COLLEGIATE WIND COMPETITION
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Blue Ridge Wind Collaborative

Project Development Report
Collegiate Wind Competition 2024

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Executive Summary

Blue Ridge Wind Collaborative (BRWC) has developed the site analysis, fuel-switch design, construction timeline, financial analysis, optimization process, and auction bid associated with the development of a 420-MW offshore wind power plant paired with an on shore 29-MW solar array and 99-MW of battery energy storage systems (BESS) off the coast of Sheboygan, Wisconsin. This project would be the first utility-scale offshore wind farm in Lake Michigan designated to back-fill for the opening capacity at the retiring Edgewater Generation Station. BRWC has designated a polygon in Lake Michigan for an auction bid in close proximity to the retiring coal plant positioned in an area that will cause the least impact on the natural environment, sensitive species, and neighboring industries in respect to other areas in Lake Michigan or Lake Superior. Site characteristics and financial projections warrant the incorporation of thirty Siemens Gamesa 14-236 DD turbines into the site design. Energy generated by this offshore project, paired with onshore BESS, will accommodate the opening load and capacity at the Edgewater 345-kV substation due to the retiring Edgewater Coal Plant. Port Milwaukee would house the pre-assembled turbine components. This project is attractive to investors given the total Capital expenditure of $1,689,715,968 dollars and total yearly revenue of $92,000,000 dollars. BRWC has outlined a maximum bid price of $75 million dollars for the identified lease area. The site design was visualized and optimized using the modeling software Furow (by Solute) and the financial analysis was facilitated by System Advisory Model (SAM) developed and supported by NREL.

1.0 Great Lakes Prospecting

Identifying offshore wind potential within Lake Superior and Lake Michigan required assessments of wind resource, site characteristics, ocean activities, environmental sensitivities, and financial opportunities, in order to develop an environmentally-conscious, energy-efficient, financially-viable project. The defined lease area within Lake Michigan was selected to be advantageous as it avoids shipping traffic and existing infrastructure, and provides access to Port Milwaukee, and available injection capacity (Figure 1).

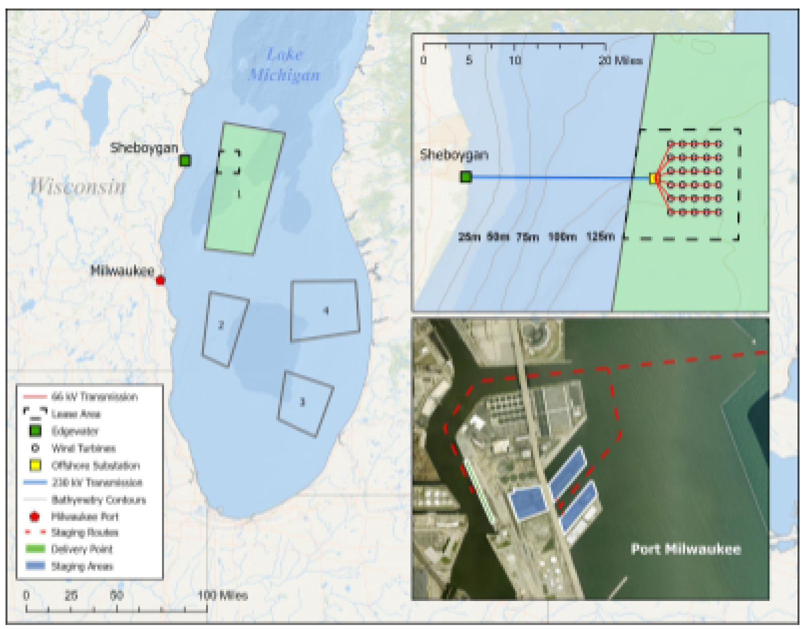

Figure 1. Map highlighting the selected lease polygon in Lake Michigan, identified POI, and access to Port Milwaukee.

1.1 Site Characterization

Preliminary siting research focused on key factors for offshore wind development in the Great Lakes, particularly Lake Superior and Lake Michigan. This included assessing wind resources, bathymetry, geotechnical data, wave heights, currents, icing effects, and potential hurricane impacts.In Lake Superior, the annual average wind speed at 140 meters above water level ranges from 9.8 to 9.9 m/s, while in Lake Michigan, it ranges from 9.6 to 9.8 m/s with less variability than Lake Superior (Bodini et al. 2021). Around 60% of the U.S. Great Lakes area, totaling 91,000 km^2, has water depths of at least 60 meters (Musial et al. 2023). This depth necessitates floating foundations for offshore wind structures due to concerns with structural and financial impracticalities of fixed-bottom foundations (Musial et al. 2023). While roughness of the lakebed surface is less important than identifying the water depth, it was explored using typical geotechnical survey techniques as part of the standard wind development process (Musial et al. 2023). Concerns about contaminants on the lakebed surface (stemming from historical pollution that occurred in 1960s/1970s due to poor regulation) require careful consideration during construction (Musial et al. 2023). Although concentrations have decreased and floating foundations would largely avoid coming into contact with toxic chemicals still present, anchors and power cables would still disturb the soil. Proper guidance from authorities including the U.S. Army Corps of Engineers is needed to mitigate potential impacts (U.S. EPA and Climate Change Canada 2022, Kiel et al. 2022).

Ice cover in winter and early spring reduces wave height formation, with average wave heights in late spring and summer at 0.5 meters or less. Water current velocities averaging between 0.015-0.02 m/s are relatively low, resulting in limited sediment transport and minimal design adjustments (Bai et al. 2013, Musial et al. 2023). Mild wave height conditions in the summer would allow for installation activities; however, further site observations are necessary to identify site-specific winter wave heights to develop a detailed construction timeline. Ice ridges and icing impacts pose risks to offshore wind structures, especially in Lake Michigan, which experiences average maximum annual ice cover of around 30%, with >50% occuring 15-45 days per year (Musial et al. 2023, NOAA 2022). Turbine manufacturers offer various cold weather options to mitigate ice related issues. Ice detection, anti-ice materials and coatings, and blade leading edge heating systems help prevent and remove ice buildup on blades in addition to extending minimum operating temperature options to between -30 and -40 ^{O}C (Siemens Gamesa 2018, Musial et al. 2023). Ice-phobic coatings or retrofitted hot-air blade heating systems can also be used (Borealis Wind 2022).

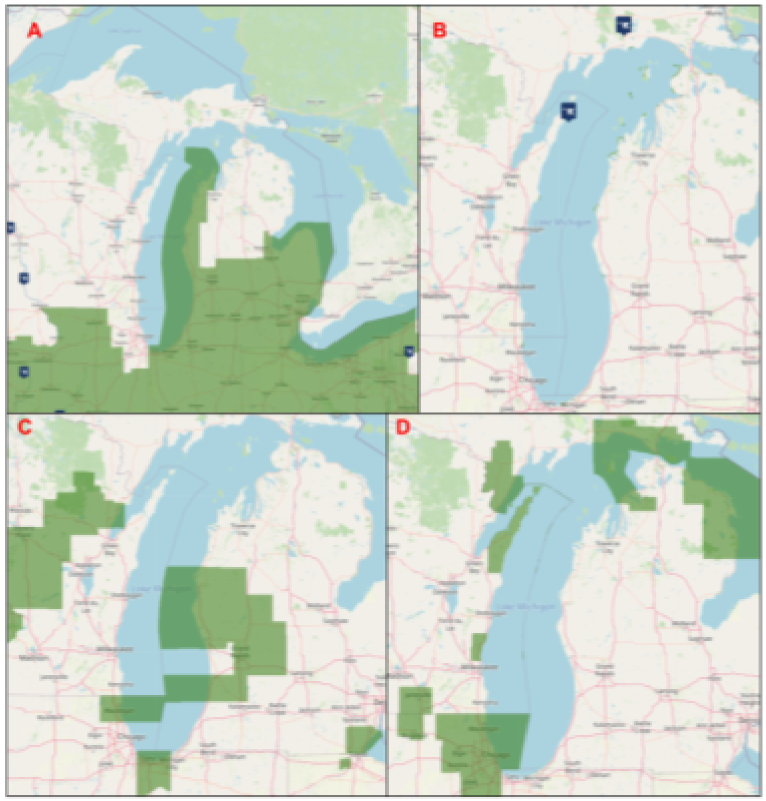

Figure 2. U.S. Fish & Wildlife Service interactive maps visualizing federally endangered avian species. A) Indiana bat habitat region. B) Piping Plover critical breeding locations are found primarily on the Northern Michigan peninsula relative to Traverse City, MI. C) Karner blue butterfly habitat. D) Hine's emerald dragonfly habitat. *Northern long-eared bat habitat region encompasses all of Lake Michigan.

The Great Lakes region hosts diverse activities such as fishing, birding, tourism, and shipping, highlighting the importance of considering multiple stakeholders in offshore wind development (Musial et al. 2023, NOAA 2019). Further, compliance with environmental protection laws, including those protecting endangered species such as the Indiana bat and Karner blue butterfly, is crucial (Musial et al. 2023). To visualize all of the valuable resources of the Great Lakes, data from the Great Lakes Environmental Assessment and Mapping Project, which applied citizen science, agency reports, and social media was used to create a map of cumulative stressors (NOAA 2023).

Offshore wind development requires compliance with state and environmental protection laws, including the National Environmental Policy Act, Endangered Species Act, Migratory Bird Treaty Act, and the Bald and Golden Eagle Protection Act. Projects must avoid endangered species such as the Indiana bat (*Myotis sodalis*), northern long-eared bat (*Myotis septentrionalis*), Piping Plover (*Charadrius melodus*), tricolored bat (*Perimyotis subflavus*), little brown bat (*Myotis lucifugus*), Karner blue butterfly (*Lycaeides melissa samuelis*) and the Hine's emerald dragonfly (*Somatochlora hineana*) (Figure 2) (Musial et al. 2023). In order to mitigate the environmental impacts of offshore wind development in the Great Lakes, areas of interest (AOI) were identified to avoid impacts on these specified species.

In the Great Lakes, while marine mammals are absent, sensitive fish species could be adversely affected by noise and vibration from offshore wind construction. Potential impacts include injury, mortality, behavioral disturbance, and displacement (Musial et al. 2023). Threatened or endangered fish and invertebrate species in the region, such as the pugnose shiner, deepwater Sculpin, and Lake Sturgeon, may necessitate compliance with federal and state Endangered Species Act (ESA) regulations, potentially affecting permitting processes for wind energy projects. Availability of required information could influence project timelines. Mitigation measures to reduce noise during construction exist and could be adapted for use in the Great Lakes context (Bellmann et al. 2020).

1.2 Site Selection

A decision matrix visualizes the annual average wind speed, ice cover, access to suitable ports, capital and operational expenditures for turbines and floating foundations, net capacity factor, and levelized cost of energy for each of these lakes (Table 1, Musial et al. 2023). Ultimately, Lake Michigan was identified as most suitable for offshore wind development as compared to Lake Superior, since it offers less annual ice cover, greater access to suitable port infrastructure, less capital and operational expenditures for turbine components and floating foundations, greater projected net capacity factor (NCF), and lower levelized cost of energy (LCOE). Further, Lake Michigan offers greater energy demand given the bigger cities to be served and more accessible transmission infrastructure.

Table 1. Favorable lake for offshore wind development decision matrix. Note that the preliminary wind farm design does not incorporate 17 MW turbine models; these projections were used to reference prospective costs—projections from Musial et al. 2023.

				17 MW Turbines with Floating Foundations Projections				
	Annual Avg. Wind Speed	Annual Ice Cover	Accessible Port Infrastructure	Turbine CapEx	Foundation CapEx	OpEx	NCF	LCOE
Lake Superior	9.8-9.9 m/s	15-90 days of ice ≥50%	1 Top Tier Port	\$2,000-\$2,600/kW	\$2,321/kW	\$81/kW-yr	51%	\$78/MWh
Lake Michigan	9.6-9.8 m/s	15-45 days of ice ≥50%	11 Top Tier Ports	\$1,900-\$2,200/kW	\$2,087/kW	\$77/kW-yr	52%	\$71/MWh

Siting research specific to Lake Michigan identified areas that avoid shipping lanes, aquatic and avian species impact, recreational activities impact, and a relatively close proximity to retiring coal plants and suitable ports for offshore wind energy (Table 2, Musial et al. 2023). Given these factors, AOI 1 was selected as the most suitable for offshore wind development (see Figure 1).

Table 2. Decision matrix for identified areas of interest (AOI) (Musial et al. 2023).

	Aquatic Species Impact	Avian Species Impact	Recreational Activities Impact	Vicinity to Top Tier Port	Vicinity to Retiring Coal Plant
AOI 1	Overlaps with 8 spawning areas	Northern long-eared bat	Moderate	26 miles from Milwaukee Port	18 miles from Edgewater
AOI 2	Does not overlap	Northern long-eared bat, Karner Butterfly	Moderate	27 miles from Port Milwaukee; 27 miles from Waukegan Port	21 miles from South Oak Creek
AOI 3	Does not overlap	Indiana Bat, Northern long-eared bat, Karner Butterfly, Hine's emerald dragonfly	High	62 miles from Gary Port	40 miles from Michigan City
AOI 4	Overlaps with 4 spawning areas	Indiana Bat, Northern long-eared bat, Karner Butterfly	High	19 miles from Muskegon Port	9 miles from J H Campbell

1.3 Resource Assessment

Wind resource data were obtained from Vortex, a company that specializes in producing high-resolution wind data that developers can use for optimal modeling purposes. Vortex's data is representative of a 20-year period at the geographic center of the project (43.713467N, -87.341745W). The reference height used for calculations was 140 meters which coincides with the hub height of the selected turbine model. This Vortex data was downloaded into Furow for further analysis. As revealed during analysis, the average annual wind speed at 140-m hub height was 8.71 m/s as the prevailing winds are out of the southwest (Figure 3c). Diurnal wind speeds peak during 0000- 0800 hrs and 1600-2400 hrs, and seasonal wind speeds are typically highest during the winter (November-January) and spring (April-May) seasons in the region (Figure 3a and b). These data informed the decisions explained in Section 5.0.

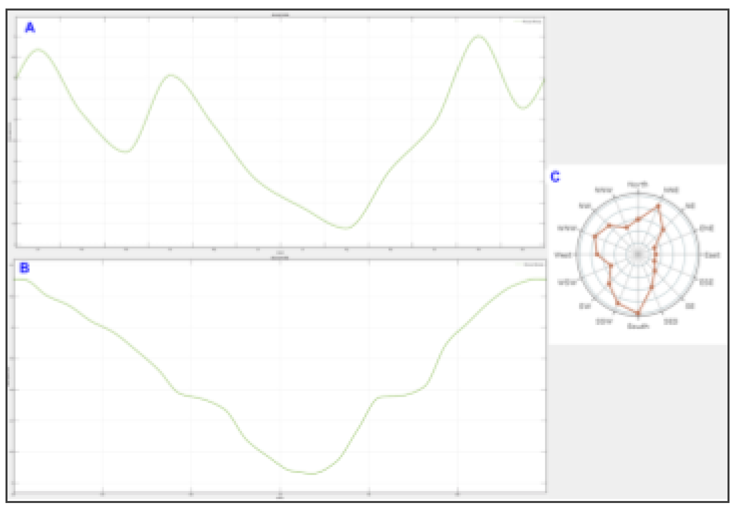

Figure 3. Wind resource assessment. a) Annual profile by month of average wind speed. b) Diurnal profile by hour of average wind speed. c) Wind rose demonstrating prevailing wind direction.

1.4 Fuel Replacement at Edgewater Coal Plant

In June 2022, Alliant Energy (Wisconsin Power and Light Company) announced an updated target retirement date for the coal-fired Edgewater Generating Station in Sheboygan, Wisconsin for June 2025 with a tentative one year window to initiate decommissioning (Alliant Energy 2023). This coal plant has capacity for 413.7 MW and is located within a 265-acre parcel that would allow for the development of BESS (battery energy storage systems) on-site to complete this hybrid project as a fuel-switch system (Figure 4). Integrating a storage system in this project will sustainably provide reliability and dispatchability despite the intermittency of the wind energy produced. By developing a fuel replacement system and incorporating offshore wind and BESS, this will significantly reduce transmission upgrade costs. In 2023, Alliant Energy filed a plan with the Public Service Commission of Wisconsin to construct a 99-MW lithium iron phosphate BESS within the Edgewater Generating Station property boundary. Storage construction is scheduled to begin in 2024 with completion expected by June 2025 (Alliant Energy 2023). As this prospective BESS project is a part of Alliant Energy's Clean Energy Blueprint, it will provide a valuable increase in capacity for new renewable generation at the site and offers financial benefits by reducing the capital investment associated with planning and building a separate system (Alliant Energy 2023). As of 2022, the active queue capacity in Midcontinent Independent System Operator (MISO) was 339 GW, the second largest of all RTOs in the U.S., with average wait times for approval up to five years (Rand 2023). A fuel replacement at this retiring coal facility will also streamline the interconnection process in a congested grid and while bringing new economic opportunity to the area.

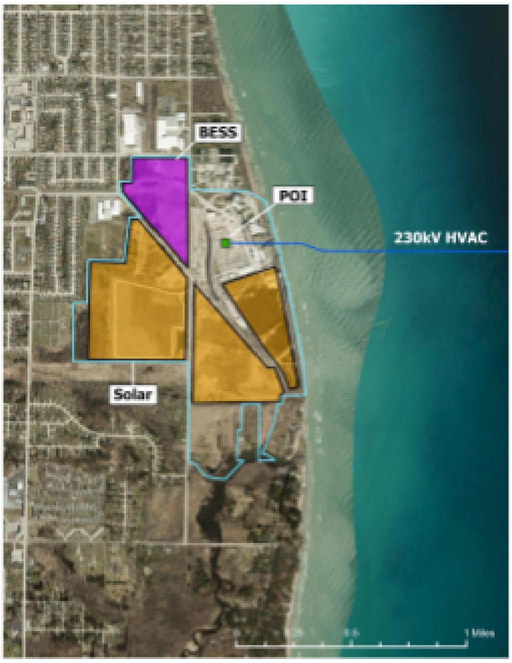

Figure 4. Aerial imagery of Edgewater Power Plant. Wisconsin Light & Power Co owns the parcel outlined in blue. Battery energy storage system (BESS). Point of interconnection (POI) at Edgewater 345 kV substation. Data from Sheboygan County Survey Viewer.

2.0 Project Design

A thorough analysis was conducted to select the most suitable wind turbine model and foundation structure given the geographic and weather conditions present in Lake Michigan. The process for selecting a turbine model involved comparing 24 different models while considering factors such as rated power, rotor diameter, and rated wind speed, with the SG 14-236 DD model ultimately chosen as the most suitable. Lake Michigan's depths exceed 60 meters, necessitating a comparison of different floating turbine options due to its deeper waters.The tension leg platform (TLP) foundation was selected for stability purposes and adaptability to icing conditions. The wind farm layout includes 30 SG 14-236 DD turbines arranged in a grid formation, with a projected annual net energy yield of 1,565,281 MWh. After consultation with key industry mentors, it was determined that the transmission design will involve submarine cables transmitting alternating current (AC) power to the onshore Edgewater Substation.

2.1 Turbine Selection

Characteristics of rated power, hub height, rotor diameter, wind class rating, capacity factor, cut-in and cut-out speeds, rated wind speed, operating temperature, serial production year, and manufacturing location were compared to select the best-fit model for the chosen site in Lake Michigan (Figure 5). Costs specific to the individual models were challenging to identify, so the team did not include cost in the selection criteria. Characteristics that were very similar across models, or could not be found for at least half of the models, were excluded from the decision matrix. Criteria pertinent to the decision matrix were weighted based on relative importance, and turbines received scores for each category on a scale of zero to ten. Rated power was given the highest weight of four, as power generation capability is most valuable to the team, and each turbine's score was calculated as sixty percent of its rated power in MW to keep the scores within the range of zero to ten. The rotor diameter was weighted out of two to not outweigh power generation capability because rated power rises exponentially with rotor diameter (Henderson et al. 2002, Kühn et al. 1998). Scores in this category were calculated by dividing each rotor diameter (in meters) by twenty-five to maintain the zero to ten scoring range. The rated wind speed was given a weight of three because it shows which wind speeds are optimal for producing the turbine's rated power (Beig, Muyeen 2016).

The average wind speed of the Lake Michigan site is 8.71-8.75 m/s (Musial et al. 2023), so selecting a turbine with a rated wind speed is close to this desired value. Rated wind speed scores were calculated by taking the absolute value of the difference between 8.75 m/s and the turbine's rated wind speed in m/s, and then subtracting that value from a maximum score of ten. Note that turbines for which rated wind speeds were not found resulted in a score of 1.25 because they were given a speed of zero. Among the remaining criteria, wind class and manufacturing location received weights of two, and hub height received a weight of one because most hub heights were customizable. The turbine scores for these last three criteria were incrementally ranked, where higher scores were given to turbines suited for greater turbulence, turbines manufactured in nearer countries, and turbines with higher possible hub heights. Upon totaling the weighted scores for each turbine, the SG 14-236 DD model ranked highest and was selected for the offshore wind farm.

Table 3. Turbine model decision matrix.

Turbine Decision Matrix		Rated Power	Rotor Diameter	Rated Wind Speed	Wind Class	Hub Height	Manufacture Location	Score
	Weight:	4	2	3	2	1	2	
	Scoring Method:	*value (MW)*0.6*	*value (m) / 25*	*10 - abs((8.75m/s - value (m/s)))*	*S=10, B=8, C=6 , just 1=2, no info=0*	*ranked; custom/taller = higher*	*ranked by distance; no info=0*	*Sum of scores*weights*
Vestas	V164-9.5 MW	5.7	6.56	1.25	6	10	6	73.67
	V164-10.0 MW	6	6.56	8.75	10	10	6	105.37
	V174-9.5 MW	5.7	6.96	1.25	8	4	6	72.47
	V236-15.0 MW	9	9.44	1.25	10	10	6	100.63
Siemens Gamesa	SWT - 6.0-154	3.6	6.16	5.75	10	10	6	85.97
	SWT - 7.0 - 154	4.2	6.16	5.75	10	10	6	88.37
	SG 8.0 - 167 DD	4.8	6.68	6.75	10	10	6	94.81
	SG 11.0-200 DD	6.6	8	8.75	10	10	6	110.65
	SG 14-222 DD	8.4	8.88	8.75	10	10	6	119.61
	SG 14-236 DD	8.4	9.44	8.75	10	10	6	120.73
GE	Haliade X - 12 MW	7.2	8.8	8.75	8	7	9	113.65
	Haliade X - 13 MW	7.8	8.8	8.75	6	7	9	112.05
	Haliade X - 14 MW	8.4	8.8	8.75	6	7	9	114.45
	Haliade 150 - 6 MW	3.6	6	8.75	2	2	9	76.65
AMSC	wt5500df	3.3	4.16	7	0	3	0	45.52
	wt5500fc	3.3	4.16	7	0	3	0	45.52
	wt10000dd	6	7.6	7.25	0	6	0	66.95
MingYang Smart Energy	MySE 12-242	7.2	9.68	1.25	0	0	3	57.91
	MySE 16.0-242	9.6	9.68	1.25	0	6	3	73.51
	MySE 16-260	9.6	10.4	1.25	0	8	3	76.95
Goldwind	GW171-6.45	3.87	6.84	1.25	0	0	3	38.91
	GWH 252-13.6	8.16	10.08	1.25	0	0	3	62.55
	GWH252-14.3	8.58	10.08	1.25	0	0	3	64.23
	GWH252-16	9.6	10.08	1.25	0	0	3	68.31

2.2 Foundation Selection

A second decision matrix was applied to select a floating foundation type for the turbines (Table 4). It has been recognized that floating turbines are developing technology and they are likely to experience significant structural changes in the coming decades (Musial et al. 2023). Given the uncertainty of structural performance in the presence of ice, the great water depths at the Lake Michigan site, the soft lake-bed soils of the Great Lakes, and the inaccessibility of pile-driving installation vessels in the Great Lakes, fixed-bottom structures were not included in the decision matrix (Musial et al. 2023). Three conventional floating substructures – spar, semi-submersible, and tension leg platform (TLP) –

were ranked across eight criteria: stability, ice risk, material costs, water depth, mooring system, assembly and installation, turbine installation method, and the structure's industry history. Criteria with greater importance were weighted higher: stability and ice risk each received a weight of four, material costs and assembly installation each received a weight of three, water depth and mooring system each received a weight of two, and turbine installation method and industry history each received a weight of one. Per each category, a ranking of three, two, or one was given to each structure, with three being the most desirable and one being the least. Upon totaling the weighted scores for each structure, the TLP floating substructure scored highest and was selected for the project. From the decision matrix, it can be seen that compared to the spar and the semi-submersible, the TLP's excellent stability, lower ice risk, low-cost tug-towing installation, convenient offshore turbine installation, lesser material cost, and applicability to a broader range of water depths outweighed its minimal history within the industry and its high-cost mooring system (Fowler et al. 2014, Musial et al. 2023, Du 2021, Lackner 2022).

Table 4. Floating foundation decision matrix.

Foundation Decision Matrix									
Criteria:	**Stability**	**Ice Risk**	**Material Costs**	**Assembly & Installation**	**Water Depth**	**Mooring System**	**Turbine Installation**	**Industry History**	**Score**
Weight:	**4**	**4**	**3**	**3**	**2**	**2**	**1**	**1**	**Σ(rank*weight)**
Spar	2	3	3	1	1	3	3	3	**46**
Semi-Submersible	1	1	1	3	3	3	1	2	**35**
Tension Leg Platform (TLP)	3	3	2	3	3	1	3	1	**51**

2.3 Wind Farm Design

Given the annual average wind speed of 8.71 m/s in the geographic center of the wind farm, the average output from each turbine was determined to be 5.957 MW based on Furow data with a net capacity factor of 42.54% (Sarkar et al. 2012). In order to get close to the maximum possible generation demand generated by Edgewater Coal Plant (3,624.012 GWh), while remaining profitable and minimizing risk, the construction of 30 SG 14-236 DD offshore wind turbines were chosen given the capacity factor of the turbines. Meeting the maximum demand with wind alone would result in a massive surplus of generated energy with no end use while also not generating enough in summer months.

This project will feature 30 SG 14-236 DD turbines, bearing a total installed capacity of 420 MW. Six rows of five turbines each will be placed in the defined lease boundary (Figure 1). The turbines are situated in a grid formation across the lease boundary, with an alignment rotation of 115° (facing Southwest) to face perpendicular to the wind. An eddy viscosity wake effect model was calculated by simulating 10 m/s winds from the wind farm's average dominant wind direction of 215° (Southwest) in order to better understand the nature of wake losses. The common practices in European offshore projects are spacings of 5–10 rotor diameters among wind turbines in the row and 7–12 rotor diameters among rows (Beiter et al. 2016). Turbine spacing was set to 1,888 m between each turbine (eight rotor diameters apart) and 2,360 m between each row of turbines (ten rotor diameters apart). Typically, offshore wind farms refrain from building the offshore substation at a central location due to vessel access risks associated with repairs and maintenance (Beiter et al. 2016). The offshore substation was placed at a Northwest location of the wind turbines, mainly to allow for shorter vessel pathways from Port Milwaukee and shorter collection cables to the onshore point of interconnection (POI).

2.4 Energy Estimation

Furow modeling software was used to calculate the energy yield estimation of the wind farm. Total losses were set at 15.5% as this was the number defined for an offshore wind reference site by NREL in their 2021 Cost of Wind Energy Review (Stehly et al. 2022). The projected annual net energy yield of the 420-MW wind farm is 1,565,281 MWh. This energy projection is likely conservative as the turbine power curve used for this model serves only as a proxy for that of the record-breaking SG 14-236 DD (Shahan 2022).

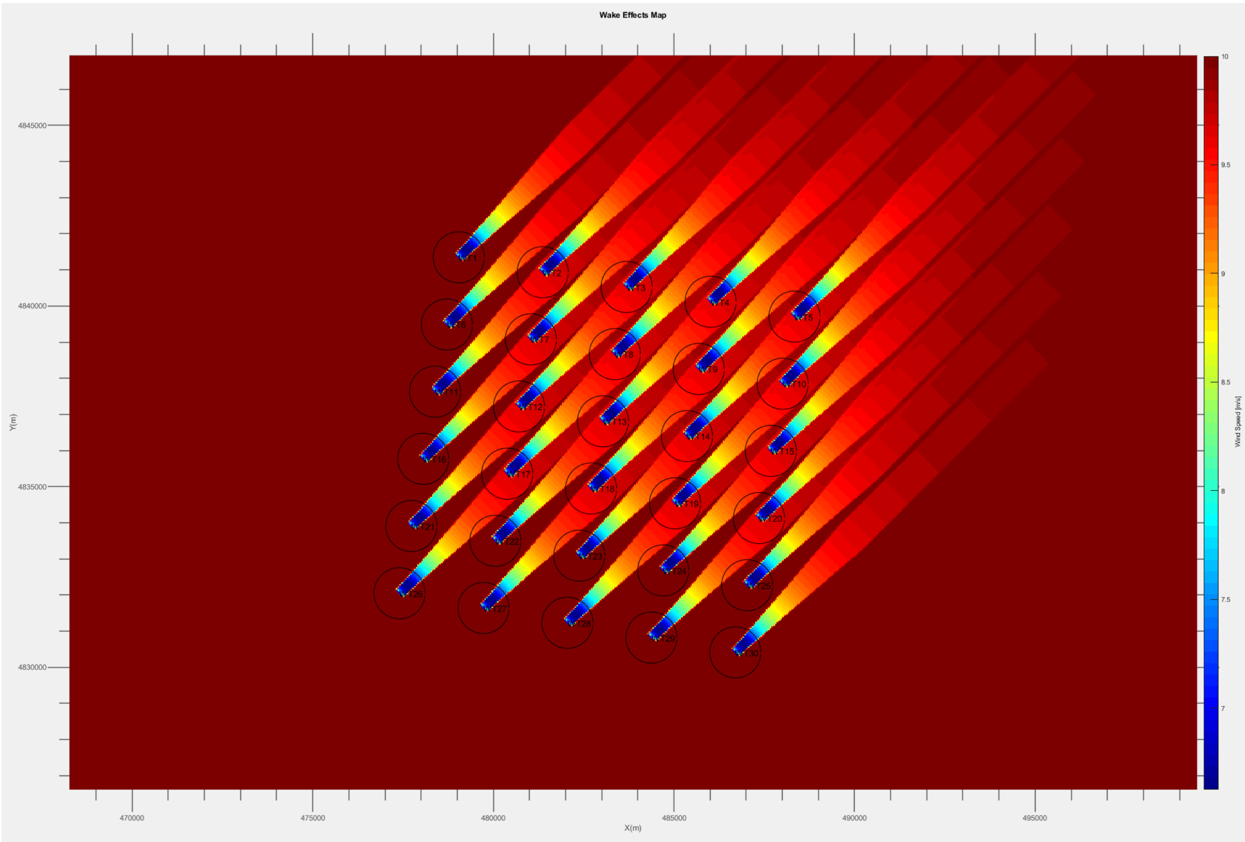

Figure 5. 30 SG 14-236 DD turbines displayed overtop of average wind direction wake effect raster in Furow.

2.5 Transmission Design

The transmission system is necessary for the interconnection of the wind farm's offshore substations and wind turbines to interconnect to the 345kV Edgewater Substation. The array cable technology is easily scalable to be able to match the size of offshore wind projects and anchor on the lake bed to protect the integrity of the cables. The array cable system diagram illustrates the means for transmission of power to the point of interconnection including, but not limited to, export cables, array cables, substations, and the point of interconnect (DNV 2022, Figure 4).

Through consultation with industry mentor Ralph Kurth, Senior Principal at Stantec, it was determined that the transmission of electric power via the submarine cables would be in the form of alternating current (AC) because of the relation of the wind farm location to shore. These technical aspects of the transmission design would result in the optimization of the layout of the cables in a manner that maintains the financial feasibility of this project and maximum energy production (Beiter et al. 2016). Kurth was instrumental in providing professional recommendation with the transmission design by explaining the necessary components, providing cost estimates, and identifying manufacturers. The single-line diagram of the transmission system from turbines to the storage facility and the point of interconnect is seen in Figure 6. Essential suppliers for the wind farm design include Siemens Energy and GE corporations to provide substation equipment, Prysmian and LS Cable companies for supplying submarine and land cables and Kiewit for the installation and construction processes. The acquisition of submerged land leases will be required for implementing submarine array cables, and consultation with myriad federal agencies including but not limited to the NOAA, the U.S. Army Corps of Engineers

(USACE), the Bureau of Ocean Energy Management (BOEM), and the U.S. Department of the Interior, will be required (NOAA), (BOEM).

To determine the necessity of reactive compensation elements associated with High Voltage Alternating Current (HVAC), preconstruction engineering assessments will need to be performed. The design of the array cable system will avoid exclusion zones in which any form of construction is prohibited, obstructions or obstacles present on the sea floor from previous infrastructure or marine habitation, and minimize damage to the sea floor during the cable-burying process. The design will also be impacted by the location of the wind turbines and their proximity to the substations. A design consideration that will impact the entire system is the prevention of overlapping cable crossings which would risk the potential for cable thermal overloading (Yi et al. 2019).

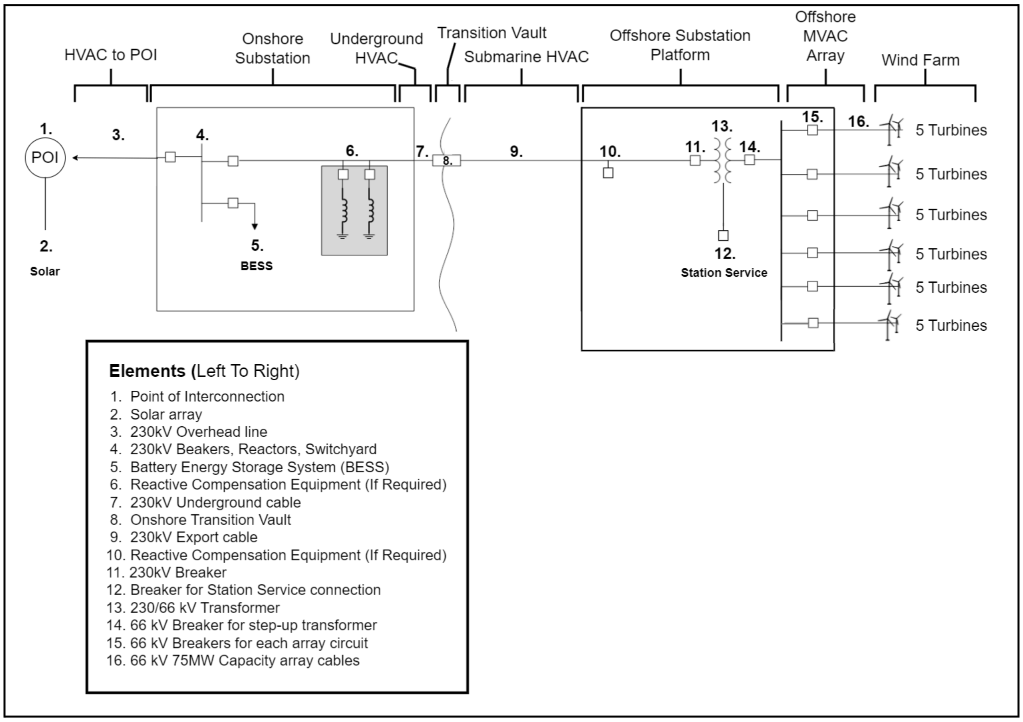

Figure 6. Visualizes transmission design from wind farm to point of interconnect.

2.6 Alternative Project Options

Extensive research was conducted to evaluate the most beneficial technologies to incorporate into the hybrid system (Table 5). Ultimately, onshore solar and BESS were selected due to the strong market demand, physical feasibility, lower costs and favorable efficiency.

Table 5. Decision matrix for alternative technologies considered for hybrid design.

	Technical Benefits to Wind	Market Conditions	Physical Feasibility	Costs	Technology Efficiency
BESS	Strong market demand	Commercially readily available	Small land area available for use at fuel switch location	$1,796,000/MW	Round trip efficiency of 90%
Floating Solar	Provides peak generation during low wind speed seasons	Experimental technology, not commercially mature	Limited feasible due to extreme temperatures and icing conditions	LCOE 20% more than onshore solar	Cooling from the water increases efficiency
Onshore Solar	Provides peak generation during low wind speed seasons	Commercially available, decreasing market prices	Limited land area available	$1.5 million/MW of installed capacity	15% to 20% efficiency
Green Hydrogen/ Wastewater	Potential storage benefits for excess wind power	Newer technology, not widely commercially available	Proximity to coal plant, existing infrastructure	$501,551/MW of installed storage	Upwards 60% efficiency
Natural Gas Peaker Plant	Provides peak generation during low wind speed seasons	Readily available, emitting less relative to coal plant	No existing pipeline infrastructure, required infrastructure upgrades	$922,200/MW plus cost for fuel transportation	Low capacity factor due to low generation periods

3.0 Project Timeline

The timeline displayed in Figure 8 details the estimated timeframe for preparing, installing, and decommissioning a wind farm in Lake Michigan with the purpose of implementing a fuel switch. The project will begin with discussing with the Edgewater Coal Plant the potential to complete a fuel switch to supply electrical power to the community it serves. After negotiations, a series of environmental studies will be completed to determine the viability of the selected location in Lake Michigan for implementing a wind farm. Additionally, the permitting process will be initiated with the Wisconsin State agencies such as the Department of Natural Resources and with the Port of Milwaukee about leasing storage space and port access for transporting turbine components.This is estimated to take place over the next five years. Once the permitting applications have been approved and the environmental surveys have been completed, the BRWC will begin the process of organizing the transportation of wind turbines to the Port of Milwaukee through the St Lawrence Seaway. From there the turbine construction will take place at Port Milwaukee, and then transported to their location within the wind farm array for installation. The wind farm's interconnection point will be at the Edgewater Plant and supply electrical power to the community that it serves. The construction and installation phase of the project is predicted to take place approximately three years with an anticipated operation lifespan for the wind farm to be twenty-five to thirty-five years, after which the planning process for decommissioning the wind farm will be about two years to complete. (BOEM 2018).

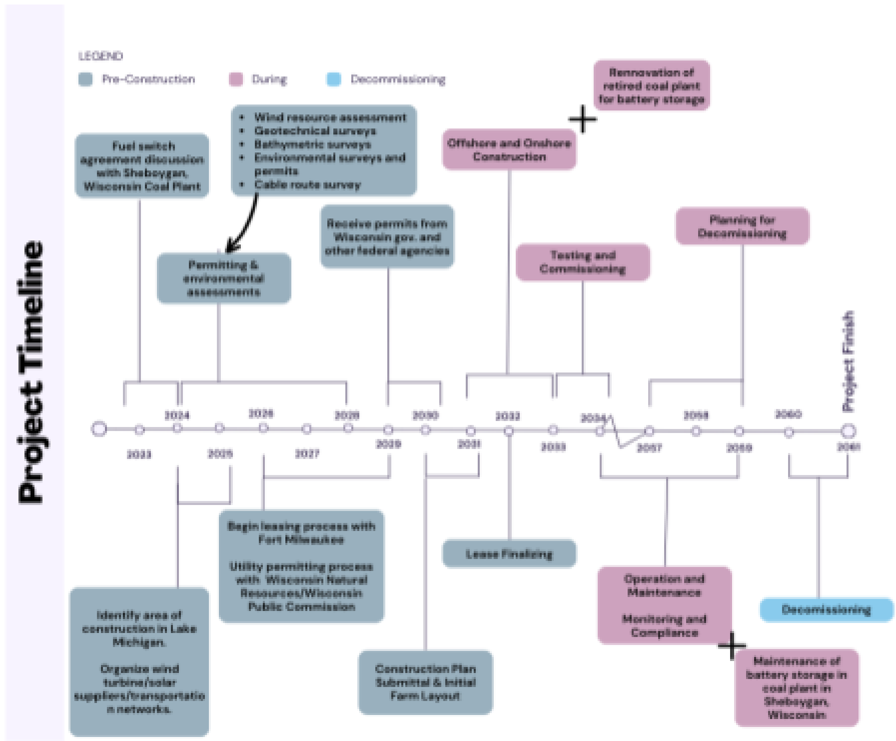

Figure 7. Timeline visualizing general project development sequence.

3.2 Site Control

Prior to project installation procedures, surveys performing geophysical, geotechnical, meteorological, and environmental site assessments will be conducted over the course of five years (WDNR, Musial et al. 2023). The most critical impact-producing factors with offshore wind development in the Great Lakes include noise, strikes, collisions, and bottom disturbance without protective measures. A solution for the proposed wind farm, to mitigate noise and vessel strikes, includes enacting a vessel traffic buffer around the project area (BOEM). For the project area, a 10-mile vessel traffic buffer would be adequate to lower impact-producing factors from major to negligible. In order to reduce bottom disturbances, turbines will be constructed on land at Port Milwaukee and then tugged out to their location in the array. Through the completion of these studies and obtaining the subsequent permits, BWRC will proceed with the wind farm construction while attempting to incur minimal environmental disruption.

3.3 Permit Acquisition

State agencies within Wisconsin will primarily facilitate the permit acquisition process. However since the Great Lakes share a border closely with Canada, the federal government does have the authority to regulate offshore lake activities relating to economics which means some permits are federal. Wisconsin requires utility project developers to provide various plans including a site assessment plan, technical design report, and O&M outline. The Environmental Protection Agency (EPA), National Oceanic and Atmospheric Administration (NOAA), and U.S. Fish & Wildlife Service (USFWS) require projects to consider predicted impacts on the environment and protected species. The U.S. Department of Defense (DoD), U.S. Coast Guard (USCG), and Federal Aviation Administration (FAA) require the development of plans and the filing of the permit 90-120 days prior to construction to ensure no disruption to military or aviation activity. Additional permits also need to be obtained from the US Army Corps of Engineering, U.S. National Marine Fisheries Service Permit and the U.S. Coast Guard Permit for navigational lighting (NYSERDA 2024). Acquiring all of these required permits will take between 2-3 years (WINDExchange).

3.4 MISO Interconnection Queue

For renewable projects to seek approval, developers must file in the respective Regional Transmission Operator (RTO) interconnection queue. MISO's generator interconnection process vets and approves the addition of new energy sources for the states surrounding Lake Michigan. It also manages generation retirement decisions to ensure that there's enough incoming energy to replace what is phased out (MISO). As this project is replacing the generation of a retiring coal power plant, this project would be filed and approved in an expedited fashion because it would be accommodating the open demand and capacity of a base-load generating station that has a preexisting interconnection with the MISO grid (MISO).

3.5 Construction and O&M

Offshore wind development in Lake Michigan requires adequate port infrastructure and the availability for ships to navigate the St Lawrence Seaway (Musial et al. 2023). The Port of Milwaukee is 26 miles from the selected project boundary. The selected lease area port provides 205,000 square feet of climate-controlled warehouse storage space which would be used for onshore construction and staging procedures for upwards of two years (Port Milwaukee 2020). The selected turbine model warrants 79,000 square meters which does not surpass the area of the available port lease area. The selected lease area (see Figure 1) is 14 acres of open storage, 65,000 lbs of forklift capacity, 5 cranes with an overall capacity up to 181.4 MT, suitable for all staging procedures. To secure this lease area, this project would have to secure a contract bid/RFP or be granted a particular waiver by the City of Milwaukee. Port strength can be quantified by the maximum throughput in tons (TEU) the infrastructure can handle over a given period (BTS 2017). The port capacity is based on the weight and dimensions of each turbine equipment piece if used in pre-assembly phases. Given the specific turbine metrics for the Siemens Gamesa 14-236 DD, Port Milwaukee consists of roadways and lease blocks that can support the dimensions and weights of these turbine pieces. Due to the limiting size of the port, the turbines will be delivered to the project site by tugboats. Docking for all operations and maintenance (O&M) vessels will require space at a separate harbor from the identified staging lease block. All O&M vessels must comply with regulations outlined in the Jones Act, which mandates that cargo shipped between United States ports be carried by ships that are flagged in the U.S. and manned by an American crew.

DOE's Office of Energy Efficiency & Renewable Energy has identified and outlined how projects can ensure security against physical and cyber attacks. After evaluating the proposed cybersecurity measures, the most suitable option for the project would be to install a firewall. This strategy is essential to facilitate secure control system data access, filter external requests, and permit Virtual Private Network

(VPN) access to stop potential cyberattacks. Implementation of a firewall is necessary in order to prevent external action or access to the internal local area network which connects to the wind turbines and transmits critical data (DOE 2020).

3.6 Community Stewardship - Sheboygan, WI

In the proposed development, leveraging spare land emerges as a pivotal opportunity for the preservation and enhancement of local ecosystems. Within a designated conservation area adjacent to the shores of Lake Michigan, the careful selection of native plant species tailored to the region's climate, soil conditions, and ecosystem stands as a foundational strategy. These indigenous plant species not only enhance the area's aesthetics but also provide essential habitat and sustenance for indigenous wildlife, requiring minimal maintenance once established.

3.7 Decommission Plan

Decommissioning obligations enforced by BOEM mandate an allotment of two years to remove all facilities, projects, cables, pipelines, and obstructions, and to clear the seafloor of all obstructions created by activities on the lease, including a project easement or grant, to a depth of 15 feet below the mud line (30 CFR §585.433, §585.910) (BOEM 2022). Within 60 days after the removal of any facility, cable, or pipeline, a final notice must be submitted to BOEM verifying site clearance that provides a summary of removal activities and a description of any environmental mitigation measures (30 CFR §585.912) (BOEM 2022). Although landfilling turbine blades is currently the most cost-effective solution to manage equipment that is removed from service, BRWC has committed to supporting blade recycling procedures.

4.0 Financial Analysis

The financial analysis was conducted using SAM software with calculations and conformations generated through Furow and Excel® analysis. The following research was informed by details noted in Sections 4.1-4.6 as well as the current global and domestic energy market dynamics, precedents set by recent domestic offshore wind projects, and forecast modeling of offshore wind cost by NREL.

4.1 Required Capital

The initial capital requirement for the establishment of a 420-MW offshore wind power plant, complemented by a 99-MW battery energy storage system, off the coast of Sheboygan, Wisconsin, has been carefully assessed. The meticulous design integrates the latest turbine technology with essential modifications to existing infrastructure, warranting an aggregate capital investment of $1,689,715,968. This figure consolidates the procurement and deployment costs of seventy Siemens Gamesa 14-236 DD turbines, the installation of advanced battery storage systems, and comprehensive site modifications at the retiring Edgewater Coal Plant to support a seamless transition to renewable energy.

4.2 CapEx & OpEx

Projected operational expenditures are calculated on an annual basis, factoring in regular maintenance, labor, insurance, and emergency reserves. Capital expenditures cover initial setup and contingency funds for technological updates and unforeseen repairs. The financial strategy ensures the sustainability of operations without compromising the project's profitability. Annual operating costs for both wind and solar are anticipated to total $46,606,700, derived from an established baseline of $122.2 per kW per year, which will be adjusted for inflation and technological advancements (NREL 2024).

4.3 LCOE

A pivotal financial metric for this project is the Levelized Cost of Energy (LCOE), meticulously calculated to evaluate the economic viability of the hybrid wind and storage facility. The LCOE, estimated at $48.60 per MWh, reflects a comprehensive assessment of the lifecycle costs against the total energy output. This calculation underscores the competitiveness of the project in the renewable energy sector, affirming its potential to deliver cost-effective energy solutions. This is attractive to Alliant Energy and is competitive to current offshore wind projects (Kennedy 2024). The price set for a PPA will be $ 37 per MWh, with an escalation rate of 2.5% in order to compensate for inflation.

4.4 Investment Incentives

President Biden's National Climate Task Force has ambitious goals for the United States which cannot be realized without the adoption of renewable energy. This requires agencies to work toward a net-zero emissions economy by 2050 (White House 2022, DOE 2022). President Biden's Justice40 Initiative sets a goal for 40% of the benefits from federal investments in climate change and clean energy to benefit communities that are "marginalized, underserved, and overburdened by pollution," (White House 2022). The surrounding area of the Edgewater Generation Station qualifies as a disadvantaged community under federal criteria as an energy community tied to petroleum.

We intend for project construction to be initiated prior to January 2025 in order it would meet all apprenticeship and wage requirements, thus this project will qualify for a 30% Federal Investment Tax Credit (ITC). This would be supplemented by an additional 10% credit in light of the project's location in a disadvantaged energy community. The project also qualifies for a Clean Energy Production Tax Credit (PTC) of 0.5 cents/kWh and a 10% energy community bonus due to the decommissioning of the coal plant (DOE 2023). Additionally a 5-year MACRS depreciation schedule was utilized. Policy intervention is essential to the feasibility of early market offshore wind projects (Dukan 2023).

4.5 Assumptions

The project will likely also qualify for the DoE Loans Program Office (LPO) Title 17 Innovative Clean Energy Loan Guarantee Program which was authorized by the Energy Policy Act of 2005. Projects eligible for Title 17 loan guarantees must meet certain innovation, emissions, location, and repayment prospect requirements. This hybrid wind farm will employ existing commercial technologies in combination with new and significantly improved technologies, helps reduce anthropogenic GHG emissions, is located in the U.S., and provides a reasonable prospect of repayment. The characteristics of this project achieve eligibility requirements to receive a Conditional Commitment and a Loan Guarantee Agreement from the DoE LPO (Loan Programs Office).

The financial forecasts hinge on several critical assumptions that influence the project's economic analysis. These include a real discount rate of 6.4 %, reflecting the time value of money, and an inflation rate of 3%, which adjusts future costs and revenue projections to current values. A DSCR of 1.3 over 10 years at 5.75% was determined through careful sensitivity analysis. An IRR of 9.8% led to the low debt percent of 13.55%. Energy production simulated with Furow is 1,565,281MWh annually, based on empirical wind data and operational efficiency of the turbines.

Table 6. Cash-flow-analysis

Year	0	1	5	10	15	20
Total revenue	$ -	$ 92,433,656.00	$ 92,298,488.00	$ 92,144,096.00	$ 92,007,744.00	$107,326,016.00
Total operating expenses	$ -	$ 46,303,700.00	$ 52,081,656.00	$ 60,334,328.00	$ 69,901,448.00	$ 80,992,368.00
EBITDA	$ -	$ 46,129,960.00	$ 40,216,836.00	$ 31,809,764.00	$ 22,106,296.00	$ 26,333,648.00
Debt interest payment	$ -	$ (13,167,359.00)	$ (7,972,187.00)	$ (1,330,468.00)	$ -	$ -
Cash flow from operating activities	$ -	$ 33,637,860.00	$ 33,004,172.00	$ 31,359,172.00	$ 23,125,692.00	$ 27,514,786.00
Cash flow from financing activities	$ 1,689,715,968.00	$ (22,317,224.00)	$ (22,963,840.00)	$(23,138,582.00)	$ -	$ -
Total after-tax returns	$(1,460,718,336.00)	$ 928,217,792.00	$ 108,300,760.00	$ 69,059,144.00	$ 15,249,591.00	$ 87,708,752.00
After-tax cumulative IRR	0%	-36%	-1%	8%	9%	10%
After-tax cumulative NPV	$(1,460,718,336.00)	$(613,742,528.00)	$(230,388,672.00)	$(43,499,372.00)	$(15,130,227.00)	$ 8,113,590.00
Federal ITC total income	$ -	$ 675,886,336.00	$ -	$ -	$ -	$ -
State ITC total income	$ -	$ -	$ -	$ -	$ -	$ -

4.6 Risks & Fatal Flaws

Recognizing and mitigating potential risks is paramount to the project's success. Identified risks include technological failures, environmental compliance issues, and market price volatility. Strategic measures, such as robust maintenance protocols, adherence to stringent environmental standards, and financial hedging, are in place to mitigate these risks effectively. These proactive strategies are designed to safeguard the investment and ensure sustained operational efficiency.

Impact-producing factors (IPF) is a term used by BOEM that identifies critical cause-and-effect relationships between renewable energy projects and affected resources, including but not limited to physical, biological, economic, or cultural resources (BOEM 2021). IPF relevant to this project include extreme weather events, ecological loss, political administration change, rising inflation rates, and supply chain challenges. Excluding extreme weather conditions, average wave heights in Lake Michigan are not considered an IPF (BOEM 2017).

For an offshore wind project to receive approval from BOEM, the project must follow the Renewable Energy Program Regulations (30 CFR 585, Section H), which outlines if the selected lease areas include endangered or threatened species (BOEM 2021). BOEM must consult with state and federal wildlife agencies to identify specific conditions for the project to proceed (BOEM). If environmental consultants conclude that project development will lead to detrimental ecological losses then BOEM will not issue permits and project development will be terminated. This project's design attempts to avoid ecological harm and BRWC does not anticipate project termination on these grounds.

Recent federal legislation, as explained in Section 4.2, has incentivized the expansion of renewable energy in the United States. Considering these laws were passed on party lines, and supported by the Democrat Party, the 2026 election results in favor of Republican control of Congress or the Presidency would be a substantial risk to these laws' continued implementation. This project would lose significant funding opportunities in the event that these laws were repealed or significantly amended.

Technical and high-investment operating costs are susceptible to unexpected price changes. In order to mitigate construction and operational risks, BRWC has identified Munich RE's offshore EPC cover insurance as a means to address the uncertainty associated with variable costs (Munich RE). Through Munich RE's insurance solution, Blue Ridge Wind will be covered against unexpected costs related to O&M and supply chain disruptions (Munich RE). Also, given the selected wind turbine for this project (Siemens Gamesa 14-236 DD) is manufactured overseas, technical insurance is required under a European entity.

5.0 Optimization Process

Optimization was done by designing the wind farm so that the turbines could maximize their potential. Furow facilitates the efficient micro siting of wind turbines by allowing the user to input specifications for their layout grid. Then, the created grid was put through many iterations of the wake effect and energy yield tools to incrementally make adjustments to optimize the layout. The spacing of eight rotor diameters between turbines took advantage of both available spaces inside the chosen lease block and induced minimal wake effects on other turbines. During this phase of micro siting, we were able to improve the wind farm design so that it creates the most possible electrons in its given location, space, wind resource, and technological constraints. These steps were vital to many other factors that go into the project since the BESS and financial returns are functions of how many electrons the farm brings to shore.

On its own, wind cannot handle the peak demands all throughout the year. Wind tends to be stronger in the spring/ winter and weaker in the summer (EIA). In order to help match the load with the demand as close as possible in the months of weaker wind resources, wind needs to be paired with some other form of generation or storage. For this project the chosen complements to the wind resource are a 29 MW solar array along with 99 MW of Lithium Iron Phosphate Storage Technology (LFP) (Alliant Energy 2023). In the summer when the wind resource is lowest, the solar is at its peak through the year allowing for the load curve to be more smooth and match the demand as close as we can manage with our land constraints.

In order to eventually improve the hybrid design to more accurately match the base-load of the retiring coal plant, several improvements can be made. Before more wind is built, solar and storage need to be built up. Even though the land resource is not enough to build more solar, the prospect of floating solar should be investigated as there is ample space between the turbines. An additional idea to increase the storage that was investigated early on was green hydrogen from the neighboring wastewater treatment plant. The experimental technology of a Microbial Electrolysis Cell was previewed as a way to store energy with the redox potential of the microbes. As these technologies are still very new and experimental it becomes clear that baseload generation with renewables is very difficult without improvements to current storage and new technologies.

6.0 Auction Bid

With all of the considerations, it has been determined that BRWC is willing to bid up to $80,000,000 for the specified wind lease boundary (see Figure 1). This maximum bid price was determined with the NPV that was calculated based off of the $1,689,715,968 of initial expenses, which calculated using the costs associated with deployment costs of thirty turbines, the installation of advanced battery storage systems, and site modifications at the retiring Edgewater Coal Plant, and $92,000,000 as the expected annual revenue. The NPV was found to be $8,113,590 so the bid if needed can be increased without impacting the revenue of any stakeholders, however to leave a comfortable amount of profit this amount was decided. This number has also been based on a standard that wind farms in NY, NJ, and MD have been following: the Offshore Renewable Energy Certificate (OREC). The OREC price for 2029 is $84.03 MWh which represents the positive environmental attributes associated with 1 Megawatt per hour (Orsted 2021).

This bid price was chosen compared to the offshore New York, New Jersey prices which range between $6,500-$11,000 per acre. The bid price falling in between the range of NJ, NY is justified since the greatest average wind speed in Lake Michigan is 9.6-9.8 at a height of 140m (NREL 2020). Having this bid price for 160 acres is justified by the higher wind speeds in Lake Michigan and thus how the turbines would be producing more energy on average then wind farms off of the coast of New York and New Jersey. It is also unreasonable for the bid price to exceed approximately $11,000 per acre based on a lease auction that occurred in 2023 which was run by BOEM. The auction was for parcels OCS-P 0561 and OCS-P 0562 which collectively form the Humboldt area. The area has an average of 9.2m/s wind speeds and two Californian based energy companies, RWE Offshore Wind Holdings, LLC and California North Floating, LLC paid approximately $2504.36 per acre for each of their parcels (BOEM).

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