COMET WIND

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Project Development Report

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1.0 Executive Summary

Comet Wind presents the following proposal for Horizon Wind Farm, a 240 MW offshore-wind-based hybrid power plant consisting of sixteen 15-MW Vestas V236 wind turbines located off the coast of Burns Harbor, Indiana with secondary generation of green hydrogen as part of the MachH2 Initiative. After analyzing potential project areas in Lake Michigan and Lake Superior with a focus on wind resources, environmental conditions, transmission distance, and hybrid power plant applications, a site was selected approximately 48.2 km from shore. Site development research for this project was conducted using Solute Furow, the System Advisory Model (SAM), and MATLAB. Comet Wind plants to sell power generated by the project at an initial PPA price of $0.09/kWh to the utility Northern Indiana Public Service Company (NIPSCO) and to Linde and BP Refinery hydrogen production facilities. The project would average an annual energy production of 855,651 MWh at a capacity factor of 44.59%. With an LCOE of 88 $/MWh and an IRR of 14.85%, our project is a regionally competitive renewable energy project.

2.0 Site Description: Great Lakes Resource and Environmental Factors

The site description section focuses on the available resources within Lake Michigan and Lake Superior, as well as the methodology used by Comet Wind to evaluate the region and select a final site.

2.1 Wind and Wave Resource Assessment

According to the Technical University of Denmark's Global Wind Atlas [1], the average annual wind speed in Lake Michigan at a height of 150 meters ranges from 8 – 9.66 m/s, while Lake Superior wind ranges from 7.35 – 9.76 m/s at 150 meters. Similar to oceanic wind assessments, the Great Lakes showed a direct correlation between wind speed and distance from shore. Using this preliminary height reference, Comet Wind was able to identify areas of interest within the Lakes and utilize NREL's Wind Toolkit to analyze these areas at a 5-minute, 2-kilometer resolution [2]. For our final downselect, 15 locations were analyzed at heights ranging from 100 – 200 meters. Further assessment to refine turbine placement consisted of statistical and seasonal analysis of the vertical wind velocity at heights of up to 250 meters using the Weather Research and Forecasting Model. Detailed wind characteristics for the project location found using Wind Toolkit are shown in **Figure A**.

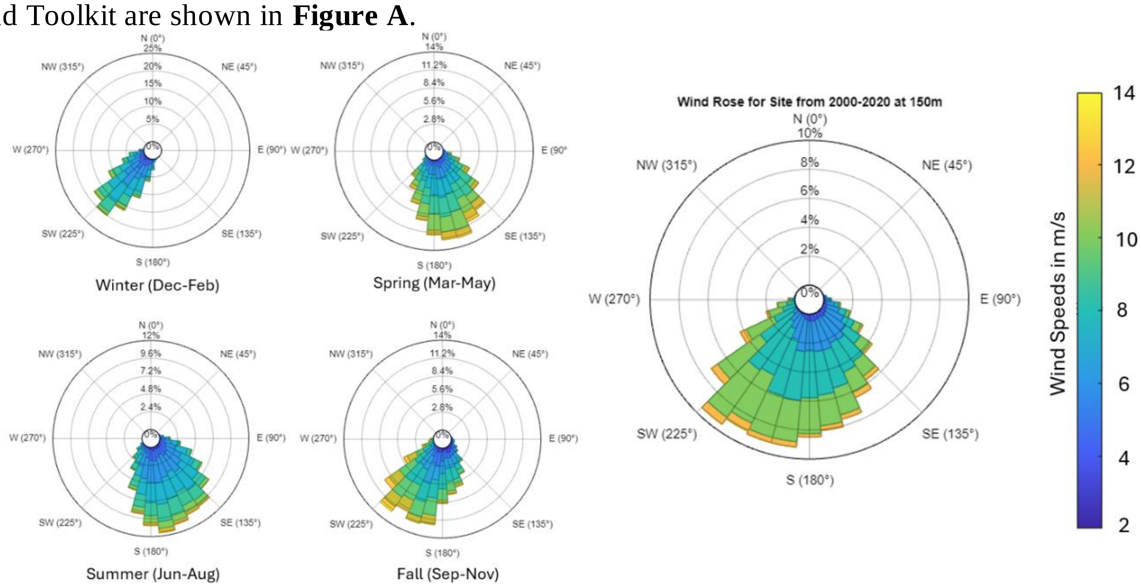

Figure A. Annual and Seasonal Wind Roses over 2000-2020. [2]

In addition to wind speed analysis within potential site locations, wave height was considered as a critical factor of wind farm design. With the unique characteristics of the region (bathymetry, wave height, and icing), these factors can influence the overall integrity of the turbine. Collecting and analyzing this information for wind turbine configurations allows Comet Wind to perform iterations with a factor of safety of 2.5 to minimize uncertainty for events such as capsizing and mooring system failure [3], these calculations can be seen in **Section 3.1.** On average, the significant wave height is roughly within the range of 0.14 - 1.23 meters [4].

Extreme Weather Conditions

While Lake Michigan does not have any direct history with hurricanes, tropical storm systems created in the Great Lakes region (such as Superstorm Sandy and The Lake Michigan Storm of Halloween) have caused Lake Michigan to experience winds of up to 70 mph and maximum wave heights of 7 meters [5] [6]. Another extreme weather condition unique to the region is freshwater icing. On average, Lake Michigan experiences annual ice coverage of 39.43%, with the highest recorded value being 93.1% coverage. The Northern Basin along the coast of Lake Michigan experiences the most ice coverage [7]. Due to the intensity of icing, project development and leasing within the Southern Basin is preferred. Measures to minimize weathering to the wind farm are outlined in **Section 3.0.**

2.2 Site Selection

Bathymetry and Sediment Composition

To determine if floating or fixed bottom wind turbines should be used, the depth of both lakes was evaluated. The deepest region in Lake Michigan (at 275 meters) is located at its center, and while Lake Superior's bathymetry is considered incomplete by the latest NOAA survey data, its maximum lake depth is confirmed to be 406 meters [8]. Given that the Lake Superior region presented limited and low-resolution data and no exploration of extreme depths, Comet Wind decided to eliminate this lake from our site plan considerations as selecting it would introduce uncertainties and risks that would adversely impact project feasibility and cost-effectiveness. Following our final site selection of Lake Michigan, we determined that the sediment composition of Lake Michigan consists of clay, hard substrate, sand, and silt [9].

Lake Activities

Tourism plays a vital role in the human activities of the Great Lakes region as the lakes' sandy beaches and clear waters promote local businesses. As such, consideration and mitigation of wind turbines' visual impact is necessary, with elimination of this concern requiring a buffer of greater than 40 km [10]. For activities such as boating, fishing, and kayaking, avoiding water canals would require a 20 km buffer from shore. Maximum buffer zone values from each state's Department of Natural Resources were used for zoning criteria for site selection across Lake Michigan.

While military zones are technically outside of the Lake Michigan airspace, the easterly neighboring Great Lake, Lake Huron, has restricted airspace located near the Straits of Mackinac. By locating the farm within or near the specialized zone, government operations would be impacted as aircraft performance can be influenced by the presence of wind turbines [11]. This risk can be avoided by developing in the southern region of Lake Michigan. The Federal Aviation Administration would also need to be consulted to evaluate air traffic impacts and to discuss coordination and approval, as well as operational measures [12].

Another consideration is shipping lanes, as commercial regulations require vessels to travel along a designated route, and government jurisdictions prohibit construction in those areas. The port with the highest ship density in Lake Michigan is the Indiana-Burns Harbor, with annual traffic of 450 barges and 100 ships [13]. This implies that leasing within or slightly around these zones are not viable as the wind farm would be obstructive and at risk of damage due to vessel strikes. Therefore, areas in relatively close proximity to the ports and within commercial boating lanes will be minimized in our site selection.

While species concerns are outlined in **Section 2.3**, there are 35 Marine Protected Areas (MPAs) across Lake Superior and Lake Michigan consisting of national parks, preserves, and marine sanctuaries [14]. The project site and cabling plans require an MPA proposal to determine the mandated buffer distance, but Comet Wind used a generous criterion of 5 km for site selection [15].

The Treaty of Washington (1836) dictates the co-management of fisheries within Lake Michigan between native tribes and the state of Michigan. Current regulations within the lake create a grid system for fisheries to report marine data regularly to the Great Lakes Fishery Commission [16] [17]. These regulations impose an obstacle towards offshore wind farm construction as environmental impacts would impede state and local marine efforts. Therefore, Comet Wind considers the coast along Michigan state to have low favorability for site selection.

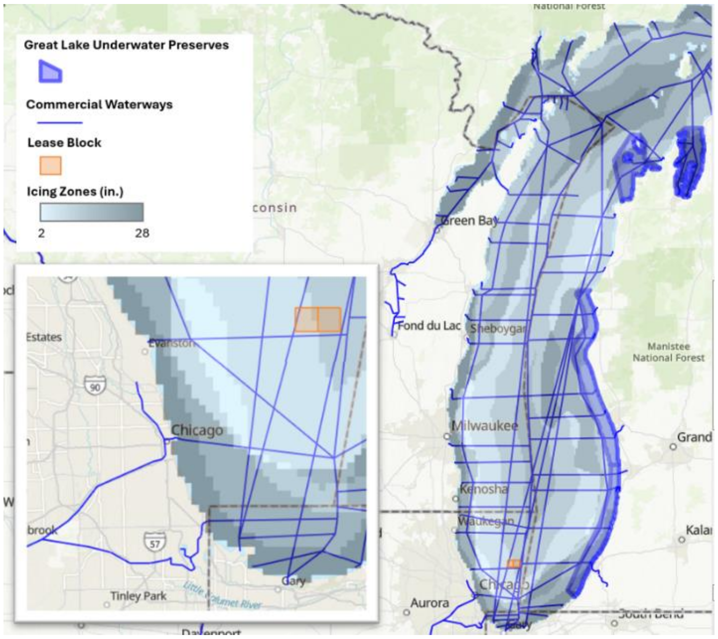

Figure B. Icing and Waterways in Lake Michigan

With the following siting criteria of avoiding shipping lanes, sensitive habitats and reefs, military zoning, recreational zones, fishing zones, protected areas, and minimizing visual impact, Comet Wind selected a project site consisting of 2 lease blocks 21.3 miles from the coast of Chicago. As seen in **Figure B and Figure C**, the project area spans 46.6 square kilometers and is located in the Illinois jurisdiction of Lake Michigan. This region features depths of 60 to 65 meters with an average wind speed of 9.09 m/s with primarily southern winds. The average ice coverage is 4% with a thickness of less than 2 inches. Throughout the project area, the sediment is composed of clay. The project site's distance from land is approximately 30 mi. or 48.8 km.

2.3 Environmental Impacts and Mitigation

Species Concern

According to the U.S. Fish & Wildlife Service, many endangered species of plants and animals are found in the Great Lakes region [18]. Migratory birds and bats pose significant concerns within the wind energy sector. Avian and bat turbine interactions, such as collisions and migratory issues due to the presence of our wind farm can be mitigated by introducing countermeasures. Implementing automated shutdown strategies using radar and remote sensing company DeTect's MERLIN avian tracking systems, integrating sound and light deterrents to prevent roosting, and intensive pre-construction monitoring to improve the effectiveness of active mitigation measures are all possible, although final selection of a method would require additional research and testing [19][20]. This can be conducted with local conservationists and government trackers that focus on the endangered bird and bat species in the region such as the whooping crane and the Indiana bat. These curtailment practices demonstrate Comet Winds' commitment to environmental stewardship and wildlife conservation, while also promoting the sustainable aspects of the wind energy projects within the Great Lakes.

The installation and normal operations of the turbines can introduce vibrations and noise that can disturb or permanently harm sensitive fish and benthic creatures within a 10 km radius [21]. Endangered benthic creatures such as the northern riffeshell and snuffbox mussel are further impacted by substrate disturbance by our transmission infrastructure and invasive species such as the zebra mussel or sea lamprey which may be brought to the area by servicing and construction vessels [22]. Any small vessels utilized for either transportation of parts or conducting maintenance will be chemically sanitized under the assumption that the aforementioned vessels have been placed in foreign bodies of water. Sanitization will reduce risk of Comet Wind's wind farm introducing harmful microorganisms into the region during our construction and operations [23].

Freshwater Drinking

Typically, wind turbines utilize polyalphaolefin (PAO) lubricant for the gearbox, main bearing, yaw and pitch, and hydraulic systems. This hydraulic fluid, if ingested by humans, could result in a delayed onset of pain and tissue damage, as well as internal bleeding in the lungs and intestine [24]. High moisture exposure can increase the oil's degradation and require intensive maintenance, creating more opportunities for hazard exposure to the water [25]. Considering roughly 27.24% of the Lake Michigan Basin population gets their drinking water from Lake Michigan [26] [27] [28] [29], Comet Wind farm will be utilizing Chesterton's biodegradable machine lubricant that is safe for human consumption [30]. Comet Wind will abide by the Great Lakes Water Quality Agreement (GLWQA) by the United States Environmental Protection Agency to ensure that this material is compliant [31]. Another potential component that might pose a risk to the freshwater integrity would be the mooring lines, as they deteriorate and introduce microplastics. This design consideration will be elaborated on in the next section.

3.0 Design & Engineering for Offshore-Wind-based Hybrid Power Plant

The design and engineering section will outline the wind farm's project details related to O&M (operations and maintenance), electrical grid interconnection and integration, and finally, hybridization for offshore wind.

3.1 Turbine and Floating Foundation Technology with Risk Considerations

Freshwater Icing and Buoyancy

Icing is considered one of the main contributors to turbine failure and performance degradation in offshore wind. Combatting these challenges at our freshwater site will be especially important since freshwater ice is stronger than saltwater ice [32]. To avoid damage to the turbine as well as minimize the likelihood of flipping due to the weight of the ice, Comet Wind plan to add several sheet metal components at a 45-degree angle to our mast at the ice level. This "ice belting" technique has been shown in European offshore systems to effectively break ice floes before it can damage the turbine [33] [34] [35]. In the case that ice accumulates or creates an uneven load on the floating foundation, unanticipated values of stress in the mooring cables would increase the risk of capsizing. To minimize this, Comet Wind conducted offshore wave dynamic analysis with the consideration of freshwater icing and buoyancy to determine stability conditions using the following equations:

Table 1. Equations for Turbine Foundation [36][37]

Desired Value:	Formula:	Assumptions:
Critical Load of Ice (F_Z)	$F_Z = \frac{\theta}{180}\frac{2}{3}\sigma_f t^2 \left[1.05 + 2\left(\frac{r}{l_c}\right) + 0.5\left(\frac{r}{l_c}\right)^3\right]$	$\sigma_f = 0.807\ MPa$
Freshwater Buoyant Force (F_B)	$F_B = \rho_f (V_{disp}) g$ $W_t = m_t g$ $W_f = \rho_c V g$	$\rho_c = 2400\ \frac{kg}{m^3}$ $\rho_f = 1025\ \frac{kg}{m^3}$

Referencing **Table 1,** the amount of fatigue stress on the foundation during the project's 20-year lifespan was approximated using extreme assumptions such as ice thickness being 28 inches and wave height being 7 meters, based on our resource analysis in **Section 2.1**. Using the data collected for wave heights in potential site areas and the expected loading stress factor based on icing, Comet Wind was able to downselect floating foundation assembly combinations – foundation, mooring system, and mooring line type – as seen in the following section.

Design Considerations and Calculations

Regardless of the technology available for floating offshore wind, the available resources within the Great Lakes region determine the overall feasibility for project development and planning. In this case, the wind energy infrastructure was analyzed based on current onshore projects, means of transport, and manufacturing facilities. Turbine considerations were determined using NREL's Great Lakes Wind Energy Challenges and Opportunities Assessment along with other considerations that will be discussed in later sections [38]. Referencing **Table 1**, Comet Wind used Solute's Furow to perform multiple design iterations that focused on maximizing the capacity factor of the wind farm by changing the hub height, turbine orientation, and turbine placement with the following wind turbines. The deciding factor for the final design was the financial analysis of each possibility which is outlined in **Section 4.1**.

Table 1. Wind Turbine Considerations [39]

Turbine:	Rated Power (MW):	Rotor Diameter (m):	Specific Power (W/m^2):
Vestas V236 15 MW	15.0	236	342.9
SG-14-222 DD	14.0	222	358.9
GE Haliade-X 12 MW	12.0	220	315.7

In addition to finding the optimal configuration of turbines, Comet Wind evaluated the floating offshore foundation components outlined in **Table 2**. The distance from the interconnection point, costs, and environmental conditions were considered to be the deciding factors for the foundation assembly. For foundation selection, wave dynamics due to icing and vessel proximity should be minimized. Due to this, the spar and semi-submersible foundations are not suitable for this environment as they are considered susceptible to movement. Additionally, the bathymetric requirements for each eliminated foundation created unfavorable conditions with icing. This resulted in the final selection of tension-leg platform (TLP) foundations, giving Comet Wind the opportunity to capitalize on the abundant wind resource due to the high stability of tension-leg platforms in deeper waters.

Table 2. Foundation Assembly [38] [40] [41] [42] [43] [44]

Foundation:	Anchor Types:		Mooring Line/Tendon:
Tension-Leg	Suction Pile	Drag Anchor	Chain
Spar	Driven Pile	Dead Weight	Synthetic
Semi-Submersible	Torpedo Pile	Vertical Load Anchor	Wire Rope

Available anchor types for TLPs were evaluated based on their pricing and installation method. Using Comet Wind's icing and wave calculations, the following mooring system would need to handle an additional loading force of 4.35% of the turbine weight. The percentile was evaluated based on the final turbine selection. Modifications to anchor types like torpedo pile, drag anchor, dead weight, and vertical load anchor would incur higher manufacturing costs to meet that standard. Additionally, installation methods for the previously listed options along with driven piles, create considerably high environmental damage to benthic habitats. The final selection for anchor type was suction pile as it presented the highest environmental considerations while balancing financial and performance factors for the Great Lakes region. The mooring lines for a TLP system were based on the downselect of freshwater compatibility and ease of transport. Synthethic materials would introduce microplastics overtime, while chain and wire rope would be composed of steel, iron, or bronze. Comparing the remaining options, chain is the larger, heavier, and costly alternative, therefore, leaving the final mooring line selection to be wire rope [44].

3.2 Detailed Layout

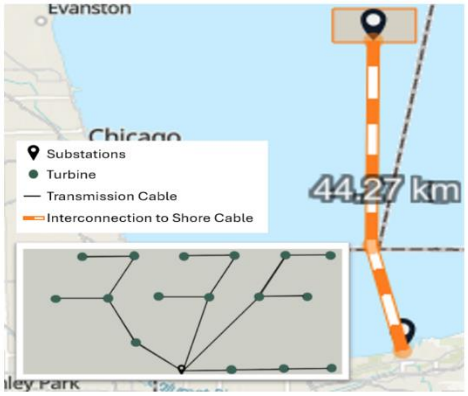

Figure C. Turbine Configuration and Interconnection [46]

In **Figure C**, the expanded version of the wind farm's layout is shown along with the cabling path between turbines and offshore substation to the onshore point-of-interconnection (POI). The final design shows 16 x 15 MW Vestas V236 connected in a staggered configuration with a hub height of 150 meters. Optimal wind turbine placements and orientation were determined based on fetch, atmospheric stability conditions, and wake effects using Furow. The minimum spacing between each turbine is 3 rotor diameters from nacelle to nacelle [45], resulting in a 6.27% wake effect. Parallel transmission lines were determined based on similar icing and wave height regions. By these groupings, similar maintenance schedules can be followed within the following sections of the wind farm without shutting operations fully. Orientation of wind turbines are roughly south-facing with ranging 5–7-degree adjustments.

Installation of wind anemometers atop the wind turbines will ensure accurate positioning of the wind turbine. The remote monitoring system can continuously collect observational data on turbine performance, wind conditions, and energy production. This data would allow Comet Wind to adjust the yaw control systems for each turbine to maximize energy capture over the project's lifespan [47].

Transmission Integration

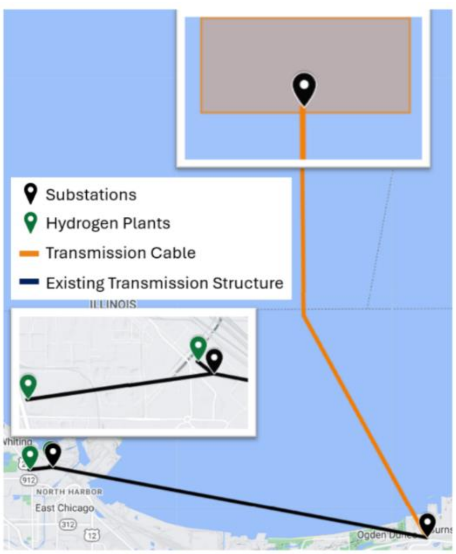

Figure D. Interconnection to Hydrogen Facilities [46]

As seen in **Figure C and D**, the point of interconnection is 48.8km from the wind farm, with HVDC cables traveling 44.27 km from the offshore substation to land and onshore HVAC cables travelling 4.53 km to the NIPSCO substation in Burns Harbor. While the distance of the offshore site is within the "break-even distance" of 50 kilometers for underwater HVDC cables, in order to minimize transmission losses an offshore substation will be created [48]. The offshore substation is optimally positioned to minimize the length of array cabling and the distance from the shore. With the turbines having a nominal voltage of 66 kV, the onshore substation transformer would be utilized to convert the voltage back to a three-phase 138 kV alternating current, which can then be connected to the main grid at Port Indiana-Burns Harbor. This would allow the newly generated power to be sent into NIPSCO Indiana-Illinois power grid, thereby becoming available for consumption for our hybrid technology facility in addition to other manufacturing industries such as steel.

As seen in **Figure D**, existing onshore transmission structure can be found to connect two substations within the NIPSCO grid to the hydrogen facilities available near Whiting, Linde and BP fuel refineries.

Hybridization for Offshore-Wind-Based Power Plant

For our end-use technology, Comet Wind aims to integrate our wind farm with green hydrogen production in Indiana, as part of the MachH2 initiative. Several other options were considered before deciding to utilize wind energy for regional green hydrogen production. Based on the MISO interconnection queue, solar and battery storage projects have a higher development rate and approval rate than onshore wind projects, but the disadvantage is a noticeable lack of unique financial incentives for these technologies. Amidst technology-blind supply chain issues that are creating on average a 2-year delay in project start time, this is especially concerning [49]. Meanwhile, regional green hydrogen will be well-funded for the next 12 years, due to the MachH2 initiative. The MachH2 initiative is a collective of three states in the Great Lakes region who have collectively received $7 billion in federal funding to develop seven regional hydrogen production hubs [50]. Given that our wind project is already highly capital-intensive, Comet Wind decided to move forward with green hydrogen production as our use case.

Originally, Comet Wind considered creating a green hydrogen production facility, with the intention of powering our facility with Horizon Wind Farm's wind energy. Upon further consideration of the costs of creating a new hydrogen production facility, as well as the associated difficulties of permitting such a project, Comet Wind opted to partner with existing hydrogen production facilities at Linde and BP. The additional capital cost of creating a new electrolyzer for green hydrogen production is $2,200/kW, which is a significant portion of our existing capital expenditures [51]. Beyond this amount, there are additional infrastructure cost components to go along with the electrolyzer and operational expenditures that raise concerns about the total cost of a new hydrogen production. However, costs aside, perhaps the biggest risk for pursuing a hybridization plan where Comet Wind is in charge of developing both facilities is a risk of misalignment between the construction timelines of said facilities. This misalignment would necessitate the purchase of storage infrastructure or the provision of energy to the grid, creating substantial additional balance-of-system costs, considering these projects' sizes of 240 MW each, minimum. Given that the DOE's focus on hydrogen is still extremely new, there is a great deal of uncertainty surrounding new hydrogen facility permitting timelines [52]. Therefore, it is in Comet Wind's best financial interests to partner with existing hydrogen production facilities, who have already navigated the permitting process.

Figure E. BP PLC Refinery (left) and Linde Hydrogen Storage (right) [59][60]

Our wind farm will provide power to the Linde and BP fuel refineries in Whiting for the electrolysis process. Comet Wind will opt to power proton exchange membrane (PEM) electrolysis as opposed to alkaline electrolysis because PEM is more robust in the face of intermittency challenges with wind and solar energy inputs. With our farm size of 240 MW, Comet Wind will be able to produce roughly 7.5 million kilograms of hydrogen annually, utilizing the energy density of green hydrogen at 33.3 kWh/kg, a capacity factor of 44.59% for our farm, and an efficiency rate of 70% for the electrolyzer [53]. This is enough to give a full tank to nearly 1 million cars running on hydrogen fuel cells of typical capacity 5 kg-8 kg hydrogen [54]. Hydrogen has a plethora of commercial and industrial applications in the aviation, transportation, and most importantly, manufacturing in the case of the Great Lakes region. Considering the hydrogen market is expected to grow annually at a rate of 9.2% yearly, and recognizing that producers are keen on moving away from fossil fuels as sources, our wind farm will be a valuable asset in the development of green hydrogen [55]. Increasing production with partnerships such as ours will help green hydrogen technology reach economies of scale and reduce the cost of a fuel cell to be competitive with existing energy sources.

Other industries, such as the steel industry, will be part of the MachH2 ecosystem as well. One of the steel industry's biggest facilities, the Cleveland Cliffs facility, is building a direct pipeline to a hydrogen refinement facility in the Whiting area, for use of hydrogen in reheating furnaces in their steel mills [56]. These companies have received substantial federal funding assistance towards the goal of finding decarbonization pathways for traditional processes, meaning they are incentivized to invest in wind projects [57]. Moreover, analysts anticipate that 40% of the initial MachH2 investments will go towards depolluting marginalized communities [58].

Project Boundary and Leasing - Fatal Flaws

Comet Wind evaluates project boundary and leasing to be a fatal flaw as a multitude of other offshore wind farm proposals such as the Icebreaker, have stagnated due to opposition from the Great Lakes community

[61]. Lake Michigan does not have an established regulation and permitting process for lakebed leasing. While wind development has always been in interest in the Great Lakes region, the lack of guidelines in their public and economic policy for offshore wind complicates the process for permitting applications. Currently, offshore wind development in Illinois and Indiana dictates that the following agencies in **Table 3** evaluate each project development proposal. In order to have a feasible permitting application, Comet Wind will be complying with the Illinois Department of Natural Resources list of recommended criteria for lakebed leasing [62]. In terms of Indiana jurisdictions, Comet Wind will cooperate with local county ordinances as these are the primary sources of authority on wind energy siting in the state [63].

Table 3. Permitting Authorities [64]

Federal and State Agencies:		
Illinois Department of Natural Resources	The US Fish and Wildlife Service	United States Coast Guard
Illinois Environmental Protection Agency	Federal Aviation Administration	Department of Energy Office of Indian Energy
Illinois Commerce Commission	National Oceanic and Atmospheric Administration	Porter County Unified Development Ordinance
The United States Environmental Protection Agency	U.S Army Corps of Engineers	Indiana Office of Energy Development

3.3 Infrastructure

Port infrastructure plays a crucial role in the installation and assembly, transportation, O&M operations, and economic dynamics of the wind project. This section highlights our considerations and final selection for port operations and logistics.

Preliminary Assessment of Infrastructure and Technology Options

According to Comet Wind's siting assessment and NREL's Great Lakes Wind Energy Challenges and Opportunities Assessment, the required vessels needed for surveying, installation, cable laying, and O&M are either optimized for open-ocean waters, not locally present, or incapable of entering the region. As such, available ports in the Lakes are not equipped to support large-scale wind development projects [65]. Innovative solutions involving port infrastructure analysis, vessels utilization, and mitigations will be outlined in the following sections.

Access to Ports

Identified port needs for floating offshore wind are heavy-duty wharves, access to means for transport and moving logistics, lay-down areas, and wide berths [66]. Based on this search criterion, Burns Harbor presents an opportunistic wind energy hub for offshore wind projects. According to the U.S. Army Corps of Engineers, this harbor features docking arms with a depth of 27 feet and is classified as a deep draft commercial harbor. Major stakeholders and manufacturing tenants within the port are Cleveland-Cliffs and 13 other steel production facilities [67]. The availability of high-quality steels makes for effective maintenance and repair sourcing for the turbine towers, nacelles, foundation, and mooring system. Burns Harbor's infrastructure contains rail connections to Class I railroads that branch to the intra-port rail network within the Ports of Indiana, allowing an active means of transport for turbine components and foundations.

Shown in **Figure F**, there is a 34-acre plot of land at Burns Harbor that would function as a site for storage, a neighboring steel production facility, and the point of interconnection. Given the growing interest in developing the Great Lakes from state governments, the current infrastructure of Burns Harbor will continue to become more conducive to offshore wind operations by 2029.

Figure F. Burns Harbor – Comet Wind Operations and Transmission

Survey, Installation, and Operations and Maintenance Vessels

To verify the bathymetric data of the site, we will use the Michigan Department of Natural Resources' surveying vessel, the Steelhead. In comparison to other available S/V (surveying vessels) in the region, Steelhead is capable of hydroacoustic monitoring that can accurately detect the number and distribution of foraging fish populations within a 0.5-mile radius [68]. This selection would eliminate the need to source another vessel for aquatic population assessments.

The process of installing floating foundations entails either assembly at sea using a wind turbine installation vessel or assembly at harbor before the foundations are towed out to their site. Based on the size constraints of all waterways leading to Lake Michigan and the large expense associated with the use of turbine assembly vessels, we plan to use the tow-out method [69]. The tension-leg foundation can be fully integrated with the turbine without the need of any special vessels. Using the calculations from the previous sections, the bollard pull required to move the assembly would be 350 tons. In order to minimize the towing duration, utilizing multiple towing vessels would allow for an increased towing speed and windows of operability during weather-restricted operations [70]. The tug boat serving will be provided by The Great Lakes Shipyard, as they operate the following vessels: 100 Z-Drive, 100 LNG, 111 Multi-Purpose, and 150 Linehaul Tugs. This fleet has the highest summation of bollard pull (359 tons), wave-height-to-hull-length ratio for performance in rough waters, and operational hub distance compared to available other tug vessels in Lake Michigan [71][72]. The anchor handling tug supply vessel (AHTS), which carry the anchors and mooring line, that will be operating in parallel with the tug boat fleet would be Great Lakes Dredge & Dock anchor barges. Horizon Wind Farm will be using the cable-laying and burying ship, CS IT Intrepid, as it is the only vessel of its kind with historical activity in the Great Lakes [73]. Operational and regular maintenance vessels will also be serviced by the Great Lakes Shipyard. Servicing boats include an ABS ice class tug boat, the 74 Multi-Purpose tug, and the 94 Z-Drive Tug, known for salvaging operations and oil response and recovery [74].

4.0 Financial Analysis for Great Lakes Offshore Wind Hybrid System

This section will outline Horizon Wind Farm's market potential, by explaining the modelling scheme, key assumptions, costs, and financing plan and results associated with the offshore wind farm.

4.1 Preliminary Financial Outlook

In the assigned region, there are a limited number of wind projects and no existing offshore wind projects. Therefore, it is challenging to find comparable developments to demonstrate the financial potential of building offshore wind in the region. However, there are several existing and potential drivers that make building offshore wind attractive from a financial perspective. In particular, MachH2 is a significant funding opportunity for green energy in the region, due to green hydrogen production requiring large amounts of energy generated from renewables. Further, our project will be able to capitalize on increasing demand for wind energy in Porter County, where Comet Wind has chosen to develop the project [75]. Lastly, national policy within the United States consistently supports increasing renewable energy generation, meaning renewable projects are likely to receive existing benefits such as the Investment or Production Tax Credits.

Based on the decision to build in the given region, Comet Wind analyzed several potential wind farm sizes composed of turbines of various sizes to determine which farm design would be the most financially viable. Based on the results of this analysis shown in **Table 4**, it was determined that a 240 MW wind farm made of 16 total 15 MW turbines would be the best option. The smaller project (192 MW) has higher LCOE and lower IRR compared to either of the larger projects, and while the larger project has similar metrics as our selected farm, it was determined that the larger project does not have enough benefit to outweigh the risk posed by significantly increased capital costs in an unproven region. The LCOE is increased as we scale from 240 MW to 300 MW, and the IRR decreases as well. Further, the 240 MW farm size is also optimal for building times as it falls exactly within the typical size range for standalone projects that historically tend to move quickly through MISO's interconnection queue (200-300 MW) [76]. Therefore, Comet Wind selected 240 MW as the farm size.

Table 4. Wind Farm Financial Metrics

	Farm Size		
	192 MW (12 MWx16)	**240 MW (15 MWx16)**	**300 MW (15 MWx20)**
NPV ($)	$63,690,064	$80,960,648	$100,753,848
Project IRR (%)	14.76%	14.85%	14.83%
LCOE (real)	88.0 $/MWh	87.8 $/MWh	87.9 $/MWh
AEP (kWh)	683,466,496 kWh	855,651,904 kWh	1,068,970,624 kWh

Project Timeline

The main steps for the project timeline are planning and analysis (2 years), lease procurement (1 year), site assessment (2 years), permitting (4 years), commissioning (2 years), construction (3 years), servicing (20 years), and decommissioning with potential repowering (2 years) [77]. All of the processes are one-time endeavors with the exception of servicing, which will last for the entirety of the project's life. It will be both on a scheduled and unscheduled basis, with one intensive maintenance period occurring once every year. The lack of uniformity in regulatory processes in regards to offshore wind in the United States has contributed to long completion time frames for the preliminary processes in starting new offshore wind projects [78] [79] [80].

Modelling Methodology

Comet Wind utilized NREL's System Advisory Model (SAM) software tool to predict the financial outlook of the planned offshore wind farm. To begin, the Single Owner ownership model was selected to generate the desired wind project. For input data into the project model, beginning with the wind resource data, Comet Wind used hourly wind resource data from NREL's WIND Toolkit at hub heights of 140m and 160m, at the precise site location (42 degrees latitude, -87 degrees longitude). As shown in **Figure C**, the layout selected for the chosen farm size of 240 MW was 4 turbines in 4 rows spaced 8 rotor diameters apart, offset by 4 rotor diameters. The specific 15 MW turbine used in our simulations was the IEA 15 MW reference turbine available within SAM.

In order to determine financial outlook for the project as a whole, we used various inputs in conjunction with predictions for future trends of financial parameters, which are further discussed within the **Key Assumptions** section below. Using these values and iterations of several possible combinations of each parameter, the best financial approach for the offshore wind farm was produced. Further discussion of financing and outputs are included in the **Financing Plan** and **Cash Flow Results** sections.

4.2 Key Assumptions

Due to the difficulties in establishing causal relationships between different site features present in wind farms and expenditures, it is difficult to establish clear financial parameters for a cost breakdown. As such, the numbers used in this report are largely based upon averages presented in NREL's Offshore Wind Market Report: 2023 Edition and NREL's 2022 Cost of Wind Energy Review, with additional considerations being made where applicable to account for unique site characteristics and trends impacting the wind industry after publication of the aforementioned documents [81] [82] [83] [84] [85] [86] [87] [89] [90] [91]. In addition to the publicly available reports, subject matter experts including faculty advisors and industry contacts were consulted for verification of financial metrics. Beyond industry-specific values, other financial variables were determined based on long-run trends or generally accepted project metrics. In **Table 5**, values for several financial factors used as inputs are included.

Market Conditions

Over the last decade, industrial energy prices in the state of Indiana have increased by 32.7% resulting in a current average price of industrial electricity in Porter County, the location of our interconnection point, of 0.06 $/kWh [92]. To compete with current prices, Comet Wind would have to set an initial power purchase agreement (PPA) price that would fail to cover our capital expenditures. This informed the decision to move away from the original plan of selling electricity directly to steel and iron manufacturers, and Comet Wind also discovered significant legal boundaries to Indiana manufacturing companies entering third party power purchase agreements in the state. Therefore, Comet Wind opted to increase project feasibility by providing energy to MachH2 and supporting activities such as Linde and BP's green hydrogen production facilities [93]. With Indiana's current energy profile being only 12% renewables (as of 2022), the projected growth of renewable energy allows higher escalation rates and initial pricing for power to guarantee supply of needed renewable generated energy [94]. In summary, the expected growth in regional demand for renewable energy sources allows for Comet Wind to set more aggressive pricing and capitalize on the current lack of renewable energy. Market conditions support the rapid growth of renewables, and Comet Wind plans to take advantage of this opportunity before the market becomes saturated.

Incentives

As previously touched upon, the significant interest in renewable energy at the national level in the United States results in significant tax credits being supplied to new renewable developments through the Inflation Reduction Act (IRA) [95]. In particular, the Investment Tax Credit (ITC) provides a tax credit equivalent to 30% of capital expenditure costs. Due to the capitally intensive nature of offshore wind projects, this results in superior financial outlook when compared to the other option provided by the IRA, the Production Tax Credit. To further offset costs, Comet Wind will also take advantage of the Domestic Content Bonus (DCB) and the Energy Community Bonus (ECB). Comet Wind's farm qualifies for the DCB because 40% of the steel that the farm shall use for manufacturing will come from domestic producer Cleveland Cliffs, located in Burns Harbor. Horizon Wind Farm also qualifies for the ECB since the unemployment rate in its governing metropolitan statistical area, Chicago-Naperville-Elgin, exceeds the national average [96] [97]. Finally, Comet Wind used a 5-year MACRS (Modified Accelerated Cost Recovery System) depreciation schedule to offset large initial capital costs in a shorter time frame than traditional depreciation schedules.

Table 5. Wind Farm Parameters

Parameter	Value	Units
PPA Price in Year 1	0.09	$/kWh
PPA Escalation Rate	4.5	%
Real Discount Rate	7.5	%
Inflation Rate	3	%
Interest Rate on Term Debt	4	%
AC Degradation	0.1	%
Net Salvage Value	5	%
Sales Tax	7	%
Federal Income Tax	21	%
State Income Tax	3.23	%
ITC (DCB) (ECB) Relative to Initial Capital Costs	30 (10) (10)	%
MACRS Depreciation	5	years

4.3 Capital and Operational Expenditures

Initial Capital Expenditures

The DOE's 2023 Offshore Wind Market Report estimates capital expenditures (CapEx) for floating offshore wind projects in the US to fall between 3,000 and 5,500 $/kW [98] [99]. Given that our project is in a challenging region for construction, we chose to set our pricing to the upper end of this range, at roughly 4,900 $/kW. Using this amount for capital costs, turbine costs are approximately 1,350 $/kW, balance of system (BOS) costs are approximately 2,700 $/kW, and soft costs are approximately 850 $/kW. A full breakdown can be seen in **Table 6** [100]. Using these figures, our total capital cost is approximately $1,200,000,000.

Lease Area Pricing

Table 6. Breakdown of Capital Expenditures in $/kW for 15 MW Offshore Wind Turbine at 150m

CapEx	2024 Cost	Units	% of Total CapEx
Turbine Costs	**1,360**	$/kW	28%
BOS Costs	**2,727**	$/kW	55%
Substructure and Foundation	**1,366**	$/kW	28%
Electrical Inftrastructure	**925**	$/kW	19%
Assembly and Installation	**222**	$/kW	4%
Lease Price	**133**	$/kW	3%
Development and Project Management	**78**	$/kW	2%
Soft Costs	**848**	$/kW	17%
Contingency	**432**	$/kW	9%
Construction Finance	**204**	$/kW	4%
Decommissioning	**117**	$/kW	2%
Plant Commissioning	**47**	$/kW	1%
Insurance during Construction	**47**	$/kW	1%
Total CapEx	**4,935**	$/kW	100%

Based upon published lease pricing for offshore wind projects, as well as lease pricing for activities other than wind within Lake Michigan, we were able to establish a price baseline for leasing within the region. This resulted in a lease price assumption of approximately 700,000 $/km^2, which is equivalent to an overall lease price of $33,148,000. To verify these results, NREL's Cost of Wind Energy Report and the Great Lakes Wind Energy Challenges and Opportunities Report suggest lease pricing as between 2% and 4% of our total capital expenditures [101] [102]. This method results in an overall lease price ranging from $25,000,000 to $51,000,000, equivalent to 500,000 to 1,000,000 $/km^2. Thus, a maximum bid price of $1 million per square kilometer is reasonable for the project.

Annual Operating Expenses

Operational expenditures (OpEx) are typically split up into two cost divisions, fixed or scheduled maintenance and variable or unscheduled maintenance. The cost of fixed maintenance for floating offshore wind is around 40 $/kw-yr and variable maintenance can be safely assumed to be slightly above this amount [103]. Comet Wind assumed a total amount 87 $/kW-yr for annual operational expenditures. These estimates were motivated by the 2022 NREL Cost of Wind Energy Report, which identified an average OpEx range of 64-97 $/kW-yr for offshore wind farms with operations start date after 2021 [104] [105]. Comet Wind chose to use values near to the maximum annual costs due to the harsh weather conditions experienced within the project location and the expected increase in preventative and reactive maintenance in response to these conditions.

Table 7. Breakdown of Operational Expenditures in $/kW-yr for 15 MW Offshore Wind Turbine at 150m

OpEx	2024 Cost	Units	% of Total OpEx
Fixed Costs/Scheduled Maintenance	**40**	$/kW-yr	46%
Variable Costs/Unscheduled Maintenance	**47**	$/kW-yr	54%
Total OpEx	**87**	$/kW-yr	100%

4.4 Financing Plan

Due to recent changes in the tax code, tax credits can now be transferred, meaning a single owner can effectively leverage tax credits from the ITC without the need for a partnership with a tax equity investor [106]. Therefore, a single owner model was selected, as it offers the ability to utilize equity financing without the need for a partnership flip, offering consistent annual returns to all parties.

Our project will be financed with traditional debt and equity financing, splitting the cost of financing the project between the project owner/developer and the equity investor(s). To determine a suitable debt-equity ratio, Comet Wind referenced projects in NREL's 2023 Offshore Wind Market Report. While the financing structures of existing offshore wind projects in the United States are quite limited, the splits that are available are fairly close to even, tilted slightly in favor of debt comprising more of the financing costs. Additionally, running simulations in SAM helped Comet Wind observe that NPV and IRR are higher when the debt-equity ratio is as even as possible. Ultimately, Comet Wind settled on the debt-equity ratio of 60-40. Given that there is precedent for the usage of 60-40 debt-equity in European offshore wind projects, it is highly likely that there will be usage of this ratio in future floating offshore wind projects in the United States [107]. Ultimately, the financing structure selected for this project allows for above average returns, proving that the construction and financing of a wind farm is bankable in this region.

4.5 Cash Flow Results

As per **Table 7 and Figure H**, Comet Wind's farm sees a large negative cash flow during Year 1 of operation due to the capital expenditures, and a large positive cash flow during Year 2 with the ITC payment after the project comes online. Years 3 through 6 see relatively high cash flow due MACRS allowing for increased depreciation payments to the project, while in Year 7 cash flow decreases. From Year 8 onward, the cash flow begins to gradually increase as debt payments are held constant, tax benefits no longer apply, and PPA pricing increases revenue. Finally in Year 21, we see another large spike after the initial loan has been fully paid with high revenue compared to costs. Ultimately, Comet Wind reached an NPV of $80,960,048 and an IRR of 14.85% with the Horizon Wind Farm.

Table 7. Cash Flow Results (in Dollars)

Year	0	1	2	5	10	15	20
Total revenue ($)	0	77008672	80393592	91467488	113416344	140632128	233598704
Total operating expenses ($)	0	20880000	21506400	23500624	27243664	31582874	36613208
EBITDA ($)	0	56128672	58887188	67966864	86172680	109049248	196985488
Debt interest payment ($)	0	-29818404	-28817050	-25566190	-19221278	-11501722	-2109702
Cash flow from operating activities ($)	0	26972926	30738276	43086264	67669744	98303840	195676112
Cash flow from financing activities ($)	1242766336	-25033856	-26035210	-29286070	-35630984	-43350536	-52742556
Total after-tax returns ($)	-497306176	376284864	70136424	30325906	16878136	32513908	143020272
After-tax cumulative IRR (%)	NaN	-24.34	-8.86	6.21	10.8	13.74	15.8
After-tax cumulative NPV ($)	-497306176	-157468864	-100261464	-31307220	694103	34717812	80960648
Federal ITC total income ($)	0	335546912	0	0	0	0	0

Figure H. Total Revenues and After-Tax Cash Flows Annually over 20-Year Project Life

4.6 Annual Energy Production

The annual energy production for our farm is 856,129,344 kWh, with an estimated capacity factor of 44.59%. For application to hydrogen-based fuel refinement the AEP is sufficiently high, and the capacity factor of the farm is commensurate with other modern wind farms.

5.0 Discussion of Optimization Process

Comet Wind performed 15 siting location assessments using Solute's Furow with 10,000 iterations for wind turbine size, placement, hub height, and orientation. Similarly, iterative calculations related to freshwater buoyancy and icing were performed with 5-minute resolution spatial data at a minimum period of 20 years using R and MATLAB. Based on these models and GIS information, these sites were identified and ranked based on their suitability. Stakeholder and community engagement were critical considerations as they heavily impacted the siting and permitting process. With this methodology, along with financial planning, Comet Wind decided that the maximum project area was to be 2 standardized lease blocks and the maximum feasible project capacity was 240 MW. Selections regarding turbine size, foundation, and mooring system were those best represented in either literature or currently operating wind farms. In terms of financial parameters, Comet Wind consistently used cost estimates in the upper-middle range of typical costs for given parameters to account for the novelty of the development region and the associated challenges and risks.

6.0 Bid for a Lease

In conclusion, considering site location and conditions, capital and operational expenditures, and PPA revenue stream, Comet Wind are proposing a bid price of $33.1 million for a region of two lease blocks which will include both our 240 MW wind farm and our offshore electrical substation.

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