a guide of offshore wind farm installation. The book is a self-proclaimed guide for project developers and financers, specializing in overcoming challenges associated with wind power plant. This book is referenced in the turbine selection process to give insight into the considerations necessary for turbine installation, transportation to site, and slight cost analysis.

"Wake effect in wind farm performance: Steady-state and dynamic behavior" [11]
This research study shows the importance of turbine spacing with consideration for the wake of the wind. It aims to provide a "rule of thumb" for generalized calculations before full data is known for the power plant. The team references this source in order to make appropriate considerations regarding the turbine spacing.

"Wake effects of large offshore wind farms identified from satellite SAR" [12]
This article reviews the effect of large-scale offshore wind farms on local wind after it passes through the farm. The researchers found that mean wind speeds had decreased eight to nine percent. The article discusses effects as far as twenty kilometers behind the wind farm. This source will be used to consider the turbine's effects as they relate to migration pathways, and will be used to aid in harm reduction plans.

Wind Energy Explained: Theory, Design and Application: Chapter 9: Wind Turbine Siting […] [13]
Chapter nine of the Wind Energy textbook delves into micro siting, introductory aspects of power plant design, and power integration. The team utilized this source to validate source [11] in basic spacing requirements. The team will continue to utilize various sections of this chapter moving forward, as it covers many topics that the project development team will need to understand.

"GE, Vestas Top Us Leaderboard in installed wind capacity, performance" [14]
This article reviews top utilized wind turbine companies used in the United States. The largest two companies are General Electric and Vestas, followed up by Siemens Gamesa. The team used this source to guide on turbine selection, having had no previous experience with turbines.

"Haliade 150-6MW offshore wind turbine" [15]
This manufacturer website provides many specifications for one of the General Electric offshore turbine designs, including hub height, power rating, rotor specifications, and tower type. This source was used to compare to other potential selections of turbine.

"Offshore wind turbines" [16]
This Vestas manufacturer website provides data about Vestas offshore wind turbine designs, including installed locations, installed power capacity, and some of the specific turbine designs. This source was used to locate suitable Vestas turbines for concept generation.

"Scaling up the use of offshore wind turbines" [17]
This manufacturer website provides data about Siemens Gamesa offshore wind turbines, similar to source [16]. Like the Vestas site, it provides installed power capacity for various countries, as well as various

turbines that have been designed for offshore. This source was used to locate suitable Siemens Gamesa Turbines for concept generation.

"Port and Shipyard Requirements for the Installation of Floating Wind Turbines" [18]
This source explains different types of ports and shipyards and related terms. It provides details on space and machinery needed for floating wind turbines. This source is utilized to ensure that when selecting a turbine, the team also considers assembly needs for it.

"Vestas V236-15.0 MW introduced" [19]
This article briefly reviews a new design for an offshore Vestas turbine, with prediction of cost. This source is used to estimate the costs of the selected turbines for comparison. While not fully accurate, it gives the team an expectation.

"*Grid Extract*" [20]
This data extraction tool is useful for inputting site data into Furow for overall farm analysis. It is a worldwide collection of raster data compiled by the National Oceanic and Atmospheric Administration and the National Centers for Environmental Information. This dataset allows for precise extraction of a tif file, which can be easily converted to an xyz file, usable for creating a site map in Furow.

"*Innovative Data Energy Applications*" [21]
This compilation of data energy applications created by the National Renewable Energy Laboratory is fundamental in getting a successful power curve out of Furow. From this collection, the team is specifically using Wind Prospector, a comprehensive wind speed dataset.

3.2.3 Anchor Selection – David Lemar Perez

There are two types of anchor foundations, gravity based and floating. For the project, the team is focusing on offshore base foundations that would focus on the most efficient locations on the great lakes without harming wildlife and the environment. To compensate for the harsh characteristics from temperature and icing, the best foundation that would mitigate this is either Tension-Leg Platform or the Hybrid. These two platforms are ideal for eliminating deep water currents which add force to the structure and movement which is undesirable. Ice can form easily but TLP's are known to have also withstand the amount of icing and capsizing force, the amount of tension by mooring ropes have been also able to withstand icing. The material used is buoyancy dependent that takes up less weight overall for efficiency.

"Vestas V236-15.0 MW introduced." [22]

Reference 22 is where it demonstrates what anchor is best suited for lakes related to lake Michigan or Lake Superior.

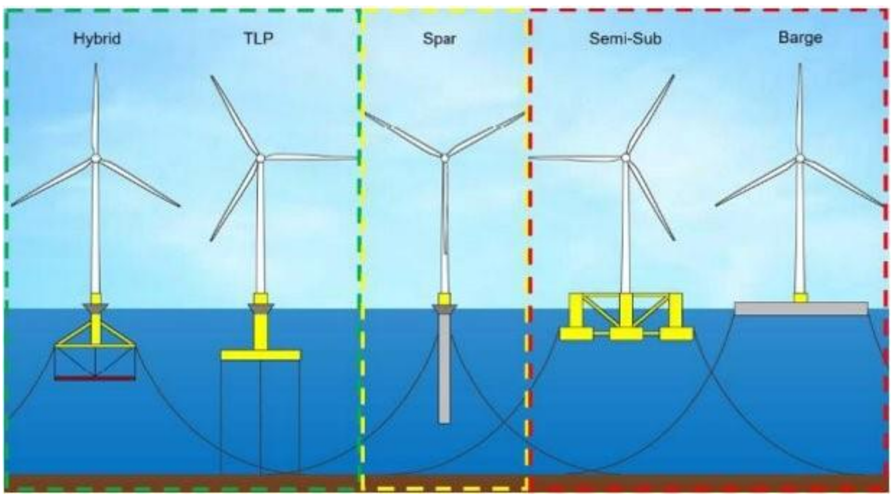


Figure 3.2.3.1: Different types of anchor designs

The type of style for the anchor is like a lattice floating hybrid or a floating structure with mooring ropes attached to it like a Tension Leg Platform.

"Semi-Submersible Platform and Anchor Foundation Systems for Wind Turbine Support." [23]

Article 23 talks about "Acteon," a program that can illustrate geological and soil properties in evaluating different types of anchors that can be simulated within these conditions. The program specifically focuses more on floating wind testing bases. In the end it also verifies the cost and the availability of certain materials.

"Great Lakes Wind Energy Challenges and Opportunities Assessment." [24]

Article 24 is focused more on specific data like micro bathymetry for Preliminary design of anchors focused on offshore wind turbines. Using data like analyzing how much force is being generated from structures to collecting soil samples in a region and finding tension in mooring lines. This resource is useful in using graphs that best represent in calculating efficient performance numbers once an anchor style has been selected and the location too.

“Numerical and Physical Modeling of a Tension-Leg Platform for Offshore Wind Turbines.” [25]

Article 25 is looking into recent offshore wind turbines that are currently working around the world as well as a brief description in which offshore wind turbine anchors are being selected for future use. It touches on the subject of whether certain regions will accept certain buildings near cities or villages due to local agreements and environmental concerns.

“Anchor types for floating wind.” [26]

Article 26 has a set of info regarding wind turbines but specifically it touches on the subject on anchors on how each factor is crucial in how anchors are affected the most. The design quality, fatigue due to corrosion, overload, manufacturing defects, installation, and out of plane bending, etc. These factors are also addressed due to the reliability of how anchors are also a big part of the whole turbine design.

3.2.4 Transmission Infrastructure – Alexander Longoria

"All Energy Infrastructure and Resources" [27]
This online map served as the main reference for finding power plants within the Lake Michigan region. For this source, the team was able to gather information such as the utility and plant name, location, type of power plant, and total name plate capacity. In order to retrieve more information about the plants, the team utilized various websites tailored to the plant.

"Edgewater Generating Station Redevelopment" [28]
This source was used to understand when and why the power plant is shutting down. As well as some of the potential outcomes the stakeholders are wanting from the plant.

"WEC Energy Group Plans to Shut Down Oak Creek Coal Plant by 2024" [29]
This online article briefly touches on what is mentioned in reference 27 alongside why the plant is shutting down and some of the revenue the plant is responsible for.

"Power Plant Profile: University Park South Power Plant, US" [30]
This is another online article that discusses some of the matrix and numbers of the plant.

"Point Beach Nuclear Plant" [31]
An addition to providing basic information about the plant, a pdf link is provided directly to the page that's redirects you to an informative flyer.

"J.H. Campbell Complex Retirement" [32]
The purpose of the article is to tell the reader why the plant is being shut down as well as some of its accomplishments and timeline.

"Lake Michigan Fishing" [33]
This article was used to aid in the concept selection process developed throughout sections 4.2, 4.3, and 4.4. This online map provided the user with information about the species of fish, the location of their dwelling, and concentration of the fish species.

"Lake Michigan Ship Traffic Live Map" [34]
In addition to the fish map, the team utilized this online map to understand the density and frequency in which private and commercial boats travel within the lake.

*"Great Lakes Wind Energy Challenges and Opportunities Assessmen*t" [35]
Additionally, this online document published by NREL was used for its detailed figures and literature about Lake Michigan. For example, the teach referenced the figure relating to mean wind speeds as different hub heights, levelized cost of energy, bathymetry data, top pier ports, point of interconnection, and popular location for recreational activities.

"How Is Line Loss Calculated" [36]
This short step by step article goes over the details of calculating loss and what it is. The governing variables that determine power loss is the power produced by the farm (watts), the voltage from the plant (kilovolts), diameter of the transmission line (feet), and the length of the transmission line (feet).

"An excerpt from ATC's 2011 10-Year Transmission System Assessment" [37]
To aid in the analysis of reference 36, this article was used to determine that Edgewater Generating Station utilizes two 345kV lines.

"Engineering Design, Construction, and Right-Of-Way Acquisition" [38]
In addition to reference 36 and 37, the last thing that is needed to find the power loss is the diameter of the 345kV line. This pdf handbook informed the team that the overall conductor diameter is 1.8 inches.

3.3 Mathematical Modeling

3.3.1 Site Selection – Alexander Longoria

In order to justify the selection of the Great Lakes, the team utilized the equations described in reference 4, Investment cost and view damage cost of siting an offshore wind farm: A spatial analysis of Lake Michigan, and coded them into MATLAB to obtain the results.

Equation 1 solves for Willingness to Pay; this variable tells the team how much a resident is willing to pay (WTP) as an additional cost or willing to accept (WTA) as a discount towards their month electric bill based on the specific distance the offshore wind farm is from the shoreline. The equation is listed below,

$$WTP\left[\frac{US\ dollar}{month\cdot household}\right] = 27.464 \cdot \ln\left(D_{farmtoshore}\right) - 90.911 = -WTA \quad [1]$$

As seen in the equation, the only input to the function is Dfarmtoshore. This variable is used to denote the offshore wind farm distance from the shoreline. The "–WTA" represents the instance in which the residents will receive a discount. After this equation is coded in MATLAB, the team will conclude that 27.47 miles is the ideal distance for keeping the WTP and WTA the lowest. This can be seen in the graph below.

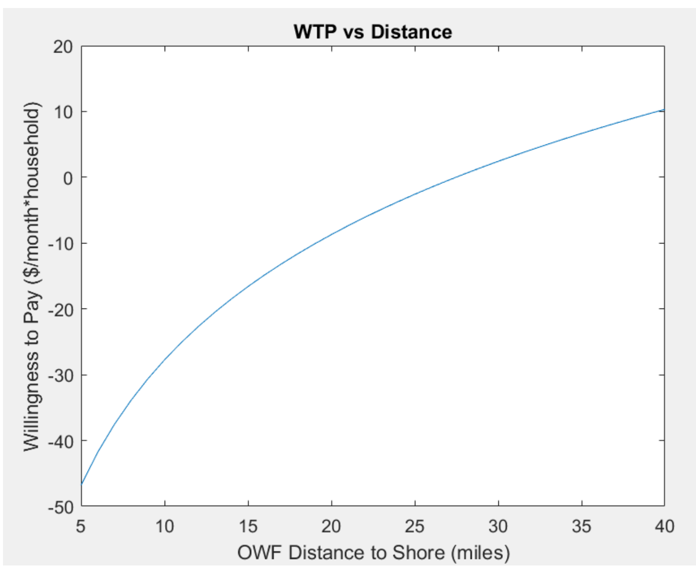


Figure 3.3.1.1: Willingness to Pay vs Farm Distance

The next equation that was derived from reference 4 solves for the Annual View Damage Cost (VDC). VDC is defined as the cost to residents from the visual disamenity of the offshore wind farm within the viewshed of the households. Equation 2 is listed below.

$$Annual\,VDC\left[\frac{US\,dollar}{year}\right] = WTA \cdot 12\,months \cdot h \qquad [2]$$

Where "h" is the total number of households within viewshed of the farm. When using this equation for analysis of both Great Lakes, the team can estimate that there are 439 households in Lake Michigan and 351 households in Lake Superior. This equation is directly proportional to equation 1, meaning that the distance between the farm and shoreline are stiff influences the results. This can be seen in the graph below.

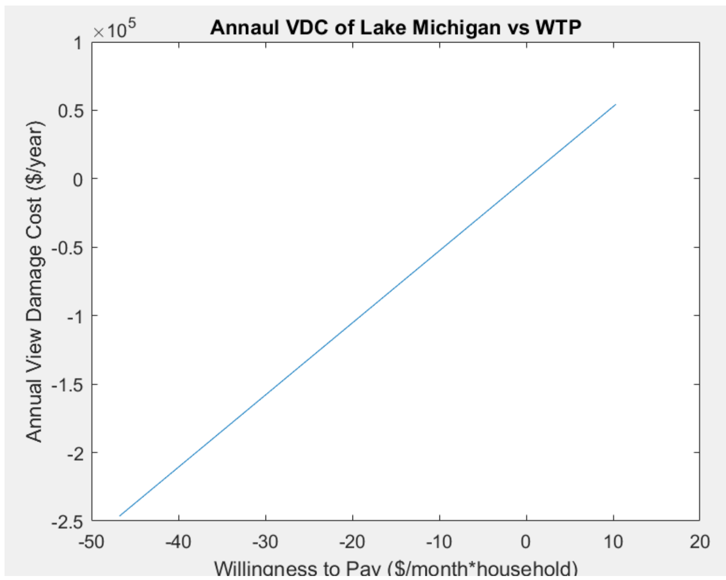


Figure 3.3.1.2: Annual View Damage Cost of Lake Michigan vs Willingness to Pay

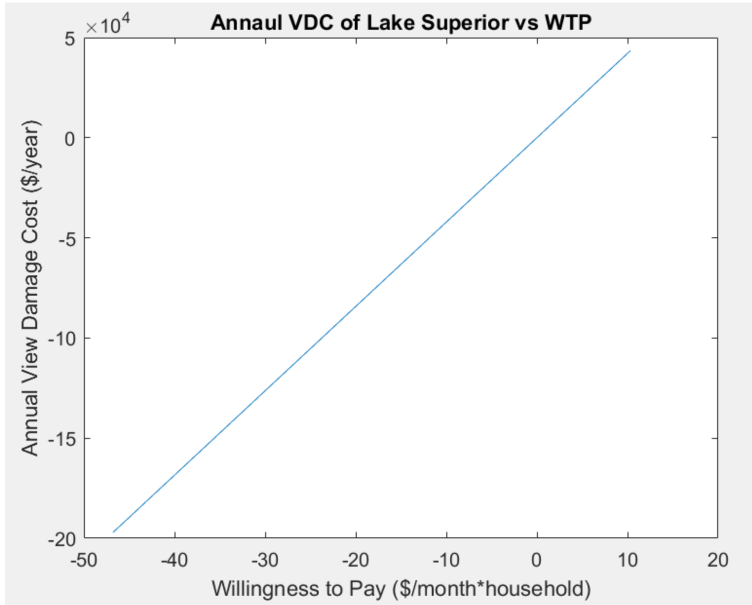


Figure 3.3.1.3: Annual View Damage Cost of Lake Superior vs Willingness to Pay

The last equation will tell the team the Net Present Value VDC. This will tell the team the present value of the VDC with consideration of an estimated discount rate of 3% per the reference. This finding will be evaluated over the 20-year life span of the farm (n).

$$Net\ present\ value\ VDC\ [US\ dollar] = \frac{Annual\ VDC}{r} \cdot \left(1 - \frac{1}{(1+r)^n}\right) \qquad [3]$$

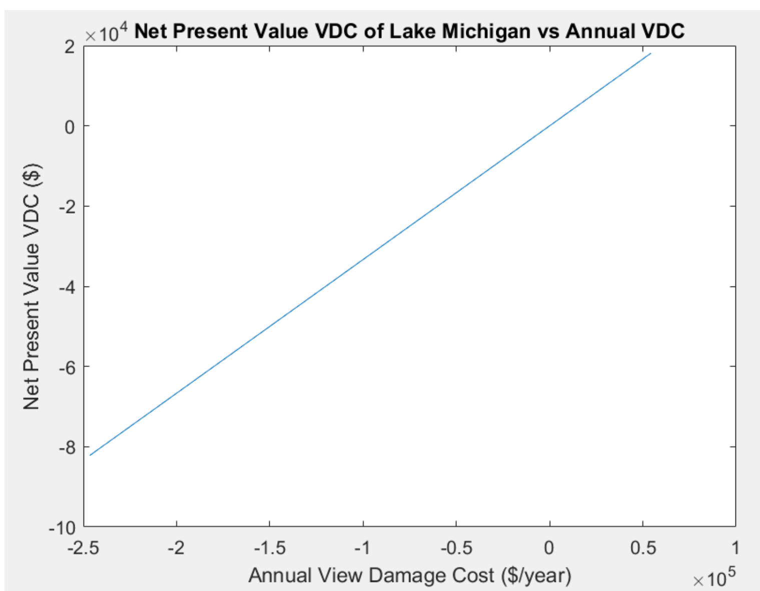


Figure 3.3.1.4: Net Present Value VDC of Lake Michigan vs Annual VDC

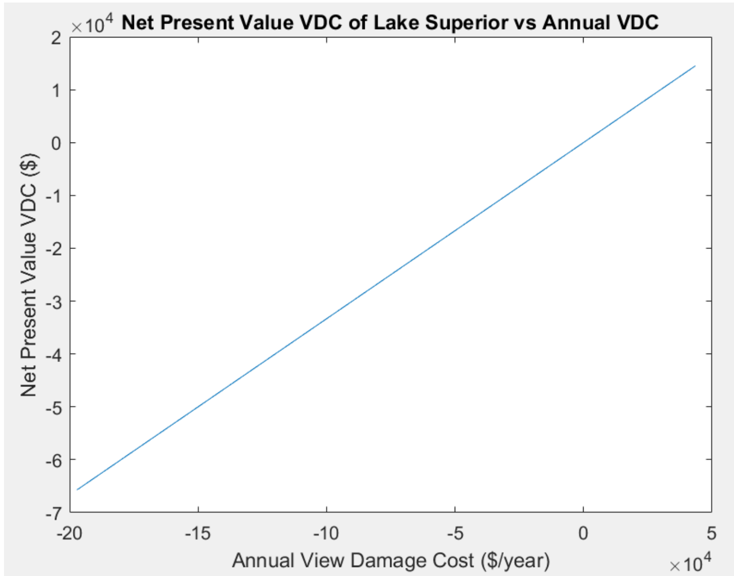


Figure 3.3.1.5: Net Present Value VDC of Lake Michigan vs Annual VDC

Part of the team's end goal is to minimize the Levelized Cost of Electricity (LCOE) and the reference provides the appropriate equation to solve for it (equation 4). However, at the time of writing this report the team does not have enough data about the annual energy production based of the turbine the team decides. Therefore, the team cannot generate a reasonable value.

$$View\ damage\ LCOE \left[\frac{US\ dollar}{MWh}\right] = \frac{Net\ present\ vaule\ VDC}{Annual\ energy\ production\ (net) \cdot n} \quad [4]$$

3.3.2 Turbine Selection – Samantha Russell

In order to justify turbine selection, some analysis is required for farm power output potential, turbine spacing, and turbine cost. The following equations are rudimentary and used for the purpose of narrowing choices and team understanding of the topic.

The first equation is guided by [13]. From the parameters there, a general special analysis was done with eight diameter spacings between turbines in the wind direction, and five diameter spacings between turbines opposite the wind direction. This has not been optimized, as each turbine may be placed closed or further from each other based upon airfoil design and wake analysis. This gives an analysis of the possible air turbines in a leasing spot. An assumption of leasing area of 100 square kilometers was used. In this equation, D represents the turbine rotor diameter.

$$Number\ of\ Turbines = 10km/(9D) * 10km/(6D) \quad [5]$$

Further, to compare the possible power output for the same area between the different turbines, the number of turbines was multiplied by the rated power output of the turbine.

$$Farm\ Power\ Output = Number\ of\ Turbines * Rated\ Power \quad [6]$$

These calculations, while simplistic, help to narrow down to three potential turbine selections. More in depth analysis will be done with the selected turbines to narrow down to a final choice using Furow, a wind plant analysis tool suggested by NREL and The Department of Energy. Figure 3.3.2.1 below displays an example of how furrow will help to visualize power output.

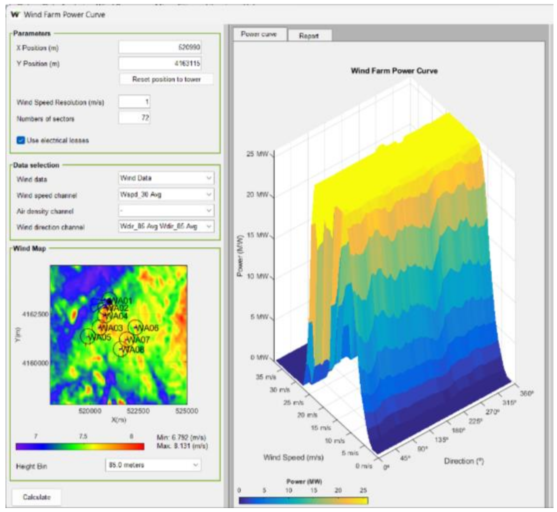


Figure 3.3.2.1: Furow Power Analysis

3.3.3 Anchor Selection – David Lemar Perez

Article 23 represents an anchor that was tested in Germany that focused on creating cost efficient floating platforms, that was reliable in lightweight, and size compared to spars and semi-submersibles. Using computer aided engineering like “aero-hydro-servo-elastic coupled simulations” help managed scale a model like in a real life wind shore turbine location. Testing from decay to mooring rope tension attached to the platform helps test many factors that could simulate real time effects like on the great lakes. The test that was conducted was a similar build like a TLP but with some modifications that added lattice designs with 8mm stainless steel threaded rods and other parts made with polyoxymethylene material for lightweight and durability; also coated with epoxy for less drag on water. Mooring ropes where attached calculations needed to be accounted for stability if such wind or wave conditions hit and did not make the platform stable. Mooring ropes are attached where OpenFAST computer program calculates the tension in the ropes in which it told how much strength is needed to not have it capsize or tear apart. The equation below is taking the Yield strength and having a certain tolerance boundary for efficiency. Then calculating the ropes extensional stiffness of within that range. The C target equation is for the correct axial stiffness for the coiled springs along with attached steel ropes. Most of this is 1:100 scaled for fitting a real time simulation which performed better than most platforms which would not be suitable for 60m or more depth offshore locations.

$$130 \times 10^3 \ \mathrm{N/mm^2} \leq E \leq 150 \times 10^3 \ \mathrm{N/mm^2} \qquad [7]$$

$$408,400 \ \mathrm{N} \leq EA \leq 471,239 \ \mathrm{N} \qquad [8]$$

$$c_{target} = \frac{EA \cdot \frac{1}{\lambda^3}}{l_0 \cdot \frac{1}{\lambda^1}} = \frac{2146,000,000 \ \mathrm{N} \times \frac{1}{50^3}}{168,421 \ \mathrm{mm} \times \frac{1}{50}} = 5.097 \ \mathrm{N/mm} \qquad [9]$$

3.3.4 Financial Analysis – David Lemar Perez

The project development team is looking into the financial analysis of the project for the required capital, financing, and project marginal costs. Our method and solvency towards gathering total financial accumulative data for building and simulating a wind farm is by using certain programs. The best programs that can be correlated with building a wind farm or selecting a specific turbine that can calculate all data at once are S.A.M. (System Advisor Model) as a single owner wind farm focused data and JEDI (Jobs and Economic Development Impact) as more of a financial aspect. These programs are useful for the time being since they can always be monitored or changed in the data on the fly for quick analysis. S.A.M is more for specifying data which focuses on selecting the number of turbines in a layout and seeing different data numbers on simulating a certain site selection. JEDI is used to calculate more financially as in like project data (Capex), balance of system costs, soft costs, opex, financial parameters, and labor parameters all in one data sheet.

JEDI:

Summary	
Project Description	
Project Name	CWC24
Economic Analysis Area	Great Lakes [Region]
Wind Plant Project Area	Great Lakes [Region]
Port Name	Port Name
Year of Construction	2030
Nameplate Capacity (MW)	250
Number of Turbines	50
Substructure Type	Semisubmersible
Foundation Type	Floating
Construction Summary	
Project Cost ($/kW)	$4,511
Total Cost ($Ring mil.)	$1,127,704,455
Total Local Expenditures	$0
Overall Construction Local Content	0%
O&M Summary	
Operating Cost ($/kW)	$119
Annual Cost	$29,778,512
Total Local Expenditures	$0
Overall O&M Local Content	0%

Project Data - CAPEX						
Construction Costs	**Expenditure/Cost ($2030)**				**Local Share**	
Turbine Components						
Nacelle and Drivetrain						
Materials	$189,106,318				0 %	
Optional turbine subcomponents entered?	**No**					
Labor	$26,143,682				0 %	
Nacelle/Drivetrain Total	$215,250,000					
Blades						
Materials	$56,225,873				0 %	
Optional blade subcomponents entered?	**No**					
Labor	$8,274,127				0 %	
Blades Total	$64,500,000					
Towers						
Materials	$38,988,486				0 %	
Optional tower subcomponents entered?	**No**					
Labor	$6,511,514				0 %	
Towers Total	$45,500,000					
Turbine Equipment Subtotal	$325,250,000					
Balance of System Costs						
Substructure and Foundation						
Semisubmersible	$0				0 %	
Materials	$311,250,003					
Labor	$51,982,236					
Mooring System	$0				0 %	
Materials	$11,650,835					
Labor	$1,777,165					
Substructure and Foundation Subtotal	**$0**					
Electrical Infrastructure Components						
Array Cable System	$45,708,307				0	

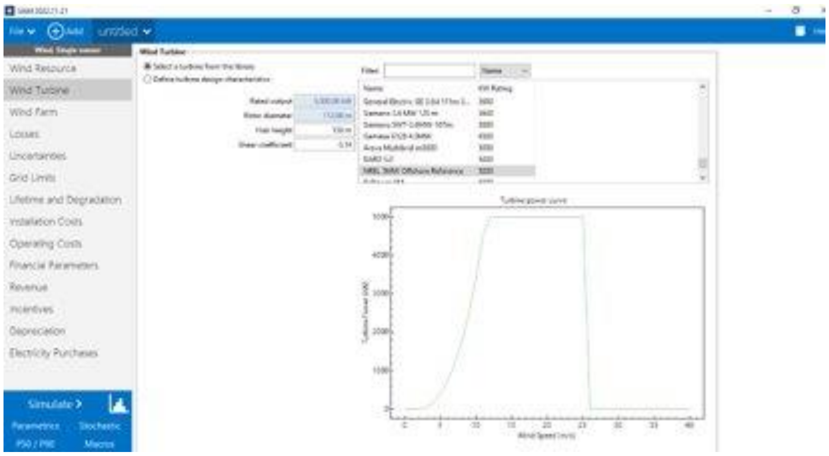
					%	
Materials	$39,166,982					
Labor	$6,541,325					
Export Cable System	$76,557,375				0 %	
Materials	$65,601,234					
Labor	$10,956,141					
Offshore Substation	$117,087,300				0 %	
Offshore substation materials	$108,511,534					
Offshore substation labor	$8,575,766					
Electrical Infrastructure Components Subtotal	**$239,352,982**					
Assembly and Installation						
Foundation	$23,642,555					
Vessel	*$20,142,237*				0 %	
Labor	*$3,500,318*				0 %	
Mooring System	$0					
Vessel	*$0*				0 %	
Labor	*$0*				0 %	
Turbine	$42,802,500					
Vessel	*$36,465,521*				0 %	
Labor	*$6,336,979*				0 %	
Array Cable	$14,770,982					
Vessel	*$12,584,115*				0 %	
Labor	*$2,186,868*				0 %	
Export Cable	$2,540,511					
Vessel	*$2,164,385*				0 %	
Labor	*$376,127*				0 %	
Offshore Substation	$2,486,486					
Vessel	*$2,118,358*				0 %	
Labor	*$368,128*				0 %	
Assembly and Installation Subtotal	**$86,243,035**					
Ports and Staging						
Foundation	$8,176,276				0 %	

Mooring System	$0				0 %	
Turbine	$15,175,342				0 %	
Array Cable	$7,995,059				0 %	
Export Cable	$1,194,801				0 %	
Offshore Substation	$170,117				0 %	
Ports and Staging Subtotal	**$32,711,594**					
Development and Other Project Costs						
Site Auction Price	$12,500,000				0 %	
BOEM Review	$0				0 %	
Construction Operations Plan	$1,000,000				0 %	
Design Install Plan	$250,000				0 %	
Site Assessment Plan	$500,000				0 %	
Site Assessment Activities	$50,000,000				0 %	
Onshore Transmission	$160,282,538				0 %	
Development and Other Project Costs Subtotal	**$224,532,538**					
Engineering and Management						
Construction Operations	$17,500,000				0 %	
Engineering and Management Subtotal	$17,500,000					
Balance of System Subtotal	**$600,340,149**					
Soft Costs						
Commissioning	$13,200,000				0 %	
Construction Finance	$54,900,000				0 %	
Construction Insurance	$13,200,000				0 %	
Contingency	$94,800,000				0 %	
Decommissioning	$17,400,000				0 %	
Soft Costs Subtotal	**$193,500,000**					
All Other/Miscellaneous	$0				0 %	

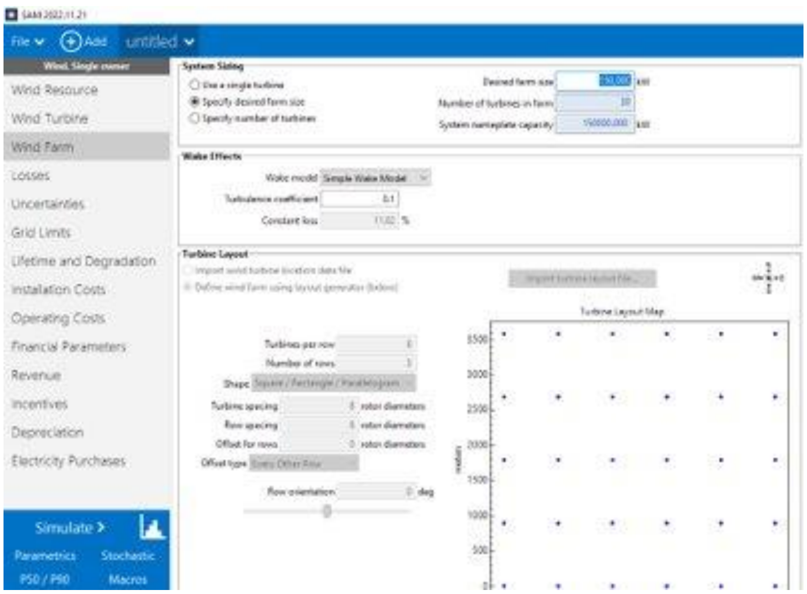
Subtotal (all costs without taxes)	**$1,119,090,149**					
Sales Tax (Material and Equipment Purchases)	$8,614,306				0%	
Total Construction Cost	**$1,127,704,455**					
Construction cost/kW	**$4,511**					
Project Data - OpEx						
Category	**Cost/Expenditure**				**Local Share**	
Maintenance						
Offshore Maintenance						
Technicians (Labor)	$2,003,529				0%	
Spare Parts	$5,949,874				0%	
Vessels	$12,385,452				0%	
Onshore Electric Maintenance	$151,783				0%	
Maintenance subtotal	**$20,490,638**					
Operations						
Operation, Management and General Administration	$849,982				0%	
Operating Facilities	$394,635				0%	
Environmental, Health, and Safety Monitoring	$151,783				0%	
Insurance	$6,374,865				0%	
Annual Leases and Fees	$1,457,112				0%	
Operations subtotal	**$9,228,376**					
Sales taxes	**$59,499**				0%	
Operations and Maintenance Total	**$29,778,512**					
Operations and Maintenance / kW	**$119**					
FINANCIAL PARAMETERS						
		Parameters				

		Local Share				
Debt Financing						
Debt financing (percent)		70%			0%	
Interest rate		5.00%				
Years financed (term)		15				
Bank fees (percent of debt)		3.00%			0%	
Equity Financing/Repayment						
Equity financing (percentage)		30%				
Return on equity (annual percent rate)		10.00%				
Repayment term (years)		5				
Individual Investors (percent of total equity)		50%			0%	
Corporate Investors (percent of total equity)		50%			0%	
Taxes and Fees						
Capital/construction sales and use tax rate on materials		1.00%			0%	
Operations and maintenance sales and use tax rate on materials		1.00%			0%	
Other Taxes and Payments						
Assumed project life		20				
Labor Parameters						
Construction Labor	**Offshore Annual Salaries**					
Foundation	$99,000					
Scour	$99,000					
Mooring	$60,000					
Turbine	$64,000					
Cabling	$99,000					
General Construction	$99,000					
O&M Labor						
Management	$100,000					
Technician	$75,000					

S.A.M:



Simulate
Parametrics
Stochastic
P50 / P90
Macros



SAM 2022.11.21
File
Add
untitled
Wind, Single owner
Wind Resource
Wind Turbine
Wind Farm
Losses
Uncertainties
Grid Limits
Lifetime and Degradation
Installation Costs
Operating Costs
Financial Parameters
Revenue
Incentives
Depreciation
Electricity Purchases
Simulate
Parametrics
Stochastic
P50 / P90
Macros
System Sizing
Wake Effects
Turbine Layout

3.3.5 Transmission Infrastructure – Alexander Longoria

The initial equations that the team found suitable for this analysis was to compute the amount of energy that is lost over the length of the transmission line. References 36 contains all the necessary equation while reference 37 and 38 provide and insight to some of the input variables. The first equation is used to solve for current.

$$I[amps] = \frac{P}{V} \quad [10]$$

The team's goal is produce 150kW of energy. Therefore, the team has assigned 200kW to variable "P" for power. As mentioned in reference 37, the team will design the plant to have 345kV transmission line. Therefore, this would be the variable "V". From this, the team has found the current to be 0.435 amps.

Given that the 345kV has a diameter, "D", of 1.8 inches. The team was able to determine that the corss sectional area of the transmission line is equal to 0.0178 feet squared.

$$A[ft^2] = \pi \left(\frac{D}{2}\right)^2 \left(\frac{1\,ft}{12\,in}\right) \quad [11]$$

The next and final step is to calculate the amount of power that is lost over the length of the transmission line. But before that can be done, there is one more crucial variable, the distance from the power plant to the nearest city, "L". In section 4.4.4, it is determined that Sheboygan – Edgewater Generating Station is the ideal location for the point of interconnection. Additionally, the nearest major city is Milwaukee, WI totaling a distance of 55 miles (290400 feet). For a detailed analysis, the team also decided to consider Chicago, IL which has an estimated distance of 144 miles (760320 feet). From these distances, the team can utilize Matlab's graphing feature to illustrate the linear relationship between the power loss in the transmission lines over the length of the transmission line.

$$P[kW] = I^2 \left(\frac{L}{A}\right) (10^3\,kW) \quad [12]$$

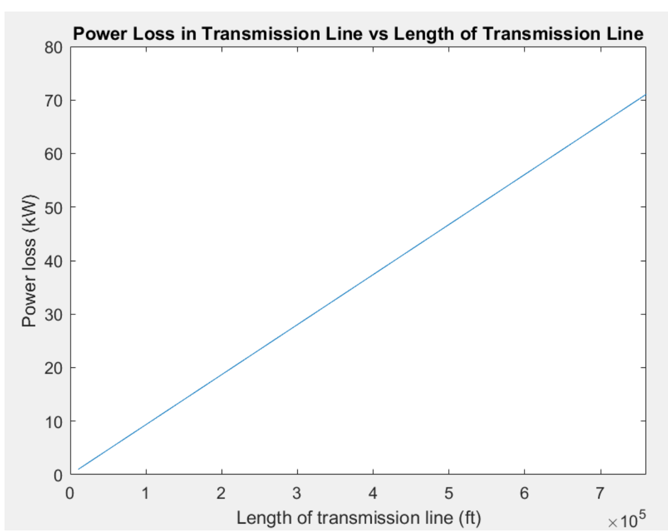


Figure 3.3.5: Power loss in transmission line vs length of transmission line

Given that the distance to Milwaukee, WI is 290400 feet, the team has found that the total power loss in the transmission line is approximately 25kW. For Chicago, IL at 760320 feet, the power loss is estimated to be 71kW.

4 Design Concepts

4.1 Functional Decomposition

The simplified overall purpose of the hypothetical wind power plant is to transfer energy from the wind to the local communities and individual houses. This explanation takes it a bit further than the team's design, as the project development team does not need to distribute the energy to individual utilities, just design the connection to the electrical grid with consideration of local energy needs. To this end, the CWC24 Project Development Competition's functional decomposition provides a visual of tracking the energy from the wind to the houses. This can be found below in Figure 4.1.1.

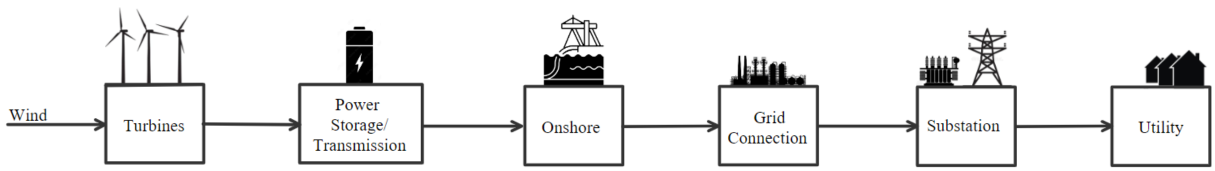


Figure 4.1.1: CWC24 Project Development Functional Decomposition

Amongst these simple breakdowns, the team must especially consider connections. Transmitting the energy onshore can often be an expensive process due to distance and cable requirements. When connecting to the electrical grid, care must be given to local and federal laws, as well as how the plant's provided energy will affect the grid's power supply and needs. Throughout the process, the team needs to consider how each connection point may best be made so as to not cause harm to any stakeholders such as the environment, local Native lands and people, and utilities, among others. The functional decomposition will help the team to recognize all the potential hazards, stress points, and the over-arching goal of the hypothetical wind farm.

4.2 Concept Generation

4.2.1 Site Selection – Alexander Longoria

Given that the DOE preassigned each team to analysis Lake Michigan and Lake Superior, there isn't much traditional concept generation that can be made. Therefore, the team's goal is to consider all the top-level and sub-level characteristics of each Great Lake and compare them receptively.

The initial evaluation of the Great Lake would be to consider some of the big picture pros and cons. The table below lists those attributes.

Lake Michigan		Lake Superior	
			
Pros	Cons	Pros	Cons
Max depth of 925 ft	Sixth largest freshwater lake in the world by surface area	Largest freshwater lake in the world by surface area	Max depth of 1,332 ft
Northern part is forest			1/4 shared between Canada
	136 species of fish	80 species of fish	
	300 miles long	350 miles long	Commerical fishing
	22,230 square miles	31,820 square miles	
	Population: 12 million	Population: 425,548 USA 181,573 Canada	

Figure 4.2.1.1: Pros and cons of the Great Lakes

The next step would be to consider some of the more technical concepts to help drive the team to come to a final decision about the location of the offshore wind farm. For example, the team will consider the mean wind speed at different hub heights, optimum LCOE locations, points of interconnection, power plants and infrastructure capacity, distance from major cities, and bathymetry data.

4.2.2 Turbine Selection – Samantha Russell

From the top three production companies in the United States for Wind Turbines, ten possible turbines were selected. Of these, several were eliminated right away for not being rated for offshore performance. These turbines were initially picked as they were a preloaded turbine possible for selection in Furow.

Two Vestas, one General Electric, and three Siemens Gamesa turbines were analyzed. Initial pros and cons of each turbine are listed in Figure 4.2.2.1 below. Each turbine is further analyzed in the next sections.

V236-15		V174-9.5		GE150-6	
pros	cons	pros	cons	pros	cons
largest power rating	not commercially manufactured till 2024	average cut in and cut out speed	mid-high initial cost	lowest port infrastucture needs	low individual power rating
above average cutout speed	high needs port infrastructure	highest rated power output for 10kmx10km area		average cut in and cut out speed	

SG132-5		SG200-11		SG222-15	
pros	cons	pros	cons	pros	cons
lowest port infrastucture needs	differing view on offshore capability	large swept area and rated power	data for cut in and cut out speed not made easily available	second highest rated power output for 10kmx10km area	high needs port infrastructure
lowest relative cost	low individual power rating				data for cut in and cut out speed not made easily available
high rated power output for 10kmx10km area					

Figure 4.2.2.1: Pros and Cons of Turbine Choices

4.2.3 Anchor Selection – David Lemar Perez

Onshore foundations are not the scope of this project but have a good idea implementation towards offshore projects. If a certain location in the great lakes is chosen where there is not much depth, then structures with this design should be considered. Gravity-Base foundations are the best since they require only flat ground which in time some soil can be disrupted due to current and can offset the turbine. Tripods are the second-best option since they require some excavating depth to place the foundation, but the soil has to be dissolved more and not disrupted or it could affect stability through time. Mono bucket is the third option since it is like Spar but with a strong excavating bucket base which supports most forces, the only problem is deep water currents which can add forces within the bucket and the outside of the bucket to move more through time since the walls of the bucket add some slippage. Monopile is not really reliable since it's thinner and requires more excavating to insert in the soil and can also sink through time. Jacket is the worst by too much material and more joints involved which can affect stability through time, plus it can collect rust easily but hey it can also build a coral reef if enough fish are around because of the electrons generated by ocean salt connected to the river.

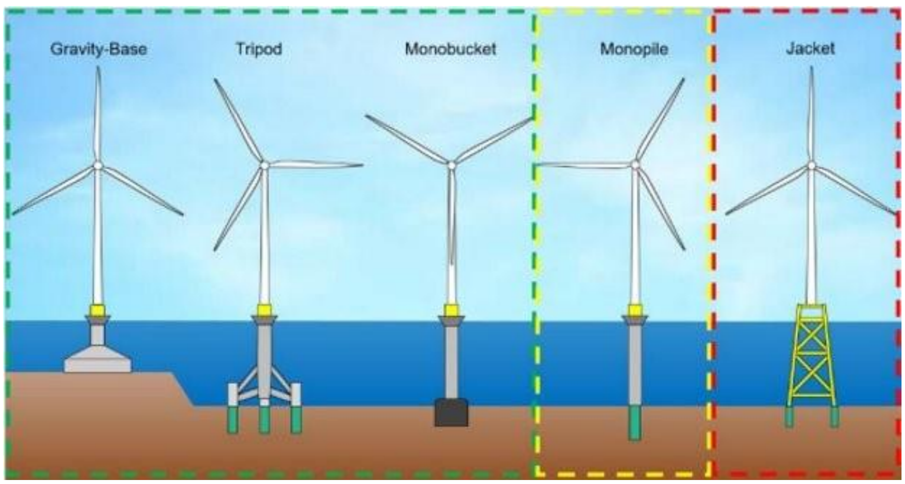


Figure 4.2.3.1: Different types of anchor designs

Offshore Wind turbines are demonstrated below ranking from best to worst on color description left to right. Hybrids are specific designs like mods that have different structural styles like TLP's that are mor focused on attachments with mooring cables. TLP's are a standard design option for offshore purposes. Both are the best option since they don't disrupt soil, have icing problems due to material and insulation wrap around structure, and is not affected by deep water currents. Hybrids can also be quite expensive due to design modding. Spars are the second-best option since they are known to be very still and easy to install by using a hammer and cutting the top of it later. Very little material is incorporated but can gather some rust through time. The last two options are the worst since they have icing problems that are collected in the platform and add weight that could tip the wind turbine. Durable but too much material like concrete.

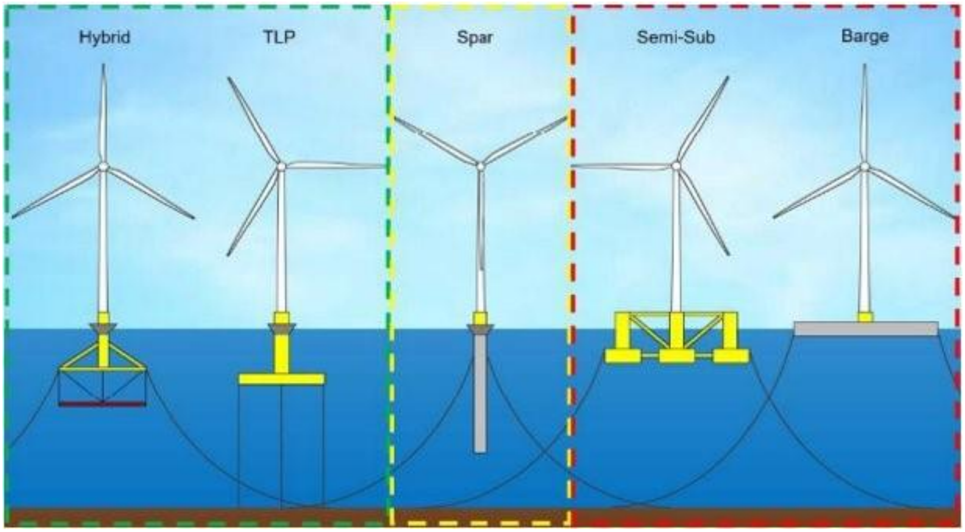


Figure 4.2.3.2: Different types of anchor designs

On Shore					Offshore				
Gravity-Base	Tripod	Monobucket	Monopile	Jacket	Hybrid	TLP	Spar	Semi-Sub	Barge
Pro	Pro	Pro	Pro	Pro	Pro	Pro	Pro	Pro	Pro
Cheap	Strong Structure	Less Material	Less Material	Strong Structure	Long lasting	Light	Simple construct	Flat reliability	Flat base reliability
close to shore	Stable	Strong base	Deep Ground Stability	Stable	Anti icing	Anti icing	Cheaper	Strong	Common construct
Con	Con	Con	Con	Con	Con	Con	Con	Con	Con
Flat land reliability	Angle balance	Not Stable	Replace bucket	Flexible	Expensive	Mathematical modeling	Less stable	Too much material	Heavy concrete
Lans stirring	Harder to Construct	Flexibility	Harder to construct	Deep ground excavation	Suitable for less strong winds	Specific wires	Flexible	Ice formation	Not long lasting

Figure 4.2.3.3: Pros and cons

4.2.4 Transmission Infrastructure – Alexander Longoria

It is the team's goal to research different power plants within the general area of the Great Lakes in order to determine the ideal point of interconnections. There are several criteria the team has set for the different plants. This form of concept generation will eliminate several power plants and give the team a narrowed scope of potential location for a point of interconnection.

It is to be noted that the team is not taking over the entirety of the power plant, the team is simply taking over the transmission capacity of that plant given the requirement that it is retired around 2030. By looking at these retiring plants it will give the team a better understanding of the distance from major cities, levelized cost of electricity, and site layout to maximize overall generation.

In section 4.4.1, it will describe the team's selection of Lake Michigan as the ideal location for the offshore wind farm. Therefore, a figure of the pros and cons of different power plants within the Lake Michigan region will be listed below.

Sheboygan - Edgewater Generating Station		WE Energies - Oak Creek Power Plant		University Park Power Station		Point Beach Nuclear Plant		Consumers Energy - J.H. Campbell Generating Complex	
pro	con	pro	con	pro	con	pro	con	pro	con
On the shoreline	Not near a port	On the shoreline	1100 MW	342 MW	In the main land	On the shoreline	1200 MW	On the shoreline	1450 MW
Transition to clean energy	Not close to a mjor city	Transition to clean energy		Close to Chicago, IL	Not retiring by 2030	Close to Greenbay, WI	Not retiring by 2030	Transition to clean energy	
Retiring by 2030		Retiring by 2030		Close to a port			Not near a port	Retiring by 2030	
380 MW		Close to a port						Close to a port	
		Close to Milwaukee, Wi						Close to Grand Rapids, MI	

Figure 4.2.4.1: Pros and cons of different power plants within Lake Michigan

4.2.5 Turbine Micro Siting – Samantha Russell

Micro siting is the choice of where the team decides to place individual turbines. Wind energy production plants need to be considerate of many things when placing turbines. This includes energy transmission lines between the turbines and from the turbines to a substation as well as effects the turbines have on the wind and therefore power output.

There are a few options for wind farm layout. Until the team can move ahead with Furow exact spacing and layout will remain as a grid with approximately eight rotor diameters between turbines perpendicular to expected wind direction, and approximately five rotor diameters between turbines parallel to expected wind direction. The department of energy puts a heavier emphasis on this detail in the second semester of work, and so the team has delayed working out the exact details to focus more on learning the program Furow and other necessary criterion.

A depiction of the current draft farm layout is visible below in figure 4.2.5.1. The figure depicts the size of the rotors of the turbines at a larger scale than reality for ease in viewing. This draft is specific to the Vestas 174-9.5 Turbine. It can comfortably contain 64 turbines with eight rows and eight colums, which at rated power would provide 608MW, well exceeding150MW that the team aims for. The team oriented the grid such that the prevalent wind direction is accounted for in from the south, with reference to the National Oceanic and Atmospheric Administration article [40].

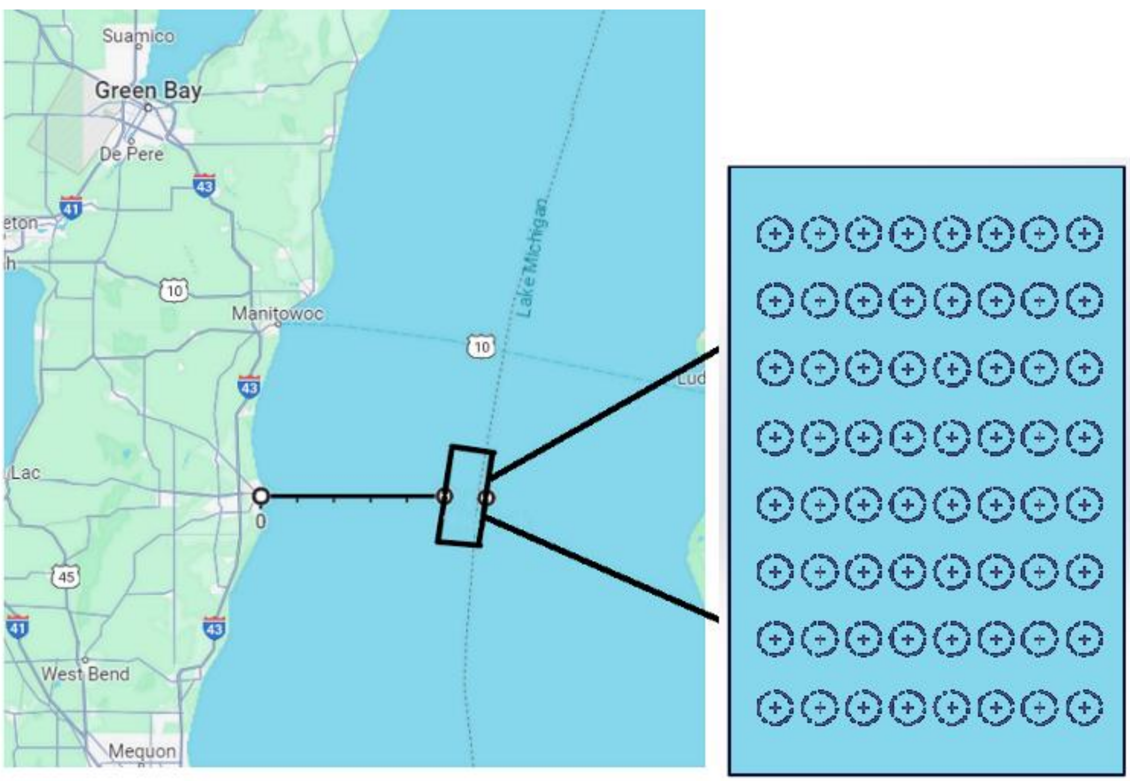


Figure 4.2.5.1: Micro Siting Turbine Layout

4.3 Selection Criteria

4.3.1 Siting Selection – Alexander Longoria

This section of the report will go into more depth about the technical concepts briefly described in section 4.2.1.

Wind speed at different hub heights is one of the key driven data that affects the whole system. For an area as big as the Great Lake, the wind speeds at different elevations vary due to the bordering tree lines and residents. Therefore, the team can see which areas would benefit from different hubs height. The figure below shows the wind speed data at a hub height of 140m.

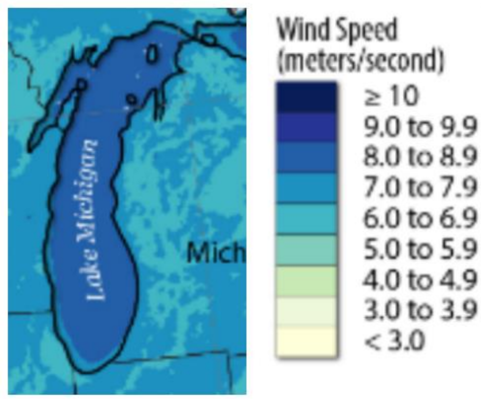


Figure 4.3.1.1: Annual average wind speeds at 100m above surface level

Finding the optimum LCOE location is an important factor to consider because this relates to the amount of money the resident is paying per Mega Watt Hour (MWh). The team strives to keep the costs low for each household while trying to make a profit. As a result, the distance from the shoreline can be estimated using the map below.

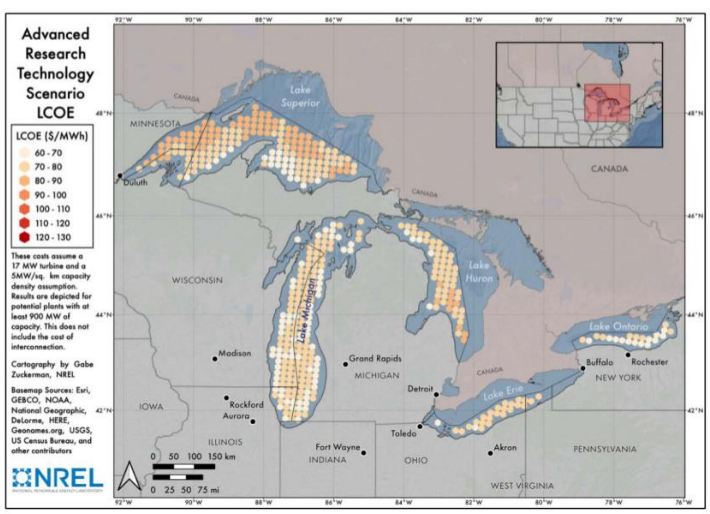


Figure 4.3.1.2: Estimated LCOE values based on location

Points of interconnection is a term used to describe the substation and power plant within a given location. As the team aims to produce an estimated 150 MW, finding existing points of interconnection is important. The ideal location would consist of minimizing the distance from the farm to the on-land substation and to major cities, finding a power plant that has similar transmission capacity and is retiring by 2030.

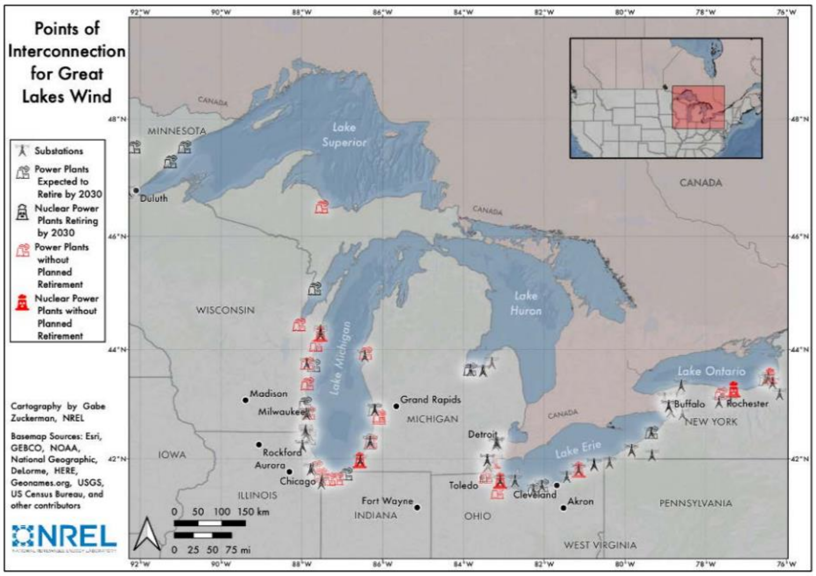


Figure 4.3.1.3: Points of interconnection

The last top-level consideration is the bathymetry data. This information will tell the team the water depth measurement at different locations within the lakes. This data will aid in lowering the total cost of the farm by telling the team where a fixed or floating anchor design is needed. The team will use the map below to make that decision.

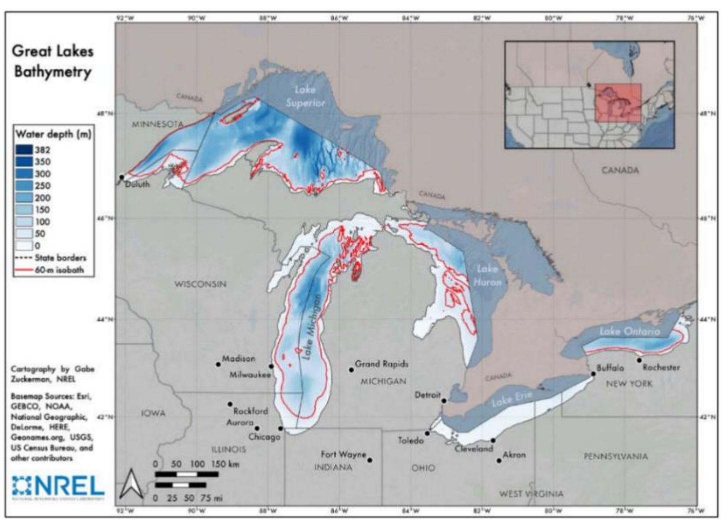


Figure 4.3.1.4: Bathymetry data

4.3.2 Turbine – Samantha Russell

Criteria used for analyzing turbines include rotor diameter, cut in and cut out speed, power rating, max possible turbines per 100 square kilometers, rater power output for 100 square kilometers, turbine cost, and port infrastructure requirements. These criteria were developed as simple and effective ways to compare the turbine selections, and ways of meeting engineering requirements from the House of Quality as they relate to turbines. The criteria were rated from the House of Quality and applicable engineering requirements, and their ratings, therein. Criteria that fell under an engineering requirement that was rated as more important received higher ratings based on the percentage importance found in the House of Quality.

4.3.3 Anchor Selection – David Lemar Perez

The criteria used for anchors is data collected from factors that affected the failure of the anchor. These factors are fatigue being the most caused issue, installation, mechanical accuracy, corrosion, design, and overload. From these probability factors, they were tested among different designs and seemed to single out the best benefactor of the design. Reference 27 has a pie chart that best describes this analysis of how anchors are affected mostly by these definitions. These are the engineering requirements we must meet to have the best quality build in our project.

4.3.4 Transmission Infrastructure – Alexander Longoria

The criteria used for the transmission infrastructure was determined based on the location and characteristics of the point of interconnection. Given that the team has decided on populating the chosen leasing block of Lake Michigan, an analysis that consists of local criteria such as the sea life habitats and migration patterns, lake recreational activity, bathymetry data, wind speeds at different hub heights, and estimated levelized cost of energy will be explored. Additionally, an analysis of the distance from the point of interconnection to the nearest major city, the population of the nearest city, the transmission capacity that is being taken over, and the expected year of retirement which was derived from the House of Qualities. The figure below drove the majority of decisions [9] [33] [34].

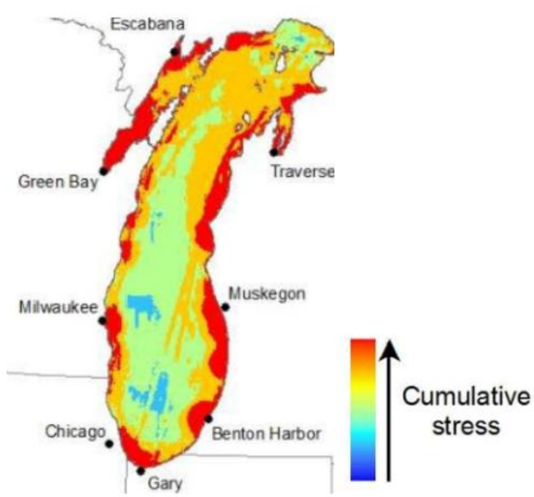


Figure 4.3.4.1: Recreation activity density

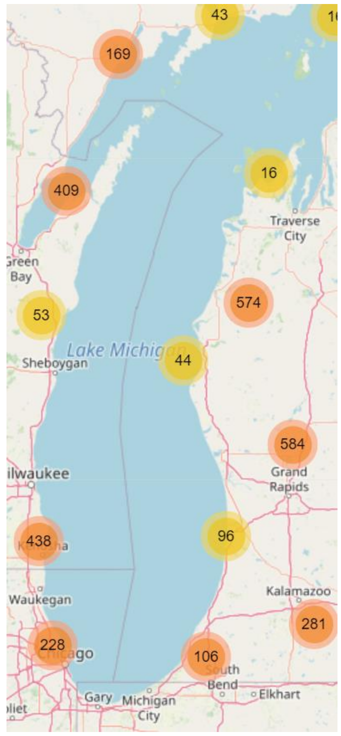


Figure 4.3.4.2: Fish habitats and population density

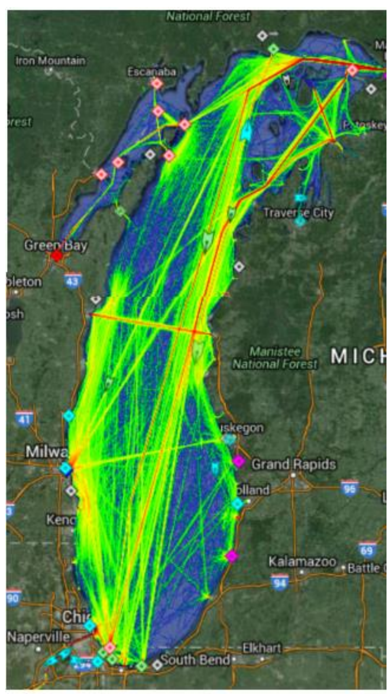


Figure 4.3.4.3: Ship traffic density map

4.4 Concept Selection

4.4.1 Site Selection – Alexander Longoria

The traditional method of concept generation consists of a Pugh chart and a decision matrix but given the nature that there are only 2 concepts to consider, the team electing to neglect the Pugh chart just move forward with a decision matrix.

Now that all the relevant resources, equations, and figures are determined, the team will into Lake Michigan and Lake Superior into a decision matrix based on engineering and customer requirements stated in the QFD. A weight is assigned to each criterion and scored based on their relevance. A weighted score is then added based on the score and this will tell the team which location to pursue. The figure below states all the criteria that analyzed with its respective scores.

		Lake Michigan		Lake Superior	
					
Criteria	Weight	Score	Weighted	Score	Weighted
Wind Speeds	20	0.9	18	0.8	16
LCOE	20	0.9	18	0.75	15
Interconectivity	20	0.7	14	0.2	4
Surface Area	15	0.9	13.5	0.8	12
Major Cities	15	0.9	13.5	0.7	10.5
Bathymetry	10	0.8	8	0.65	6.5
Total: 100			85		64

Figure 4.4.1.1: Site Selection Decision Matrix

4.4.2 Turbine Selection – Samantha Russell

The six turbine selections were analyzed via a decision matrix. Before analyzing them, however, each criterion in section 4.3.2 was weighted with importance. To do this, the team utilized the engineering requirements from the QFD that were relatable to turbine analysis. This included the area of the leasing block, farm power output, levelized cost of energy, wind data, and port infrastructure. Then, using the importance percentage weight from the House of Quality for each related engineering requirement, each turbine criteria within an engineering requirement was given a point value, such that the sum of the points was equal to the importance of that engineering requirement. For example, levelized cost of energy, rated 9% in the House of Quality, was made up of the criteria rated power output per area and turbine cost, each of which were given points that summed to nine, such as five and four. These points correspond to a weighting percentage to ensure that more important aspects of the turbine selection are represented as such in the selection process.

Then, a scale of one to ten was created for each criterion. This scale is shown in Table 4.4.2.1 below. More favorable outcomes were rated higher.

Turbine Scoring Explained:										
Rotor Diamete (m):	0-30	31-60	61-90	91-120	121-150	151-180	181-210	211-240	241-270	271-300
Score	1	2	3	4	5	6	7	8	9	10
Cut In Speed (m/s)	4.1-5	3.1-4	2.1-3	1.1-2	0-1					
Score	2	4	6	8	10					
Cut Out Speed (m/s)	15-20	21-25	26-30	31-35	36-40					
Score	2	4	6	8	10					
Power Rating (MW)	0-1.5	1.6-3	3.1-4.5	4.6-6	6.1-7.5	7.6-9	9.1-10.5	10.6-12	12.1-13.5	13.6-15
Score	1	2	3	4	5	6	7	8	9	10
Max Possible Turbines in 100km square	0-10	.11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100
Score	1	2	3	4	5	6	7	8	9	10
Rated Power Output for 100km^2 (MW)	200-280	281-360	361-440	441-520	521-600					
Score	2	4	6	8	10					
Turbine Cost ($)	>15 mil	14.2-15	13.4-14.1	12.6-13.3	11.8-12.5	11-11.7	10.2-10.9	9.4-10.1	8.6-7	<7 mil
Score	1	2	3	4	5	6	7	8	9	10
Port Infrastructure Requirement	1a	2a	3a	4a						
Score	2.5	5	7.5	10						

Table 4.4.2.1: Turbine Selection Criterion Scoring

Finally, each turbine was scored based on this scoring rubric in a decision matrix, visible in Table 4.4.2.2 below. The top three turbines were selected to continue in the down-selection process. These turbines are the Vestas V174-9.5, General Electric GE150-6, and Siemens Gamesa SG132-5. Each of these turbines will undergo much more rigorous analysis and modeling in Furow with full farm data. The team chose to model the top three turbines so as to have each team member model one farm. An enlarged view of this table is available in Appendix A.

		V236-15		V174-9.5		GE150-6		SG132-5		SG200-11		SG222-14	
Criteria	Weight	Score	Weighted	Score	Weighted	Score	Weighted	Score	Weighted	Score	Weighted	Score	Weighted
Rotor Diameter	9.76	8	0.780488	7	0.682927	5	0.487805	5	0.487805	7	0.682927	8	0.780488
Cut in Speed	4.88	6	0.292683	6	0.292683	6	0.292683	8	0.390244	6	0.292683	6	0.292683
Cut out Speed	7.32	8	0.585366	4	0.292683	4	0.292683	6	0.439024	4	0.292683	4	0.292683
Power Rating	4.88	10	0.487805	7	0.341463	4	0.195122	4	0.195122	8	0.390244	10	0.487805
Max Possible turbines/100km^2	2.44	3	0.073171	6	0.146341	8	0.195122	10	0.243902	4	0.097561	4	0.097561
Rated Power Output for 100km^2 (MW)	21.95	6	1.317073	8	1.756098	8	1.756098	8	1.756098	6	1.317073	8	1.756098
Turbine Cost	19.51	4	0.780488	9	1.756098	10	1.95122	10	1.95122	8	1.560976	5	0.97561
Port Infrastructure Requirement	29.27	2.5	0.731707	7.5	2.195122	10	2.926829	10	2.926829	5	1.463415	2.5	0.731707
Total			5.04878		7.463415		8.097561		8.390244		6.097561		5.414634

Table 4.4.2.2: Turbine Selection Decision Matrix

4.4.3 Anchor Selection – David Lemar Perez

The anchor selection was based off numbers ranking from 1 through 10, that being ten the best and 1 the worst. Then rating each one from factors that were crucial in technicality, cost, safety, environmental impact, installation, port accessibility, weight, and modeling. TLP came out on top because of standard issue over hybrid but hybrid is the most efficient in build, but cost could be a problem because of design quality. For the Pugh chart, each anchor was ranked from a positive to a negative according to the criteria.

SubDesign:										
	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7	Option 8	Option 9	Option 10
	Gravity -Base	Tripod	Mono-bucket	Mono-pile	Jacket	Hybrid	TLP	Spar	Semi-Sub	Barge
Criteria										
Price	+	-	+	+	+	-	-	+	+	+
Weight	-	+	-	+	-	+	+	+	-	-
Stable	+	+	-	-	+	+	+	-	+	+
Material	+	-	+	+	-	-	+	+	+	+
Life expentency	-	+	+	-	+	+	+	-	-	-
Icing	-	+	-	-	-	+	+	-	-	-
+	3	4	3	3	3	4	5	3	3	3
0	0	0	0	0	0	0	0	0	0	0
-	3	2	3	3	3	2	1	3	3	3
Total	0	2	0	0	0	2	4	0	0	0

Figure 4.4.3.1: Pugh chart

		Option 1		Option 2		Option 3		Option 4		Option 6	
		TLP		Hybrid		Gravity-Based		Tripod		Monobucket	
Criteria	Weight	Score	Weighted	Score	Weighted	Score	Weighted	Score	Weighted	Score	Weighted
Technical Feasability	3	8	24	4	12	9	27	5	15	9	27
Cost	6	7	42	7	42	4	24	2	12	8	48
Safety	8	8	64	7	56	7	56	7	56	7	56
Environmental Impact	7	9	63	8	56	3	21	4	28	2	14
Installation	1	3	3	8	8	6	6	8	8	7	7
Ports	4	4	16	8	32	4	16	8	32	6	24
Heavy Lift Eqiupment	5	8	40	8	40	3	15	4	20	6	30
Modeling	2	7	14	7	14	8	16	9	18	8	16
Total			266		260		181		189		222

Table 4.4.3.2: Anchor Selection Decision Matrix

4.4.4 Transmission Infrastructure – Alexander Longoria

Now that the team has a basic understanding of the different points of interconnection, a top-level concept selection can be made utilizing a pugh chart and decision matrix using the criteria described in section 4.3.4. To compare the characteristics of the different points, the team has randomly selected University Park Power Station located in University Park, IL and the datum. The other 4 points were evaluated off this datum with a "+" to indicate that it is a better design choice than the datum, a "-" to represent that it is not better than the datum, or a "0" to show that it is more or less the same. The figure below shows the pugh chart and gives the team 3 possible points of interconnection.

Cirteia \ Power Plant	Sheboygan - Edgewater Generating Station	WE Energies - Oak Creek Power Plant	University Park Power Station	Point Beach Nuclear Plant	Consumers Energy - J.H. Campbell Generating Complex
Distance from nearest major city	-	0	Datum	0	0
Population of the nearest city	-	-		-	-
Transmission capacity	+	+		+	+
Expected year of retirment	+	+		-	-
Sea life habitats and migration pattern	-	-		-	-
Recreational use of lake	+	-		-	+
Ship traffic map	+	-		+	+
Bathymetry data	0	0		0	-
speeds data at a hub height of 100m	0	0		0	0
Estimated levelized cost of energy	0	0		-	-
+	4	2	0	2	3
0	3	4	0	3	2
-	3	3	0	5	5
Σ	1	-1	0	-3	-2

Figure 4.4.4: Transmission infrastructure pugh chart

It is clear from the figure above that Sheboygan – Edgewater Generating Station, WE Energies – Oak Creek Power Plant, and University Park Power Station are the top 3 locations for a point of interconnection. However, given that University Park Power Plant is not retiring by 2030, this is excluded from the decision process and replaced with Consumer Energy – J.H. Campbell Generating Complex. The next step in this concept generation stage is to create a decision matrix. Each criterion was assigned a weight value that was derived from the House of Qualities. A score out of 10 is then scored to each criterion (10 being the highest and 1 being the lowest). The score and weight are then multiplied to get a weighted value. After all weight values are computed, the team will end up with the best location for the point of interconnection. From the figure below, it is evident that Sheboygan – Edgewater Generating Station is ideal for the team's offshore wind farm.

		Sheboygan - Edgewater Generating Station		WE Energies - Oak Creek Power Plant		Consumers Energy - J.H. Campbell Generating Complex	
Criteria	Weight	Score	Weighted	Score	Weighted	Score	Weighted
Distance from nearest major city	15	0.7	10.5	0.9	13.5	0.8	12
Population of the nearest city	20	0.9	18	0.9	18	0.6	12
Transmission capacity	10	0.9	9	0.4	4	0.2	2
Expected year of retirment	5	0.7	3.5	0.8	4	0.5	2.5
Recreational use of lake	5	8	40	6	30	4	20
Sea life habitats and migration pattern	10	0.9	9	0.6	6	0.7	7
Ship traffic map	10	0.6	6	0.5	5	0.75	7.5
Bathymetry data	5	0.85	4.25	0.9	4.5	0.9	4.5
Average wind speeds data at a hub height of 100m	5	0.85	4.25	0.85	4.25	0.85	4.25
Estimated levelized cost of energy	15	0.9	13.5	0.9	13.5	0.85	12.75
Total			118		102.75		84.5

Figure 4.4.4: Transmission infrastructure decision matrix

5 Schedule and Budget

5.1 Schedule – Samantha Russell

Throughout the course of this semester, the team closely followed a Gantt chart to keep track of scheduling. It can be seen below in figure 5.1.1. This Gantt chart followed the ME476C class deliverables more so than the client deliverables, which are more applicable to the second semester.

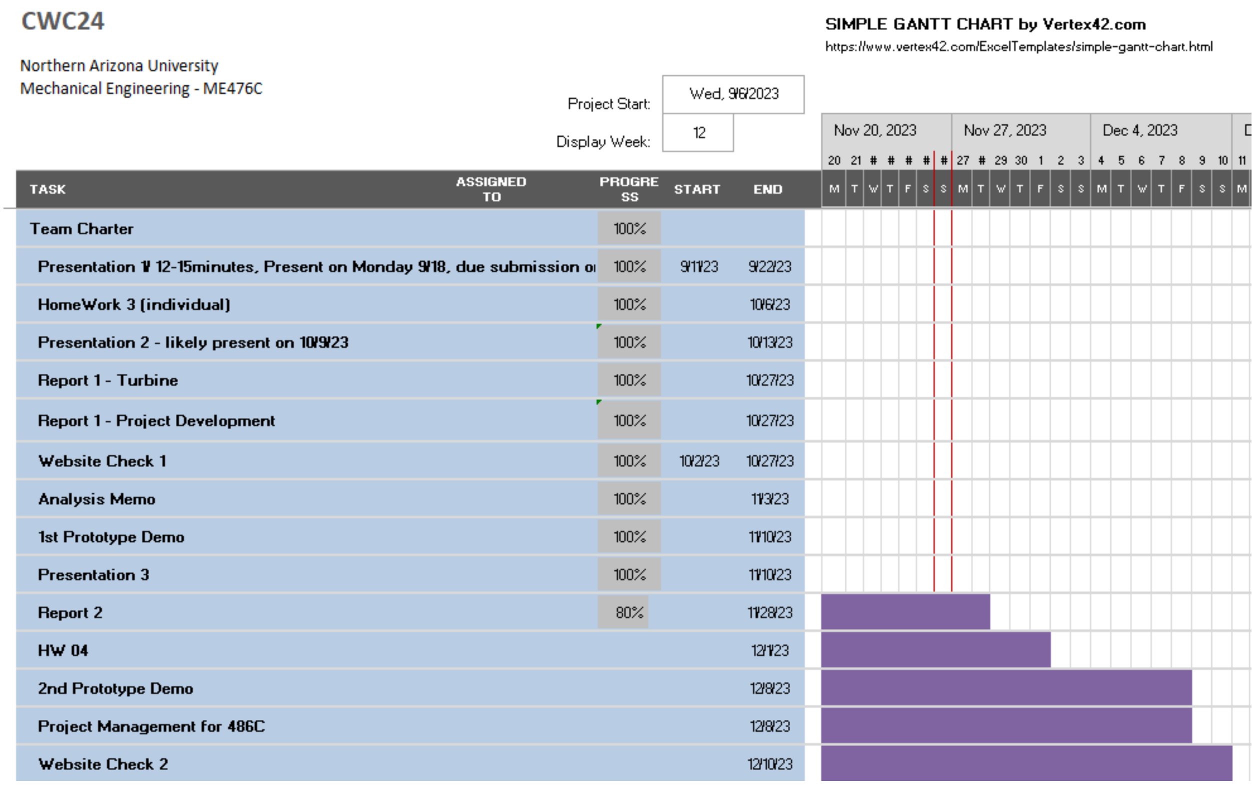


Figure 5.1.1: First Semester Capstone Schedule

From prior year's scheduling for ME486C, the team created an additional Gantt Chart for next semester. The days are rough estimates, and will be updated when more information is made available. In the deliverables, there are five individual assignments, four of which are peer reviews and the other is a self-learning assignment. The other deliverables fall into one of these categories: class submission, undergraduate symposium submission, Department of Energy Submission, and submission to advisor for review. Each of these tasks is essential in ensuring the CWC teams stay on track to be successful in the competition. This Gantt Chart is visible in the next page in figures 5.1.2 and 5.1.3, which have been cropped for easier viewing.

This schedule is applicable to both sub teams, and hence will be featured in both reports.

CWC24

Northern Arizona University
Mechanical Engineering - ME486C

SIMPLE GANTT CHART by Vertex42.com
https://www.vertex42.com/ExcelTemplates/simple-gantt-chart.html

Project Start: Mon, 1/15/2024

Display Week: 1

TASK	ASSIGNED TO	PROGRESS	START	END
Self Learning/ Individual Analysis	(Individual)		1/15/24	1/29/24
Hardware Status Update - 33+%	Team		1/15/24	2/12/24
Peer Eval 1	(Individual)		1/29/24	2/12/24
Website Check 1	Team Web Developer		2/12/24	2/26/24
Undergrad Registration	Team		2/26/24	3/5/24
Hardware Status Update - 67+%	Team		2/26/24	3/5/24
Peer Eval 2	(Individual)		2/26/24	3/5/24
Poster Draft for Ugrad	Team		3/19/24	3/26/24
Finalized Testing Plan	Team		3/5/24	3/26/24
DOE Submissions -1st Draft to Advisor for Review	Team		1/15/24	3/28/24
Hardware Status Update - 100% Build	Team		3/5/24	4/2/24

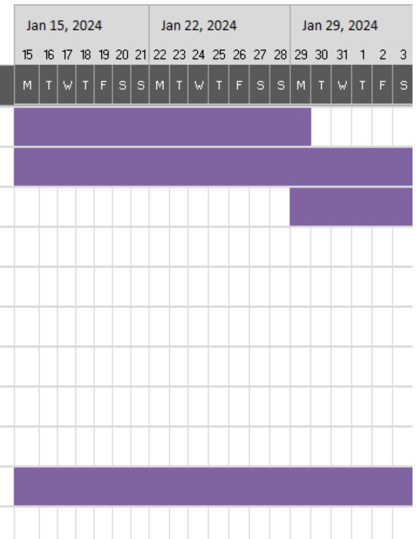


Figure 5.1.2: Second Semester Schedule Part 1 of 2

TASK	ASSIGNED TO	PROGRESS	START	END
Peer Eval 3	(Individual)		3/5/24	4/2/24
Final CAD Packet	Team		3/5/24	4/2/24
Initial Testing Results	Team		3/26/24	4/9/24
Final Poster and Powerpoint for Ugrad	Team		3/26/24	4/9/24
DOE Submissions - 2nd Draft to Advisor for Review	Team		3/28/24	4/11/24
Product Demo and Final Testing Results	Team		4/2/24	4/16/24
Final Report	Team		4/2/24	4/16/24
Final Website Check	Team		4/2/24	4/16/24
DOE Final Submissions	Team		4/11/24	4/18/24
Ugrad Symposium	Team		4/9/24	4/26/24
Peer Eval 4	(Individual)		4/2/24	4/30/24
Client Handoff - Spec Sheet and Op. Manual	Team		4/16/24	4/30/24
DOE Competition	Team		5/6/24	5/9/24

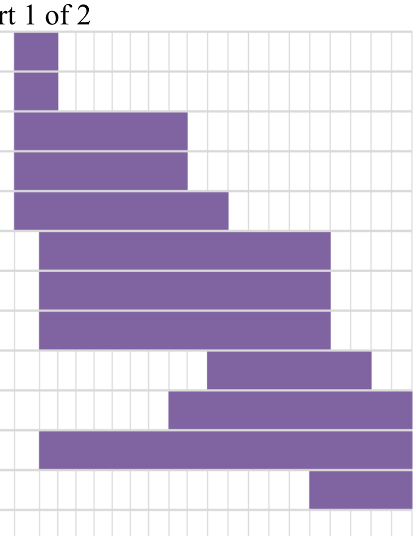


Figure 5.1.3: Second Semester Schedule Part 2 of 2

5.2 Budget – Sam + Niki

The Project Development sub team has no real expenses excepting competition travel. This expense is considered by the Turbine Design sub team in their record of expenses. Further, the Department of Energy requires hypothetical expenses in the second semester, so the team has decided that aside from David's work in SAM and Jedi, time would be better spent with current requirements. The financial manager of the overall team, Niki Wilson, has reported the following for real budgeting.

As of this report, the team has received two grants totaling $7000 dollars from the Department of Energy and W.L. Gore. Should the team advance to Phase 3 after the submission of the mid-year report, the DOE will award a further $15000 grant. However, given that this is not a guaranteed amount, all budgeting is based on current assets.

Expenses				
Item	Quanitity	Price (per unit)	Shipping	Total Cost
Fish scale	1	9.99		9.99
Digital level	1	29.97		29.97
PLA Plus	1	25.98		25.98
Brake pad material	1	5.9	10.29	16.19
Female ball joint	3	12.5	9.37	65.61
Male ball joint	3	12.5	6.89	58.17
Prony Brake	1	120		120
Bearings (assorted)	1	49.31		49.31
Steel shaft	1	9.98	11.71	21.69
				0
				0
				0
				0
				0
				0
				0
				0
				0
				0
				0
Total				396.91

Funding			
Source	Amount	Foundation	Assets
Dept. of Energy	2000	100	1900
W.L. Gore	5000	250	4750
Team Donation	24	0	24
Team Donation	150	0	150
Team Donation	19.31	0	19.31
		0	0
		0	0
		0	0
		0	0
		0	0
		0	0
		0	0
		0	0
		0	0
		0	0
		0	0
		0	0
		0	0
		0	0
		0	0
Total	7193.31	350	6446.4

Internal Fundraising	
Source	Amount
Team donation	193.31
Total	193.31

Figure 5.2.1: Current expenses and funding sources

Future Expenses			
Source	Amount	Percentage	
Competition	8000	124.100273	
Prototype 2,3,4	500	7.756267064	
Testing	1000	15.51253413	
Raw materials	350	5.429386945	
Final turbine	2000	31.02506826	
		0	
		0	Tot. w/o Comp. :
TOTAL	11850	183.8235294	59.72326

Figure 5.2.2: Future expenses with corresponding percentage of budget

5.3 Bill of Materials (BoM) – David and Sam

Following is the Bill of Materials for the current draft of the Hypothetical Wind Power Plant. This is not finalized, as the Department of Energy expects refinement past the first semester of work, but it up to date with current Project Development knowledge. Further, several costs are estimates due to the privacy that Vestas has for its technology. Installation cost estimates originate in the System Advisor Model, and so do not have a manufacturer listed.

Item	Manufacturer	Quantity	Total Price	Lead Time
V174-9.5 Turbine	Vestas	64	~ $512 Million [19]	~4 years
Turbine Transport (Rental Equipment)		100		
Port Space Rental		6 years		~6 months
Electrical Transmission Line	Xcel Energy	~100 miles worth	~ $250 Million [39]	~1 year
Floating Installation	NA	1	$36,500,000 (Support), $10,950,000 (Towing Vessel), 1 Towing Group	~1 year
Offshore Substation Installation	NA	1	$182,500,000(Floating Heavy Lift), $43,800,000(Floating Barge)	~2 year
Cabling Installation	NA	1	$43,800,000 (Array & Export Cable Installation Vessel)	~1 year

The team does not have prototyping expenses, as the programs utilized are all open source and free for students. Per the staff meeting prior to this document submission with the team's advisor, the team is neglecting the cost of the programs if they were not for student use.

6 Design Validation and Initial Prototyping

6.1 Failure Modes and Effects Analysis (FMEA) - all

6.1.1 Site Selection – Alexander Longoria

Considering the big picture aspect of the site selection requires a detailed and top-level analysis of potential failures. The team will look at different areas where failure can occur, the effects of the failure, risks it unravels, and ways to mitigate this issue for occurring. The first area of concern begins at the offshore substation. Given the nature that this substation has to be located within the water, the team foresees poor placement raising red flags. For poor placement, the team recognizes that Lake Michigan is heavily used for recreation fishing, swimming, activities, and aquatic life. Therefore, the team is worried that these offshore substations could interfere with the general public and wildlife. With proper analysis using a GIS program, the team will better understand popular recreations activity locations within the lake and map sea life habitats and migration patterns. Given that the placement is a low severity case, the team believes it can be easily avoidable and fixed given a low occurrence rate for a high detection rate.

Alongside poor placement, the team has also contemplated the integrity of the offshore substation's site security. The main issues that arise is the potential risk of electrocution if a transmission line connection fails or if a life form comes in contact with sensitive components of the station. To avoid this situation, the team will implement security measures like key card access, high fences, elevated platforms, cameras, and a security team to prevent and stop a potential hazard. Additionally, the team will consider a design that incorporates underwater netting to prevent sea life or other objects from coming in contact with the station. Even though this is a relatively low hazardous risk, the team is recognizing it as a high-risk hazard. In light of the low occurrence rate, the team must not be oblivious to its ease of detection.

The last foreseeable failure to the offshore substation would be damage to the components. To the team's advantage, Lake Michigan is fresh water and not salt water. Making it easier for the team to design a system that doesn’t need to be protected from the salt. However, it is still important to consider watertight connections, freezing conditions, and the activity of the lake that can cause premature wear to the components. To prevent such disasters, the team will implement a safety check at the beginning and end of the shift to ensure all components are well protected and safe by utilizing a rigorous "walk down" procedure. Because of this procedure, it will increase the detection rate and lower the occurrences of this high-risk failure.

The next area of potential failure is at the onshore substation. With respectively shared concerns such as the offshore substation (poor placement, site security, and damage to components), the team sees construction of the onshore substation as a concern. This new construction will restrict lake and port access to the affected areas, create an eye sore, and disturb the residents and the animals wellbeing. To help mitigate this, the team will work alongside the city and locals to create an ideal construction plan and timeline to eliminate negative backlash. Given that this will be a lengthy, one-time occurrence, the team recognizes the moderate severity of the addition.

For such a complex system, the team expanded beyond the substation and considered potential failure within the grid connection. For the projected power output the team is expecting (150 MW) and the transmission capacity the team is taking over from Edgewater Generating Station (380 MW), it is apparent that it won't be a smooth transition for the end users. Not meeting the transmission capacity can cause unhappy customers and put the plant's future at risk. Therefore, the team will need to optimize wind resource data at different hub heights, understand peak load times, and maximize hybrid energy storage. For something that is low risk, the team will recognize this issue early on in the plant's production.

6.1.2 Turbine Selection – Samantha Russell

An integral part of wind energy production is the wind turbine and its placement in the farm layout. For this, the team was able to identify several potential modes of failure and mitigation strategies therein.

There are several items within the turbine design itself that could lead to failure. These failures include a very high severity danger of incorrect electrical grounding within the turbine, and a much lower severity of failure of turbine downtime and reduced power output due to wear of gearbox bearings. As the project development team is not designing a turbine, merely selecting which technology to use, mitigation strategies are limited to maintenance plans. In increasing maintenance inspections in these areas, the team recognizes that operational expenditures will likely increase, however have decided that the safety of all personnel and the prime operating condition of the facility should be higher in priority than an expected small rise in expenditure.

With the placement of the turbines, more concerns were identified as a result of poor placement. If proper care is not given to placement of turbines using a GIS software to map shipping routes and migration patterns, there are possibilities of impeded shipping and injury to birds in turbine rotor strikes. The best mitigation strategy for this that the team determined was to thoroughly research and map both shipping routes, migration patterns, and bird occupational areas before finalizing farm layout. This may slow the project output, but is an essential step in ensuring that undue harm is not done.

In relation to poor placement, a failure in low power capacity was identified as a possibility due to both turbine placement and poor analysis of wind resource. This failure could mean that the design does not meet power demand for the area and is potentially a financial loss. The team is expected to do a thorough analysis of wind resource, but due to this identified potential failure, have also decided to overdesign for power need, including more turbines than is strictly necessary. This will add a need to calculate the most efficient number of turbines to include in design, but will ensure that the design is optimized for the area it is located.

A final potential failure of decreased power production was identified with the source of the wind turbine rotor blades freezing during the winter, decreasing the turbine’s efficiency. The team has identified two potential mitigation strategies for this. The first ties in with the prior identified failure, and is to increase the number of turbines so as to compensate for the loss in efficiency. In a second option, the team identified the possibility of a developing technology to heat the individual rotor blades to prevent ice buildup. This technology is still developing, and may not be feasible for the timeline of this project, so the team plans to overdesign.

6.1.3 Anchor Selection – David Lemar Perez

The TLP or Hybrid design is the optimal selection for offshore plantation near the Great Lakes due to its strong stability and lifelong reliability. The area near Great Lakes develops icy waters which can affect other anchor structures but not the TLP or Hybrid since they have certain material that compensates for it and the structure is not affected by it. The only issue with using either of these structures is the specific design for the location and turbine selection because it can increase cost rapidly but for the size of the area it should be that many turbines which is a win. Most offshore turbines rely on ground sediment use but not that much for these structures since they just need mooring lines which are optimal for these types of freezing conditions. Since offshore is the focus and not onshore, these two structures eliminate the need to disrupt the seabed since it could affect the landscape and might cause further instability if a structure were dug underneath it. According to most lakes, the deeper depths have currents that can cause structures to move in short- and long-term conditions which can accumulate further complications. Floating anchors also eliminate the need to develop more ice since ground structures are more likely to develop ice that becomes harder to remove through time, but with floating anchors they maintain their stability without having too much wind and wave forces affecting movement or ice formation from water. Ground anchors are more likely to be scrapped from the beginning if the entire system starts to fail but as with floating anchors, they are more easily to have maintenance worked upon it.

6.2 Initial Prototyping

6.2.1 Furow – Farm Layout

With an initial Furow prototype, the team wanted to answer what format wind data must be inputted for viable use. Only two tests were necessary to find that a text file was easier and faster read in Furow than an excel file, and that all the windspeed data must be a single column. From this, the team learned that data acquired from NRELs Wind Prospector would need to be modified to fit the formatting requirements.

In the still developing prototype, the team is testing the power output of the three chosen turbines when place in Furow and comparing them to each other so as to decide on which turbine to move forward with.

6.2.2 System Advisor Model (SAM) – Financial

With creating a virtual prototype, starting with S.A.M. is helpful but with a complication in the financial side and so we started with JEDI to be implemented first so we can have a better output data and compare the results between the two so the better decision would be revealed. The results we got from S.A.M. are reasonably well but we are also trying to find a simulation that can virtually analyze the results even further instead of just graphs or a layout. The program made us also investigate availability of turbine specs that is being offered in the program and modify specs if it works better or not for efficient results.

6.3 Other Engineering Calculations - all

6.3.1 Site Selection – Alexander Longoria

At the point of writing this report, there are no additional calculations that have been performed.

6.3.2 Turbine Micro-siting – Samantha Russell

Minor calculations have been done specific for the hypothetical leasing area that the team has created. Considering a 5 mile (8km) by 8 mile (12.9km) leasing area with the wind prevalently perpendicular to the 5 mile sides, and a spacing of 8 rotor diameters between turbines in the wind direction and 5 rotor diameters between turbines in the opposite direction, the team was able to do a simple calculation to find the number of turbines that fit in the leasing space. This is using the same equations listed in section 3.3.2 above. Using the largest turbine, the Vestas V174-9.5MW turbine, the team will be able to fit 64 turbines within the lease area, which would give the facility a power rating of 608MW. This is concurrent with section 4.2.5 above, and is visible in the section's figure 4.2.5.1.

6.3.3 Anchor/Financial – David Lemar Perez

JEDI is the one of the last programs we will be monitoring since most of it is financial due to data that is mostly analysis and can be changed any time. These numbers depict minimal cost and the broad aspect of how much it will take finalize in building a plantation. We mostly used these programs to also look for turbine specs but still compensated for anchor systems that will be incorporated into the project.

6.4 Future Testing Potential

Moving forward in this semester, the winter break, and next semester, the team will be able to test turbines with real wind data for Lake Michigan and the selected site to find the expected power output of the facility. This program will allow for direct comparisons of slight layout changes, turbine changes, and seasonal wind resource variations.

The team will also be progressing with the use of the System Advisor Model and Jedi to test different layout expenditures and inform decisions on bid price, which are required in the second semester.

7 Department of Energy Relevant Conclusions

This section is for outlining purposes as agreed upon with Dr Willy during staff meeting 8. To the best of the team's ability, repetition was avoided for the purposes of the class report 2 submission, and GTA grading time. The team will use the referenced sections in full in the separate report to the Department of Energy

7.1 Specific Lease Area

The Northern Arizona University Project Development team has created the following draft hypothetical leasing spot off the coast of Lake Michigan in Sheboygan, WI. Referencing the calculation done is section 3.3.1 figure 3.3.1.1, this displays the ideal distance of the outermost turbine with respect to the shoreline (willingness to pay). As seen in the figure, when the willingness to pay (y axis) is 0, it tells the team that the distance is approximately 27.5 miles (x axis). To summarize, if the distance is less than 27.5 miles, the team is inclined to incentivize the residence because the turbines are so close to their residences. Consequently, if the distance is over 27.5 miles the team can expect a substantial increase in costs. Therefore, it is ideal to keep the turbines within a reasonable distance.

These next few points will be derived from NREL's Great Lakes Wind Energy Challenges and Opportunities Assessment [9]. Figure 4.3.2.2 illustrates that the Sheboygan area can receive an annual average wind speed of 8.0-8.9 m/s at a hub height of 100m which is the projected height of the team's design. Figure 4.3.1.2 shows an estimated levelized cost of energy to be approximately 70-80 $/MWh given the constraints of the teams selected leasing spot. Figure 4.3.1.4 provides the team with an estimated bathymetry depth of 50-100m which falls within the constraints of the TLP anchor design. These key points were the leading factors that helped drive the teams leasing spot selection.

The leasing area boundary is approximately represented with the coordinates West: 43.719, East: 43.717, North: -87.118, South: -87.140 and is represented in figure 7.1.1 below.

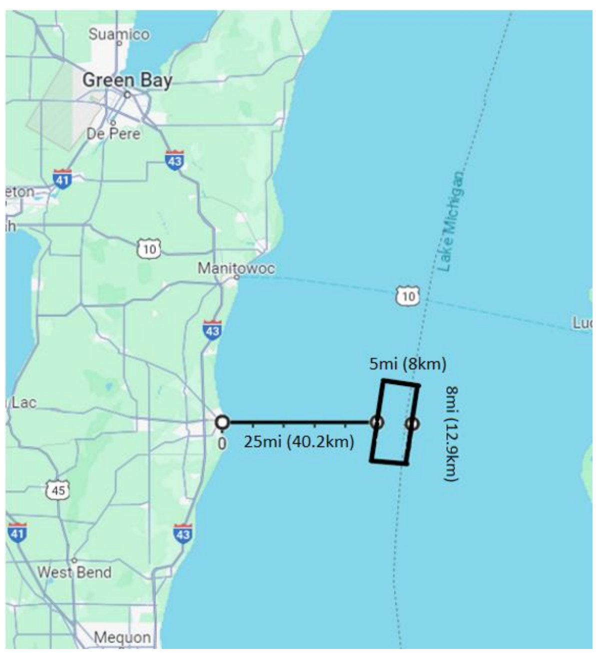


Figure 7.1.1: Proposed Hypothetical Leasing Area

This created leasing area covers just over 100 square kilometers of area, and in this current draft is centered off the coast of Sheboygan. The team found in source [https://www.energy.gov/sites/default/files/2022-09/offshore-wind-market-report-2022-v2.pdf] that most leasing areas were less than 200 square kilometers, with a significant amount being less than 100 square kilometers. For overdesign with the intent to optimize moving forward, the team chose to draft a design that is larger than necessary. Concurrent with section 4.2.5, the team oriented the leasing spot to be longer in the wind prevalent direction to account for further spacing between turbines.

Source [41] showed that the mean wind speeds the team could expect for this location would be from 9.4-9.8 meters per second. The team is still attempting to access the data used by this source to be able to directly confirm the wind resource for this leasing area, as it uses a great deal of storage space.

7.2 Preliminary Wind Farm Design

In order to create the first wind farm design iteration, several more key factors were considered. For example, these criteria can be cross referenced from sections 4.2.4, 4.3.4, and 4.4.4 of the concept generation. By having the wind farm in the middle of the lake, latitude in reference to Sheboygan, the concentration of lake activity (recreational boating, birding, sportfishing, beach use, and park visitation) is inferior to other locations of the lake (Figure 4.3.4.1). From figure 4.3.4.2, the coast of Sheboygan has a relatively small population of King Salmon. additionally, directly across the lake toward Ludington, MI, the fish population is substantially larger. However, the middle of the lake shows no evidence of fish occupancy. Lastly, from figure 4.3.4.3, a clear visual of the ship traffic map shows that there are no areas that aren't impacted. But to the team's advantage, the lease block area shows signs of "free space" that won't impede the bulk of the shipping routes.

For the current draft of the wind farm, the team is utilizing the Vestas V174-9.5 Turbine. Explanation of this turbine selection can be found in section 4.4.2. In the current leasing area size, the team was able to fit 64 of these turbines as described in sections 6.3.2 and 3.3.2. This can be visualized below in figure 7.2.1.

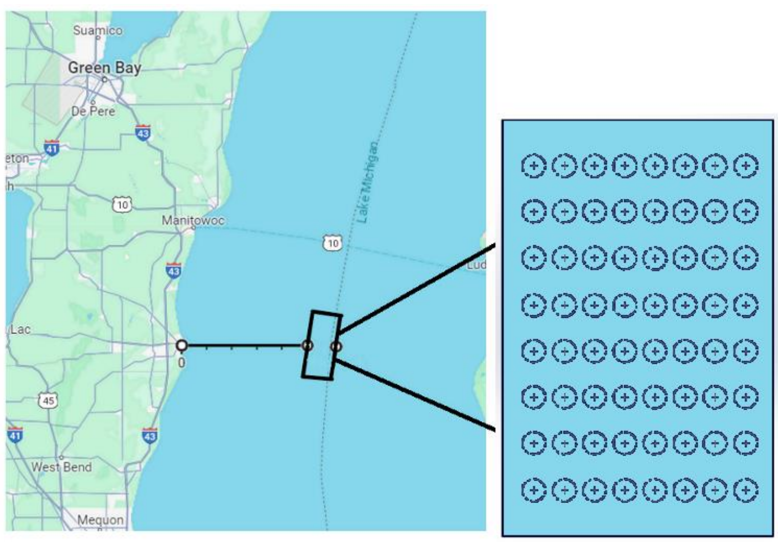


Figure 7.2.1: Midyear Draft Micro Siting Layout

The current choice of anchoring is TLP. This decision is explained in section 4.4.3.

8 CONCLUSIONS

Per the rules of the DEO's CWC, the project development team was tasked to research wind resource data, transmission infrastructure, and environmental factors to create a site plan and financial analysis for a hypothetical offshore wind farm. Some key factors the team consider in this report were the physical site characteristics, transmission infrastructure, geospatial concerns, turbine selection, anchor design, ports, transmission, grid integration, environmental and wildlife impacts, and the coexistence between the residence and the turbines.

To summarize the content of this report, the project development team has successfully selected Lake Michigan as the host of the wind farm, a TLP anchor design, Vesta V174 9.5 turbines, the lease block size, and a first iteration prototyping and financial analysis. This was done by finding literature review that aided in the design and mathematical calculations to enforce a concept generation of each sub section. The team's current bill of materials, schedule, and budget were as provided.

At the time of writing this report, the team feels confident where they stand. However, the team is aware of some areas that can be improved and analyzed more in preparation for the next submission. The team feels that they have a better grasp of the requirements set by the DOE and feel as if they are well prepared. The team's next steps are to continue the prototype and financial iterations as well as unravel any more governing equations.

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10 APPENDICES

[Use Appendices to include lengthy technical details or other content that would otherwise break up the text of the main body of the report.]

10.1 Appendix A: Larger Decision Matrices and Pugh Charts

	Desired direction of improvement (↑,0,↓)	↑	↓	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
1: low, 5: high Customer importance rating (for full competion points)	Engineering Requirements (How's) → Customer Requirements - (What's) ↓	Area of Leasing Block (km^2)	Levelized Cost of Energy ($/kWhr)	Farm Power Output (150 MW)	Wind Data (85-100m height)	Bathymetry Data (m)	Weather Data (WindSpeed max for 100yr storm, and frequency below freezing)	Port Infrastructure (area of port, machinery available)	State/Country Policies	Species Migration Paths (km^2 mapped)	Shipping Routes (mapped)	Power Grid Utility Line Connections (<80km to plant, connection type)	Community Usage Data (<100 people in area monthly)
5	20 year lifespan	0	0	0	5	5	9	5	5	0	0	0	1
5	Siting Selection	9	0	0	9	9	9	9	5	9	9	5	9
5	Technology Selection (Turbine, Anchor, Energy Transmission)	5	9	9	9	9	5	9	5	5	0	5	0
5	Development and Technical Integration Plans	9	5	5	1	0	0	9	9	5	9	9	5
5	One other generation, storage, or end-use technology	5	5	5	0	9	5	5	5	5	1	5	1
4	Harm mitigation strategies for affected ecosystems	9	0	0	5	5	1	0	5	9	5	0	1
3	Local Community Impact	1	1	5	0	1	1	5	5	1	5	5	9
5	Financing Plan - annual costs, market incentives, etc	5	9	9	5	0	0	5	1	0	1	1	1
4	Cost of Energy and cash flow analysis	1	9	5	5	0	0	5	5	0	0	5	0
3	Annual Energy Production	5	1	9	9	1	5	0	0	1	0	0	0
5	Bid for potential Lease Block	9	9	5	5	0	0	5	5	0	0	1	0
	Technical importance score	228	179	155	165	138	122	225	205	134	135	140	116
	Importance %	12%	9%	8%	8%	7%	6%	12%	11%	7%	7%	7%	6%
	Priorities rank	**1**	**4**	**6**	**4**	**6**	**8**	**1**	**2**	**5**	**3**	**7**	**12**

Figure 2.3.2: House of Quality

10.2 Appendix B: Descriptive Title