COLLEGIATE WIND COMPETITION 2024

PROJECT DEVELOPMENT REPORT

HOPKINS STUDENT WIND ENERGY TEAM

Blue Jay Wind

Leads:

William Chavez
Grace Qiu

Members:

Raghav Agrawal
Adit Bajaj
Amelia Chen
Brendan Glennon
Lulu Grubb
Evan Kuo
Christopher Lo
Sophie Patrick
Eduardo Sores
Ian Raley
Enqi Yang

Volunteers:

Rory Jacobson | Department of Energy
Caroline Jo | Rondo
Ian Zheng | Silverpeak

Mentors:

Bill McNamara | EcoEnergy LLC.
Jamie Mears | Ørsted
Kyra Rothwell | Scout Clean Energy
Guy van Syckle | HASI

JOHNS HOPKINS UNIVERSITY

jhuwindenergy@gmail.com

"No confidential information was used from resources outside of HSWET."

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Executive Summary

The Hopkins Student Wind Energy Team, hereafter referred to as "HSWET," has developed a 288 MW floating offshore wind farm named Blue Jay Wind, hereafter referred to as "BJW." BJW is located approximately 56.17 km from the Iroquois Landing Terminal and has a rectangular area of 71.45 km^2, centered at 42.1761889°N, 87.22305298°W. The construction phase is scheduled to commence in 2031, with the Commercial Operation Date (COD) anticipated in 2034, with the project expected to operate for 20 years. The project offers a 13% tax equity Internal Rate of Return (IRR) at flip and a 12% sponsor equity IRR. The siting assessment of wind resources was conducted using Furow, a software developed using Solute, and financial evaluations using the Pivotal180 Tax Equity Model for Renewable Finance.

HSWET will partner with Fulcrum BioEnergy to supply energy to their Centerpoint waste-to-sustainable aviation fuel (SAF) plant located in Gary, Indiana. HSWET will meet Centerpoint's annual energy requirements of 106.65 MWh using both electricity and thermal energy supplied via Rondo heat batteries. The energy will be sold through a fixed-amount Virtual Power Purchase Agreement (VPPA) at a price of $104/MWh in year 1, with an annual escalation rate of 2.5%. Excess capacity will be sold at the prevailing day-ahead Locational Marginal Price (LMP) at the Midcontinent Independent System Operator (MISO) Indiana hub. The BJW will sell approximately 66.04% of its annual MWh output to Centerpoint and 33.96% into the MISO open market.

1.1 Siting Opportunities

Lakes Michigan and Superior have a total surface area of 139,850 km^2, differing in physical parameters due to water volume, depth, and solar irradiance.[1] Great Lakes waters can amass freshwater ice during the winter, which can collide with turbine foundations at approximately three times the force of sea ice.[2] Ice thickness, floe size, and speed also aggregate ice loads, declining turbine performance.[3-6] To minimize ice risks on farm production, HSWET only considered Lake Michigan waters for offshore wind development due to Lake Superior's vulnerability to ice. Great Lakes' February ice concentrations and sea surface temperatures – the month of maximum ice cover – as well as annual ice duration were assessed, serving as a proxy for freshwater ice risks.[4,7] Historically, Lake Michigan waters experience less ice formation than Lake Superior waters.[8] Lake Superior has observed complete ice cover during cold years, with the 1996 winter serving as an example.[9-10]

Site selection addressed momentous offshore wind developments within the surrounding Lake Michigan states. Illinois is advancing legislation, among other processes, that will facilitate offshore wind development. In April 2023, the Illinois General Assembly successfully passed HB2132, a bill setting regulations that offshore wind developers must meet to receive tax credits.[11] The Illinois Senate has also introduced the bill, titled SB0193.[12] HB2132/SB0193 states that "(Illinois) has excellent and available port infrastructure on the South Side of Chicago," indirectly referencing the Illinois International Port District.[12] This port was one of the eleven ports identified by Musial et al. (2023) as developed enough to support offshore wind in Lake Michigan.[13] Musial, in a separate comment, presumes that the state of Illinois would directly receive money from territorial leases, which would incentivize the state to support offshore wind development.[14] According to HB2753 from the Illinois 99th General Assembly, lease bids would be placed under the name of the State of Illinois.[15] Additionally, Illinois has been provided $1.1 billion for clean energy development within the next two years.[16] Michigan, Indiana, and Wisconsin have passed state legislation facilitating or managing onshore wind development, but offshore wind development has experienced sparse progress.[17-20] While Michigan's S.B. 0271 declares a goal of zero carbon emissions by 2040, previous attempts at offshore wind development have been shut down by the state.[21-22] Due to Illinois' reception toward offshore wind, siting only considered Illinois waters for offshore wind development.

At a height of 150m, Illinois wind speeds range from 8.27 to 9.17 m/s.[23] Ice concentration, thickness, and duration are minimized toward the center of Lake Michigan, as indicated by Figure 1. As of 2010, there are seven out of thirteen oil and gas wells still in operation, drilling under Lake Michigan.[24] Significant wave heights can reach up to 8m in southern Lake Michigan.[25] Hypoxia and dead zones are also not present within Illinois waters.[26] Indian reservations within Illinois have not been recognized by the federal government.[27] HSWET could not conclude BJW's impact on Indian communities due to a lack of spatial data detailing reserved areas within Cook County and Lake County, which are found on the coast of Lake Michigan. To prevent any potential conflicts, HSWET will host community outreach events to determine how BJW's development may impact Indian communities.

Monopile foundations reaching depths deeper than 100m are expected to be commercial in Europe by 2026.[28] However, the wind turbine installation vessels required for transport and installation will not be able to fit through the St. Lawrence Seaway's breadth of 23.8m.[29] To circumvent this issue, HSWET will utilize floating technologies, which can be constructed by onshore cranes and transported by smaller vessels.[13,30] Illinois waters deeper than 60m were considered for siting since these depths can facilitate floating technologies.[13]

HSWET avoided siting within reserved and protected areas operated by federal or state governments in Illinois. Figure 2 maps restricted areas along with military zones and other environmental considerations.[31] 33 C.F.R. § 334 regulates four danger zones within Lake Michigan waters. Specifically, 33 C.F.R. § 334.845 restricts the largest area, approximately covering 3,235 km^2 in the center of Lake Michigan. Since HSWET has previously decided to only site within Illinois waters, 33 C.F.R. § 334.845 will not affect BJW's operations.[31] Furthermore, Illinois waters are preferred for siting since restricted areas are predominantly localized near central Lake Michigan. While northern Lake Michigan may be an attractive site due to the lack of restricted areas and greater wind speeds, Figure 1 indicates that greater ice loads may be present within this region.

Coupling Illinois' push for offshore wind and the attractive physical parameters near the southern area of Lake Michigan, BJW will be sited within Illinois waters at 42.16770554°N, 87.21028137°W. The coordinates correspond to the lease area's centroid. Historically, these Illinois waters have dealt with less ice formation and average 9.13 m/s wind speeds at 150m.[23] Furthermore, the site avoids vessel pathways–as indicated by Figure 1–and minimizes fishery impact, which is congested around the coast of

Lake Michigan.[32-33] The proposed site can also employ floating technology while minimizing turbine visibility issues, with the closest turbine located approximately 35.18 km from shore.[34] BJW will not impact two of Lake Michigan's most profitable ferry tourism routes, with the closest ferry pathway found more than 94.52 km from BJW's closest turbine. HSWET considered mitigation of tourism visual impacts paramount since Michigan grossed $15.4 billion from water-related tourism in 2017.[35] Failing to account for Michigan's tourism assets was one of the reasons previous offshore wind farm developments have failed in Lake Michigan.[22, 35-37] Buoys located on the Great Lakes, managed by the Great Lakes Observation Systems under the U.S. Department of Homeland Security, will not be impacted by BJW.[38-40]

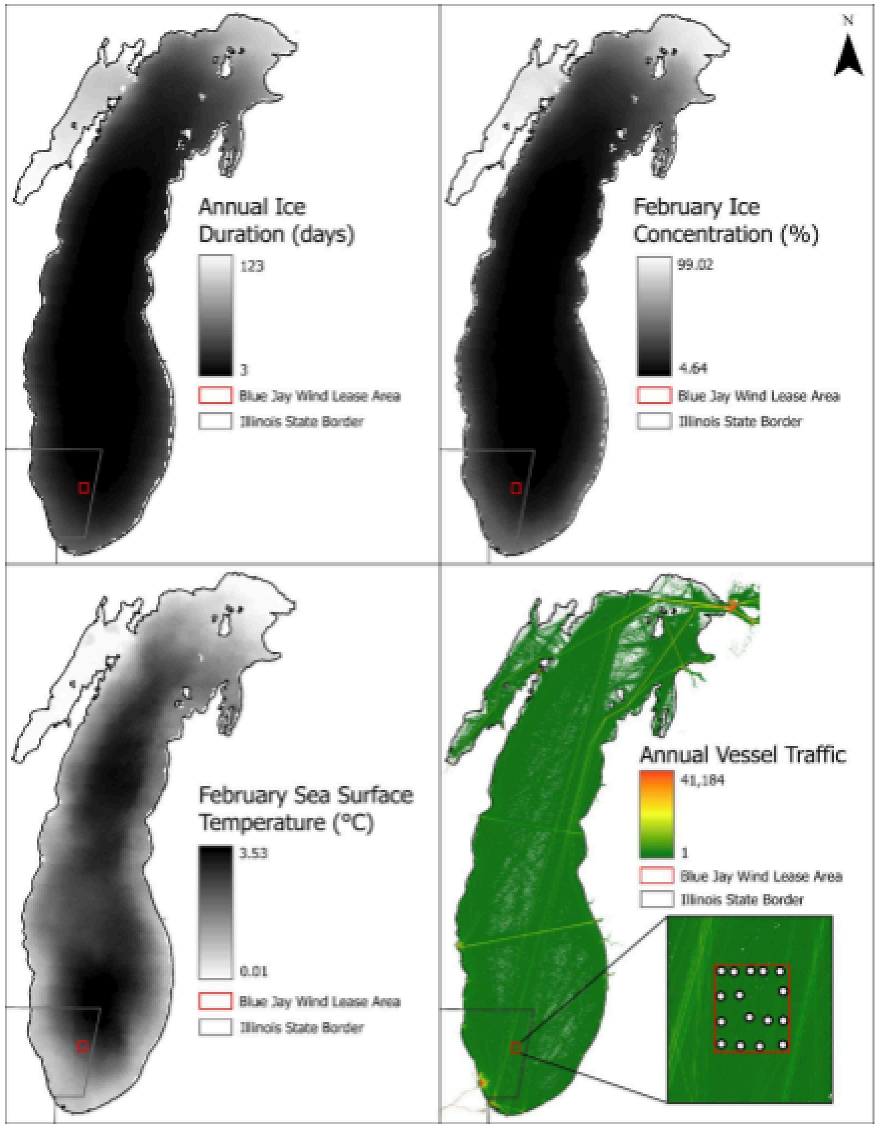

Figure 1. Ice risks and vessel traffic in Lake Michigan.

1.2 Environmental Factors

HSWET examined a variety of environmental repercussions arising from BJW development. Research predominantly centered on aquatic life, birds, and various endangered species.

The Great Lakes Aquatic Habitat Framework provided spatial data on common spawning areas for fish throughout the Great Lakes, which are scattered along the entire coastline and nearby rivers.[8] To account for this, the onshore substation is located on the lakeside to ensure minimal contact with fish species in the nearby Calumet River.

The National Audubon Society provides an interactive Bird Migration Explorer, which HSWET uses to mitigate avian impact, particularly those of endangered species.[41] Since Lake Michigan sits in the territory of four U.S. States–Indiana, Illinois, Michigan, and Wisconsin–endangered species from all of those states, as well as at a national scale, were taken into account.[42-46] Considered species included the Eastern Whip Poor-Will (*Antrostomus vociferus*), Prothonotary Warbler (*Protonotaria citrea*), and the Tundra Swan (*Cygnus columbianus*). HSWET will also implement two bird collision mitigation strategies: painting a turbine blade black and the Merlin-Avian Radar System. Birds have enhanced turbine visibility with the painting of a single turbine, possibly reducing collision deaths by up to 70%.[47] The Merlin-Avian

Radar System will emit sounds deterring birds from the BJW boundaries. With a roughly 97.5% success rate, DeTect Radar Systems, the developers of the Merlin-Avian Radar System, states that utilizing these mitigation strategies can reduce bird deaths by 33-53%.[48]

Furthermore, a general list of endangered species, provided by the U.S. Fish and Wildlife Service (USFWS), as well as Marine Protected Areas, sourced from NOAA, were assessed when siting BJW.[49-50] Cross-listing these species with the Bird Migration Explorer and geospatial data in ArcGIS, site selection intentionally avoided these species and areas, which are predominantly localized around central Lake Michigan, northeast of Milwaukee. A Habitat Conservation Plan can also be created in order to apply for an incidental take permit and ensure the reduced risk of these endangered and threatened species.[51]

In addition, installation can be a loud process that may be sensitive to nearby animals: for example, fish have air-filled bladders that are sensitive to noise. Some efficient mitigation strategies HSWET can employ include bubble curtains and the Hydro-Sound-Damper-System, which significantly reduce these harmful effects.[52]

Cabling and installation also accounted for environmental factors. The Bureau of Ocean Energy Management (BOEM) conducted a study proving that areas with clay/silt are best for BJW installation, and the region selected by HSWET successfully fits this description.[52] Analyzing detailed maps of chemical concentrations and sediment data from the United States Geological Survey, HSWET selected a transmission path that minimizes sediment disturbances, avoiding regions with toxic metals and pollutant chemicals such as polyhalogenated carbazoles and mercury.[53-55] In regions where the bottom of the lake is sandy, the cabling can be temporarily brought to the surface and covered using concrete and frond mattresses to reduce erosion effects.[56] And although there may be concerns about the sediment effect on drinking water, the previous methods and sedimentation process facilities conduct will certainly prevent the consumption of these harmful chemicals.

2.1 Offshore Wind Farm Design

HSWET will utilize 18 MW turbines, which will be sourced from a manufacturer in Europe. Vestas V236-15.0 MW turbines will be used in the instance that 18 MW turbines are not available. Parameters for an 18 MW prototype were extrapolated from IEA's 15 MW reference turbine parameters. The 18 MW turbine will operate at a hub height of 160m, selected to mitigate floating foundation instability. Furthermore, tuned mass dampers and multiple tuned mass dampers will be placed along the turbine nacelles and platforms to stabilize BJW against Lake Michigan's intense significant wave heights.[57-58]

Furow was utilized for a wind resource assessment. Figure 1 shows the wind farm layout, which was constructed after 10,000 iterations within Furow's Optimizer tool. BJW will utilize 16 turbines, which are spaced apart by an average of 6.91 rotor diameters. BJW outputs a net capacity factor of 56.137% and a net annual energy production (AEP) of 1,416,267.9 MWh. The maximum ice throwing distance of an 18 MW turbine with a rotor diameter of 263m is 634.5m, following Seifert et al.'s (2003) simplified calculation for potential ice throw, which is depicted in Equation 1.[59]

$$ice\ throw\ distance(m) = 1.5(rotor\ diameter(m) + hub\ height\ (m))$$

Equation 1. Wind turbine maximum ice throw distance.

BJW lease boundary intersects with the outermost turbine's maximum ice throw distance, providing a rectangular lease area of width 7.802 km and length 9.159 km.

A bathymetric and substrate analysis by Krauland et al. (2023) determined a monopile foundation as being appropriate for BWJ's coordinates.[60-61] HSWET did not follow this recommendation due to the St.

Lawrence seaway vessel constraints, deciding to employ floating technologies instead. Instead, a semisubmersible foundation will be used due to this platform's advantage of being constructed onshore and towed to the offshore site.[62] HSWET recognizes that a spar buoy floating foundation provides greater resistance to ice and stability.[63-64] However, spar buoys require waters with a minimum depth of 100m, which is not available within the proposed BJW lease area.[65] Furthermore, spar buoys require heavy lift installation vessels, which removes the convenience of constructing the floater on shore.[63,66] The 18 MW semisubmersible platform will preferably be sourced from SeaWind, a company currently collaborating with SeaTech Solutions to construct an 18 MW semisubmersible platform in Italy.[67] In case of any logistical issues, HSWET will instead contact Shanghai Electric, which unveiled an 18 MW semisubmersible platform in 2023.[68] It's important to note, however, that the Uyghur Forced Labor Prevention Act may prevent the potential sourcing of offshore wind components from China.[69]

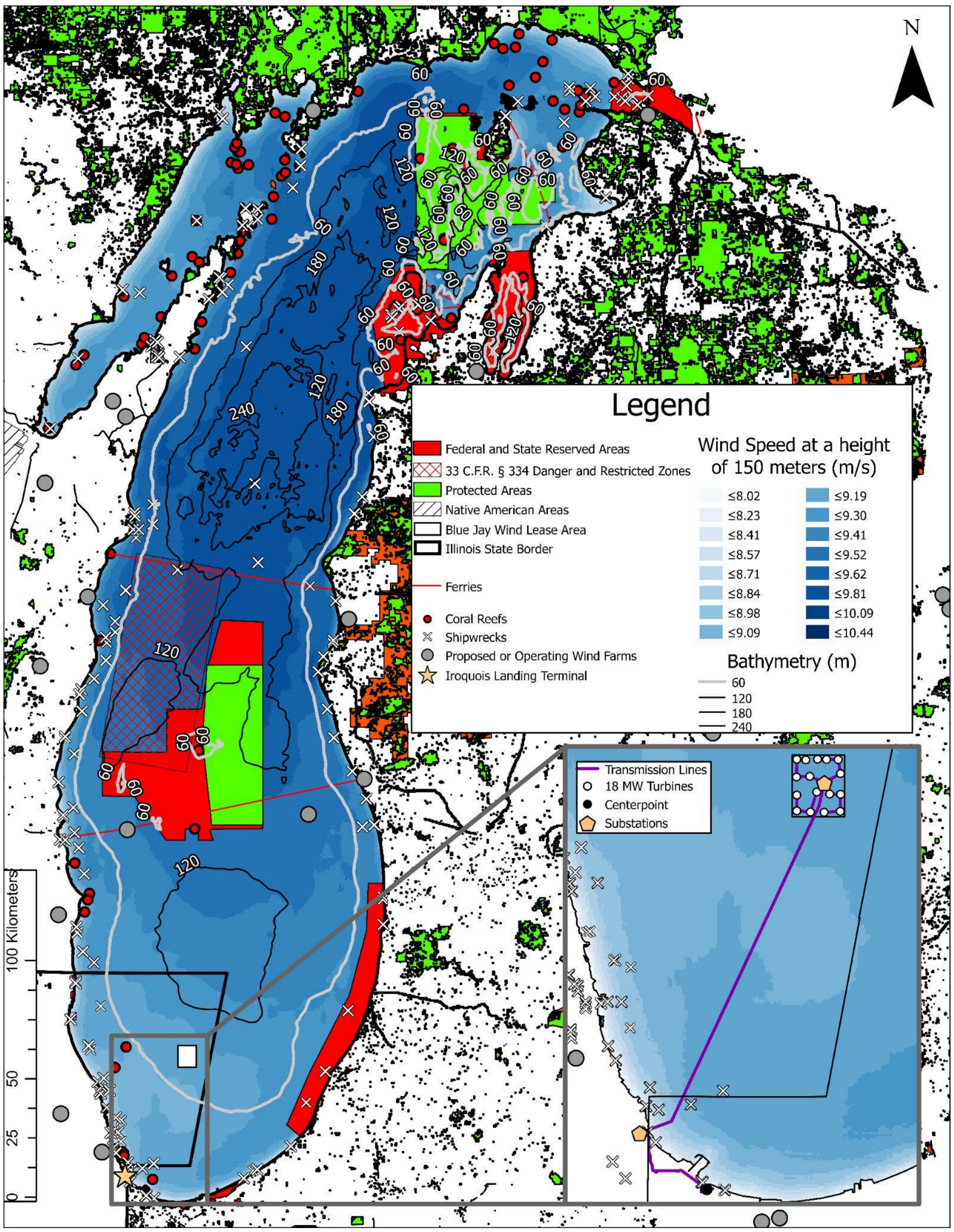

Figure 2. Overview of siting constraints and physical parameters in Lake Michigan.

2.2 Transmissions Plan

BJW will follow a common model for floating offshore wind technology. First, inter-array cables will transmit the power from the offshore wind farm to an offshore substation, near the center of the proposed boundary. The offshore substation will increase the voltage from 66kV to 220kV to facilitate the transfer to the onshore substation and minimize energy losses, an important factor when constructing floating offshore wind farms.[70-72] Next, export cables will bring the energy from the offshore substation to an onshore substation, which will be distributed both to the pre-existing set of transmission lines, as well as to Fulcrum BioEnergy's nearby plant. These cables will predominantly be buried 2m (6ft) underground to reduce EMF effects and erosion (in muddy/clay areas), although the previously mentioned techniques of using concrete mattresses, for example, will be utilized in regions where the floor of the lake is sandy. HSWET proposes that this onshore substation will be built near the S. H. Bell Co. Chicago Terminal in the East Side region of Chicago, IL.[73] To bring the energy on land, horizontal directional drilling will be used to connect the export cables underground to the onshore substation.[74] According to Xiang et al., HVAC cables are an inexpensive alternative to LFAC cables at distances less than 70km; HVAC cables will connect the offshore substation to the onshore substation because the distance between these substations is approximately 60km.[75] Additionally, utilizing GIS data, the export cables from the floating offshore wind farm can connect to pre-existing transmission cables in our onshore region. In this case, there are 138kV cables throughout eastern Chicago and Gary, IN.[75]

2.3 Staging, Construction, and Operations and Maintenance

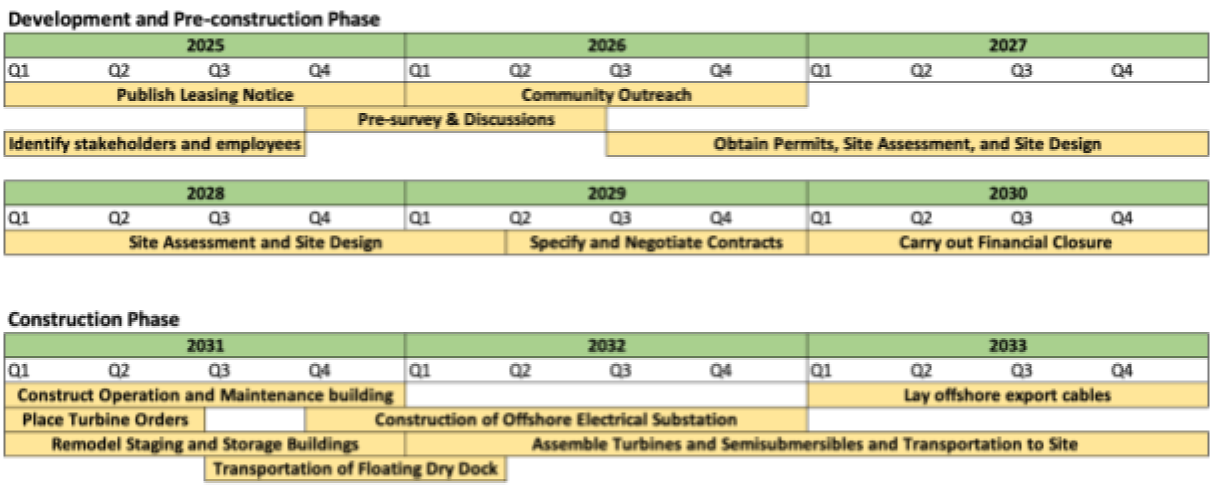

Figure 3. Gantt chart overview of Blue Jay Wind's operations.

HSWET's wind turbine project will begin logistical procedures in 2025, start construction in 2031, and will operate by 2034. The gantt chart above was based on the Maryland Offshore Wind and Moray East Wind Farm.[76-78] The construction site will be the Iroquois Landing at the Illinois International Port district, which offers Marine Highway 90, six Class I railroads, two nearby airports, interstates, state routes, and US highways.[79] The Iroquois Landing Terminal has 251 thousand square feet of storage space and an additional six canopy structures with over 72 thousand square feet of space. The berthing space can accommodate both barges and large ships due to its navigation channel of 27 feet.[79] The development and pre-construction phase will begin in 2025 and end in 2030. During the first two years, leasing notices will be published, stakeholders and employees identified, the environment accessed, and public opinion reviewed. The Illinois Rust Belt to Green Belt Legislation HB2132/SB0193 states that a permit for the offshore wind farm construction and operation will be granted after the site assessment permit is obtained and the site assessment is finished.[80] Therefore midyear of 2026 to the first quarter of 2029 will be dedicated to completion of the site assessment plan. Construction and installation are expected to begin in 2031 and finish by 2033. Land-based construction will happen before the offshore components and the majority of transportation to the floating offshore wind farm will occur outside the summer tourist season. The Illinois International Port District is currently leased to the North American Stevedoring, which provides leases to warehousing and storing facilities, HSWET will spend one year remodeling existing facilities for staging purposes.[81] Wind turbine orders will be placed soon after financial closure to account for manufacturing and shipment. If 18 MW turbines are not available by 2030, the original 15 MW turbines by Vestas will be used. Small floating drydock can be transported to different locations and will be docked at the S. H. Bell Co. Chicago Terminal since it does not interfere with the movement of other ships as does docking in Turning Basin Number 1.[82] Existing staging and storage buildings near the shipping ports will be used, but they will be remodeled to fit a construction, assembly, and installation site for wind turbines. Semi-submersible floaters will be constructed at the dry dock, loaded out, and floated off using a semi-submersible barge, avoiding the need for a wind turbine installation vessel. Floating system technologies can be assembled at the port and then towed to the proposed floating offshore wind farm using smaller tugboats and Anchor Handling Tug Supply vessels.[13] Anchor Handling Tug Supply vessels are a good choice for installing offshore wind turbines due to their high abundance and ability to install anchors and tow.[83] Companies such as Bigge, located in Iowa, can provide specialized crane services for wind turbines.[84]

Turbine components and other necessary parts will be shipped through the St. Lawrence Seaway. The Illinois International Port District is working with the North American Stevedore to expand capabilities to handle a wide range of wind cargos.[85] The maximum length of ships allowed by the St. Lawrence seaway is 225.5 m, which is ample room for the 18 MW turbine blade length of 131.5 m and tower height of 160 m.[86] The Living Stone cable laying vessel will be used and are exempt from the Jones Act.[78] Chartwell - Offshore Wind Support Vessels will service the proposed floating offshore wind farm operations and maintenance since they are Jones Act-compliant Crew Transfer Vessels, available for charter, and can support up to twenty-four personnel.[86] Service operating vessels will not be used because they are currently not Jones Act-compliant and can cause visibility repercussions due to their large size and likelihood of staying offshore for extended periods of time. During decommissioning, the semisubmersible platforms will be towed to shallow water, completely taken out of water inside staging facilities, and dismantled.[76]

Figure 4. Overview of transmission lines to Fulcrum BioEnergy's Centerpoint facility and Blue Jay Wind's facilities.

3.1 Power Offtake Plan

In 2023, Fulcrum BioEnergy, Inc. announced the launch of Centerpoint, a waste-to-SAF plant project located in Gary, Indiana. Construction is expected to begin in 2024, with operations commencing in 2026.[87] Upon completion, the plant will source waste from Chicago landfills, processing the matter into feedstock to begin the waste-to-SAF process.[88] Gasification then follows to produce syngas–a blend of carbon monoxide and hydrogen molecules. Following refinement, the syngas undergoes Fischer-Tropsch chemistry and hydrocracking to produce SAF.[88]

Centerpoint requires electricity and heat for the plant's general operations, but the primary loads stem from gasification (250-400°C), Fischer-Tropsch (150-250°C), and hydrocracking (300-450°C).[89] Currently, Fulcrum BioEnergy's Sierra Biofuels plant uses natural gas to meet these heat loads, and Centerpoint has yet to disclose the plant's energy source.[90] HSWET plans to partner with Centerpoint to provide the plant's total energy demand through electricity and heat.

By sourcing its energy from HSWET, Centerpoint would be eligible for the SAF credit provided by the Department of Treasury and the Internal Revenue Service.[91] This credit requires a minimum 50% reduction in lifecycle greenhouse gas emissions for a base credit of $1.25/gallon of SAF, with an additional cent per percentage point above 50%, up to $0.50.[92] Consequently, SAF produced from Centerpoint would receive credits totaling $1.75/gallon. Based on calculations and insights from industry experts, Centerpoint's energy cost per gallon of SAF using non-renewable sources (electricity from the grid and natural gas) is $1.13/gallon. However, by sourcing energy from HSWET, Centerpoint could potentially reduce their energy cost to $1.08/gallon of SAF. Furthermore, Centerpoint could also charge a premium for this cleaner SAF to airlines with net-zero carbon emission goals.[93] Fulcrum BioEnergy currently has long-term product offtake agreements with oil majors and airlines including BP, Marathon Petroleum, Cathay Pacific, Japan Airlines, and United Airlines.[94] These offtakers have substantial net-zero goals and budgets that could push them to pay a premium price for the net-zero SAF produced by Fulcrum BioEnergy. United Airlines, for example, aims to be net zero by 2050 without relying on traditional carbon offsets.[95]

HSWET proposes to provide Centerpoint's hourly energy demand of 106.65 MW through a fixed-amount 20-year Virtual Power Purchase Agreement (VPPA), priced at $104/MWh for electricity and heat.[96,97] Any extra capacity will be sold to the MISO Indiana hub at wholesale merchant price. The VPPA avoids actual electron delivery, thus making sure that Centerpoint has a consistent electricity supply despite the intermittency of wind energy. Under "book-and-claim" accounting, Centerpoint can still be qualified for SAF credits without directly consuming the electrons produced by HSWET.

HSWET will purchase four Rondo Heat Battery 300s, totaling an hourly heat discharge of 80 MWt, which will meet Centerpoint's heat demand of 72.27 MWt/hr.[95, 97] Centerpoint's hourly energy demand was calculated using numbers from lifecycle greenhouse gas emission analyses at Fulcrum Bioenergy's Sierra Biofuels plant as a proxy. SAF combustion amounted to 70.97 gCO_2eq per MJ of Fischer-Tropsch diesel produced at the Sierra Biofuels plant. The equivalent number of gallons can be converted through a conversion factor relating gCO_2eq to a quantity of SAF product. SAF and JetA fuel emit similar amounts of greenhouse gasses, thereby allowing HSWET to use a conversion factor relating to the amount of CO_2 emitted during JetA combustion: 3.16 $kgCO_2$/1 kg JetA.[98-100] However, this conversion factor does not account for non-CO_2 emissions, which include water vapor, volatile organic compounds, NO_x, SO_x, and soot.[101-103] With limited data detailing the equivalent CO_2 emissions resulting from non-CO_2 emissions, HSWET assumed that the aforementioned conversion factor only accounts for 70% of JetA fuel's total $kgCO_2$ combustion emissions.[102] This assumption, however, does not factor in the differing global warming potentials of these chemicals. Equation 2 details the calculations performed by HSWET to arrive at Centerpoint's estimated MWh demand per gallon of SAF, using common conversion factors.[103,104]

$$\left(\frac{70.97\ gCO_2eq}{1\ MJ\ of\ SAF\ combusted} \cdot \frac{1\ kgCO_2eq}{1{,}000\ gCO_2eq} \cdot \frac{1\ kg\ of\ SAF\ combusted}{(3.16/0.7)\ kgCO_2eq} \cdot \frac{1.25\ L}{1\ kg} \cdot \frac{0.264\ gallons}{1\ L} \cdot \frac{1\ MJ}{0.000278\ MWh} \right)^{-1} = \frac{0.026256762\ MWh}{gallon\ of\ SAF}$$

Equation 2. HSWET's calculations to arrive at Centerpoint's hourly demand.

Centerpoint states that the plant will produce 31,000,000 gallons of SAF. Assuming a daily uptime of 90%, HSWET calculates that Centerpoint has a power demand of 106.65 MW to produce 3,932 gallons of SAF an hour. HSWET consulted SAF industry experts from the Department of Energy (DOE) and McKinsey and estimated that Centerpoint's energy usage is likely split 70/30 between heat and electricity. The low capital costs ($50/kWh) associated with installing a Rondo Heat Battery 300 ensures that an underestimation of heat/electricity split would not have an impact on model outputs. Proceeding with the 70/30 estimate, Centerpoint will require 75.68 MW_t and 30.97 MW_e supply, totaling 106.65 MW. The MW_t demand has accounted for a 95.5% conversion efficiency between electricity and heat.

4.1 Capital Expenditure (CapEx)

To develop the costs of the project, HSWET uses industry-standard pricing as outlined by NREL 2022 Cost of Wind Energy Review and 2023 Annual Technology Baseline and adjusts for recent cost increases by referring to recent earnings reports released by leading turbine and balance of plant component manufacturers.[105-106] HSWET then verifies these prices using NREL's JEDI model.[107]

Capital expenditures (CapEx) are broken down into turbine costs including nacelle, blades, and towers, and balance of plant costs including development, installation, substations, cabling, and the estimated Rondo heat battery installation and purchase costs. Turbine costs were taken conservatively based on NREL's models due to the assumption of 18 MW capacity.

Development cost refers to preconstruction environmental monitoring, surveying, legal counseling, project management, and permitting costs. Other BOP costs include wind farm control and monitoring equipment, operations and maintenance facilities and equipment, shipping, and insurance costs. The Engineering, Procurement, and Construction (EPC) contractor handles the detailed engineering design, manages the acquisition of all required materials and equipment, and supervises the actual construction activities.

In total, construction cost is estimated to be $1,425,024,000.00, or $4,948/kW, and CapEx including contingency and soft costs such as commissioning and financing fees is estimated to be $1,755,360,000, or $6,095/kW. Soft costs are 12.96% of the total capital expenditures.

Cost Type	Subtype	Total Cost ($)	$/kW	% Breakdown
Soft Costs				
	Interest during Construction	$148,489,920.00	$515.59	8.46%
	Financing Fees	$63,648,000.00	$221.00	3.63%
	Decommissioning	$17,752,320.00	$61.64	1.01%
	Commissioning	$15,128,640.00	$52.53	0.86%
	Subtotal	$245,018,880.00	$850.76	13.96%

Construction Cost				
Turbine Cost				
	Nacelle	$285,819,840.00	$992.43	16.28%
	Blades	$89,928,000.00	$312.25	5.12%
	Towers	$60,416,640.00	$209.78	3.44%
	Subtotal	$436,164,480.00	$1,514.46	24.85%
Balance of System Costs				
	Development Cost	$121,824,000.00	$423.00	6.94%
	Wind Turbine Installation	$43,444,800.00	$150.85	2.47%
	Foundation + Mooring	$470,468,160.00	$1,633.57	26.80%
	Foundation Installation	$7,784,640.00	$27.03	0.44%
	Cabling	$159,750,720.00	$554.69	9.10%
	Cabling Installation	$19,903,680.00	$69.11	1.13%
	Onshore Substation	$52,364,160.00	$181.82	2.98%
	Offshore Substation	$41,760,000.00	$145.00	2.38%
	Rondo Heat Battery	$14,400,000.00	$50.00	0.82%
	Other BOS	$57,087,360.00	$198.22	3.25%
	Subtotal	$988,787,520.00	$3,433.29	56.33%
Construction Cost		$1,425,024,000.00	$4,948.00	81.18%
Contingency (6% of construction cost)		$85,536,000.00	$297.00	4.87%
Capital Expenditure		$1,755,360,000.00	**$6,095.00**	100.00%

Table 1. Breakdown of Capital Expenditures

4.2 Operating Expenses (OpEx)

18 MW turbine prototypes are currently not available in Europe. In February 2024, General Electric rescinded the company's plan to upscale the Haliade-X, focusing their attention on a 15.5 MW model over 18 MW.[108] HSWET acknowledges the risk of 18 MW turbines not being commercial in the US by Q1 2031, which is the predicted time period for placing BJW's turbine orders (Figure 3). Furthermore, HSWET acknowledges that it's currently unknown as to what European original equipment manufacturer will be available in the US by 2031. However, General Electric's Haliade-X 15.5 MW filing indicates that the model could be upscaled to 18 MW.[109] If given the opportunity to source the Haliade-X 18 MW, HSWET will hire General Electric as the O&M contractor.

OpEx includes maintenance costs (preventative, corrective, and spare parts costs), Environmental Health and Safety (EHS) monitoring, lease costs, site security, project management, and operational insurance. Based on the National Renewable Energy Laboratory's (NREL) 2023 Annual Technology Baseline, the estimated OpEx for the Vestas V236 15.0-MW turbine ranges from $76/kW-year to $105/kW-year in 2034.[110] HSWET adopts an OpEx estimate towards the upper limit at $90/kW-year due to the innovative and as-yet untested nature of the project's 18 MW turbine. HSWET plans to hire the turbine producer as the full-service O&M contractor with a 95% uptime guarantee.[111]

4.3 Incentives

HSWET plans to utilize the Clean Electricity Investment Tax Credit, codified in 26 U.S. Code § 48E: a technology-agnostic extension of the previously offered Investment Tax Credit (ITC).[112]

According to the U.S. Code, the credit must be applied to a 'qualified facility'.[113] BJW notably generates electricity with zero greenhouse gas emissions and will be placed in service after 12/31/24. This allows BJW to achieve the 6% base rate. In order to earn the 5x multiplier to achieve a 30% rate, BJW will also meet prevailing wage and registered apprenticeship requirements.[114-115] BJW will require 15% of the total labor hours of construction, alteration, and repair work on our facilities to be performed by qualified apprentices. All wages for construction, alteration, or repair of the wind facilities will meet or exceed wage rates indicated by the FLC Data Center's Online Wage Library for similar jobs in the locale where the work is performed.[116]

A 10% bonus is provided if the facility is located in an energy community. Using the DOE's Energy Tax Credit Bonus explorer, HSWET verified that the coordinates of BJW lie in Census Tract 9900 in Lake County, Illinois with a qualifying coal closure.[117] This raises our total credit from this incentive to 40%. HSWET cannot claim the 10% domestic content adder based on our component sourcing from Europe. The Rondo heat battery also qualifies for the 30% ITC with the same energy community 10% adder.

The ITC is preferred over the Production Tax Credit (PTC) due to the higher achievable credits. Specifically, the PTC is set to phase down by the expected COD in 2034, from an initial 2.75 cents/kWh base credit plus 0.3 cents/kWh to 2.0 cents/kWh base credit plus 0.2 cents/kWh. This adjustment results in a total achievable PTC of $391.47 million over 10 years. In contrast, the ITC is calculated based on the construction start date, which allows the project to qualify for the full 40% credit, amounting to a total achievable ITC of $680.29 million.

4.4 Financing Plan

The project financing will be structured as follows: 82.40% of the construction costs will be funded by a construction loan of $1,401.68, and 17.6% will be funded by sponsor equity. After reaching COD, the construction loan will be refinanced using a tax equity bridging loan of $724.62 million and back-leverage debt of $677.06 million. Tax equity sponsors typically restrict financing to back-leverage debt rather than allowing project-level debt, because project-level debt grants creditors a primary claim on the project's assets, which in the event of a default could lead to the project's liquidation and potential recapture of the ITC. In contrast, back-leverage debt is secured at the holding company level, which ensures that the tax equity investors retain the primary claim on the project's cash flows and tax benefits.

Sources	Cost ($M)	Percentage of Total
Debt	$677.06	39.8%
Tax Equity	$724.62	42.6%

Sources	Cost ($M)	Percentage of Total
Sponsor Equity	$299.29	17.6%
Total Sources	**$ 1,700.97**	**100.00%**

Table 2. Capital Stack Summary

HSWET used the Pivotal180 Tax Equity Model for debt, tax equity, and sponsor equity sizing.

Debt is sized through debt sculpting using a P50 target Debt Service Coverage Ratio (DSCR) of 1.60x.[118] The term loan base rate is based on the 3-month SOFR forward curve, and the term loan margin is 2.75% based on the 1.75% quoted in Norton Rose Fulbright 2024 Cost of Capital Outlook, adding 1% premium for the risk associated with floating offshore wind farms and the unique offtake structure with a SAF plant with a lower credit quality, hitting an average all-in interest rate of 6.7%.[119-120] The construction loan all-in rate is 7%, the upfront fee is 1.5%, and the commitment fee is 1%.[120]

The tax equity size is solved based on a target tax equity yield of 13%.[121] The partnership allocates 20% cash and 99% taxable income, loss, and tax credits to the tax equity investor until the investor reaches a target yield of 13% in year 6. Post-flip, starting year 7, the tax equity sponsor receives 5% cash and 5% taxable income, loss, and tax credits.

The PPA price is solved based on a target sponsor equity IRR. According to RWE's Capital Markets Day 2023 presentation, the unlevered IRR (post-tax) is 7-11%, being conservative with our assumptions and considering the additional risks involved with floating offshore equipment and the Rondo heat battery system, HSWET started with the higher end of that range.[122] A 1% premium is added to the 11% to account for the leverage to get to the levered IRR (post-tax) of 12% and use it to solve for the PPA price.

HSWET chose Citi as our construction loan creditor given their history of investing in green energy projects and their $500 billion commitment to environmental finance by 2030.[123-124] HSWET chose JP Morgan as our tax equity sponsor given its large tax base, strong financial health and longevity, and its $1 trillion commitment to green finance by 2030.[125] HSWET chose Wells Fargo and Bank of America as our back-leverage lenders. Syndicated debt helps spread the risks of the project and increases bankability. The $2.3 billion financing of the Vineyard Wind project in 2021 was led by nine banks.[126] To further increase the bankability of the project as suggested by S&P Global, HSWET plans to negotiate a full-service O&M contract with a leading turbine supplier with a guaranteed uptime of 95%.[127-128]

Under IRS specification, turbines, balance of plant, and thermal energy storage are eligible for the 5-year MACRS depreciation deduction, and cabling costs are eligible for the 15-year MACRS depreciation deduction.[129-132]

The Illinois state corporate income tax rate is 9.50%, and the federal corporate income tax rate is 21.00%. Thus, the blended tax rate is 28.51%.[133-134]

HSWET proposes a maximum bid of $160,000,000 for a total acreage of 17,655 acres, at a rate of $9,045/acre. Lake Michigan is not considered BOEM-leased waters. The Illinois Department of Natural Resources's Wind Energy Committee would handle any proposed leases for offshore wind development.[135] However, since Illinois' Wind Energy Committee has not developed any siting matrices available for offshore wind or organized the bidding process, HSWET will refer to BOEM's 2022 offshore wind energy auctions in New York Bight and Carolina Long Bay.

The power output of a turbine increases proportionally with wind speed. For example, a 1 m/s increase in average wind speed from 7 m/s to 8 m/s can lead to an estimated 40% increase in power output. For example, using the Vestas Wind Systems' V164-8.0 MW offshore wind turbine, with a potential 10%-15% change in the capacity factor.[136] An increase in capacity factor directly leads to an increase in revenue. Thus, the bid price increases with the wind speed of the lease area. HSWET performs linear regression on BOEM's 2022 offshore wind energy auctions in New York Bight and Carolina Long Bay. BJW's site has a 20-year average wind speed of around 8.7 m/s, correlating to a winning bid price of $9,045/acre.[13,137-138]

Auction	Provisional Winner	Lease Area Number	Lease Area Size (acres)	Winning Bid Price ($)	20-Year Average Wind Speed (m/s)	Price Per Acre ($/acre)
New York Bight	OW Ocean Winds East	OCS-A 0537	71522	$765,000,000	8.78	106962
	Attentive Energy	OCS-A 0538	84332	$795,000,000	8.63	9427
	Bight Wind Holdings	OCS-A 0539	125964	$1,100,000,000	8.71	8732
	Atlantic Shores Offshore Wind Bight	OCS-A 0541	79351	$780,000,000	8.65	9829
	Invenergy Wind Offshore	OCS-A 0542	83976	$645,000,000	8.72	7680
	Mid-Atlantic Offshore Wind	OCS-A 0544	43056	$285,000,000	8.56	6619
Carolina Long Bay	TotalEnergies Renewables USA	OCS-A 0545	54937	$160,000,000	7.87	2912
	Duke Energy Renewables Wind	OCS-A 0546	55154	$155,000,000	7.91	2810
Hypothetical	BJW		17655	$160,000,000	8.7	9045

Table 3. Wind Speed vs Winning Bid Price

4.5 Market Conditions

Under the proposed fixed-amount VPPA, HSWET will supply Centerpoint's energy demand of 106.65 MWh at a price of $104/MWh in year 1 for combined electricity and heat, assuming a 2.5% escalation rate. This is a competitive price, especially considering that this price accounts for both electricity and heat. The floating base and the integration of the Rondo heat battery system introduce higher risks, necessitating a higher DSCR. This conservative approach to debt sizing results in a larger proportion of sponsor equity, thereby elevating the VPPA price required to achieve the target IRR. The Vineyard Wind project off the coast of Massachusetts has a levelized PPA price of about $98/MWh, but this project uses a fixed-bottom base, which has a much lower levelized cost of energy in comparison to floating-based projects.[139-141] The two most recent 2024 New York contracts averaged $150.15/MWh, also fixed-bottom based, though this price may be subjected to the recent increase in levelized costs associated with offshore wind farms. In comparison, BJW's $104/MWh is within a reasonable range.[142-144]

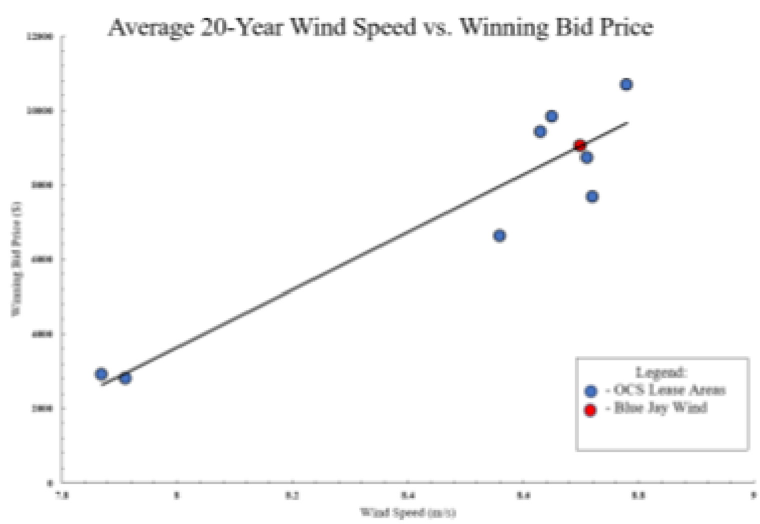

Figure 5. BOEM 2022 Offshore Wind Average 20-Year Wind Speed vs. Winning Bid Price

Any surplus electricity will be sold to the MISO Indiana hub at day-ahead Locational Marginal Pricing (LMP) which offers more stability than real-time pricing.[145] Because BJW is on the MISO-PJM regional transmission seam, the wind farm will not qualify for MISO credits. To maximize revenue, HSWET intends to strategically sell electricity during on-peak hours and charge the Rondo heat batteries during off-peak hours.[146-147] This approach is expected to yield an average price of $45/MWh starting in COD 2034, assuming a 1% annual escalation rate.[148-150]

At the current VPPA price of $104/MWh to Centerpoint and the rest at $45/MWh to the grid, Centerpoint's unit energy cost of SAF is $1.08/gallon, 5 cents lower than its non-renewable energy cost of $1.13/gallon if they were to use natural gas priced at $25/MWh and an average Indiana retail electricity price of $85.5/MWh.[151-152] However, this price would inevitably result in P75 and P90 scenarios' returns lower than the hurdle rates.

	Weighted Average PPA Price ($/MWh)	**Hurdle Rates**		**Tax Equity IRR**			**Sponsor Total IRR**	
Case	Yr 1	Tax equity	Sponsor	@ flip	Total hold	Total call	Hold	Call
P50	$84.25	13.00%	12.00%	13.00%	14.65%	14.81%	12.00%	11.97%
P75	$84.25	13.00%	12.00%	11.45%	13.13%	13.17%	7.10%	7.30%
P90	$84.25	13.00%	12.00%	10.12%	11.81%	11.74%	4.07%	4.37%

Table 4. Equity Returns under VPPA price $104/MWh

To achieve the target hurdle in P75 and P90 scenarios, the weighted average PPA price needs to go up, resulting in a higher VPPA price for Centerpoint and thus a higher unit energy cost. In the P75 scenario, the unit cost increases to $1.28/gallon, 15 cents higher than the non-renewable energy cost of $1.13/gallon. In the P90 scenario, the unit cost is 32 cents higher. From the unit cost perspective, Centerpoint will have fewer incentives to purchase HSWET energy. However, HSWET believes that Centerpoint is incentivized to continue with the higher PPA price.

	Hurdle rates		**Weighted Average PPA Price ($/MWh)**	**VPPA Price ($/MWh)**	**Unit Energy Cost ($/gallon)**
Case	Tax equity	Sponsor	Yr 1	Yr 1	Yr 1
P50	13.00%	12.00%	$84.25	$104	$1.08
P75	13.00%	12.00%	$94.48	$112	$1.28
P90	13.00%	12.00%	$104.98	$118	$1.45

Table 5. Unit Energy Cost under P50/P75/P90 Scenarios

By sourcing its energy from HSWET, Centerpoint secures the maximum SAF tax credits currently available, protected against future changes in the lifecycle assessment methodologies that determine these credits. The U.S. Treasury's ongoing updates to the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model, which is pivotal for calculating emissions reduction percentages required for SAF credit eligibility under the IRA, suggest a trend toward more stringent lifecycle assessment standards.[153X] By partnering with HSWET, Centerpoint can navigate these uncertainties more effectively, as the energy supplied would already align with anticipated sustainability benchmarks, reducing reliance on specific LCA outcomes that may evolve. Furthermore, Fulcrum can establish itself as one of the lowest carbon SAF providers, distinguishing it from competitors in the market. This unique positioning could facilitate quality offtake contracts from airline buyers or sell the SAF at a premium, lowering the risk of the project and generating additional revenue. Global airlines might be motivated by foreign SAF standards that are stricter than those in the US.

5.1 Optimization

HSWET's optimization addressed turbine selection, unit economics, hub-height selection, and micro-siting.

Turbine selection balanced the capacity size expected for floating offshore wind farms by 2032 while simultaneously accounting for the expected load of Fulcrum Bioenergy Inc. and the site's wind speeds. BJW's proposed site averages a wind speed of 9.13 m/s at a hub height of 150m, which would be considered Class I or II wind speeds.[154] A capacity factor of 52.11% is expected by 2031, which is the year HSWET will place turbine orders.[155] To meet the expected capacity factor for a competitive floating offshore wind farm, HSWET decided to utilize a Class I wind turbine. As of 2024, there are five Class I prototypes: Haliade-X 14 MW, SG 14-222 DD, Vestas V236-15.0 MW, GWH252-16 MW, and MySE 16-260. European manufacturers were preferred over manufacturers based in China due to risks with sourcing from China, thereby making the GWH252-16MW and MYSE 16-260 unsuitable.[69] The Vestas V236-15.0 MW is the only remaining turbine selected as the preferred model for currently developing floating offshore wind farms.[156] This indicated to HSWET that by 2031, floating offshore wind farms could upscale to 18 MW turbines. Therefore, BJW will source an 18 MW turbine prototype from Europe.

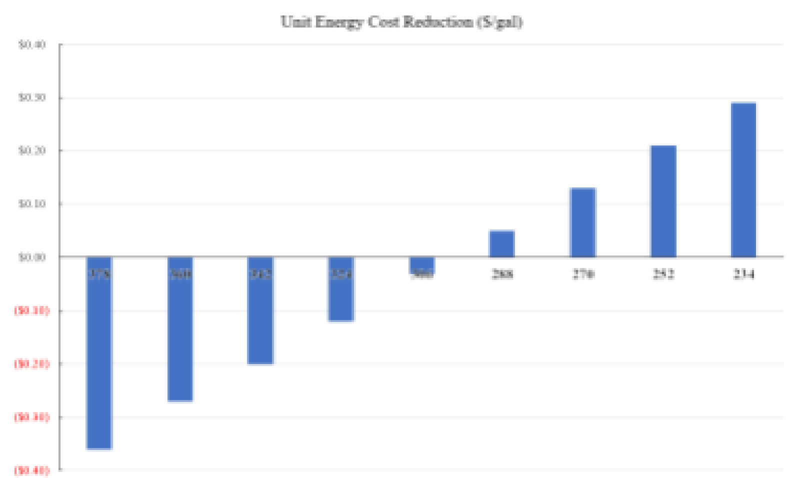

Figure 6. Centerpoint's unit energy cost reductions at differing farm capacity

Different net capacity factors were tested to evaluate Centerpoint's projected unit economics per gallon (Figure 6). A capacity of 288 MW was chosen because it results in a VPPA price that makes Centerpoint's unit energy cost lower than its non-renewable energy cost of $1.13/gallon, while maintaining a positive excess capacity even under the P99 scenario, ensuring consistent energy supply.

After determining BJW's farm capacity, 288 MW farms were tested at hub heights of 160m, 180m, and 200m. Each farm ran through 10,000 iterations to determine which produced the greatest net AEP in a 20,000 km^2 area (24710.5 acres). As a result of increasing the hub height to 180m and 200m, a 0.135% (1,912 MWh) and 0.297% (4,206 MWh) improvement to net AEP were observed in comparison to 160m, respectively. However, these improvements also brought about foundation stability concerns, since floating structures experience greater turbulence.[157] To account for potential structure instability, HSWET decided to use a hub height of 160m. Optimization then focused on minimizing site acreage while maintaining farm production. Furow underwent 10,000 iterations within a rectangular lease area with a width and length of 7.802 km and 9.159 km, respectively, minimizing HSWET's size down to 17,655 acres from 24,710.5 acres. By reducing the acreage, BJW's net capacity factor decreased from 56.42% to 56.137%, leading to a revenue loss of $3,491.48. However, HSWET saved $63,506,472.50 on the bid price, resulting in total savings of $63,502,981.02.

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