Final Site Design Report

Collegiate Wind Competition 2022

Wildcat Wind Power at Kansas State University

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Wildcat Wind Power dedicates our work this year to our longtime advisor, Dr. Warren White, who passed away in May of 2021. Dr. White cared deeply about our mission, and his presence is sorely missed.

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Site Design

Overview

The team was given a set of lease plots near the coast of Galveston, TX, in which to design a wind farm and analyze its financial and operational parameters. Due to existing infrastructure, available geographical data, and proximity to shore infrastructure, 4 plots in the lower left-hand quadrant of the plot set were chosen for the design, and a 288MW wind farm was designed within the four plots. The wind farm specifies 12MW GE turbines and includes two grid-tie transmission lines that lead to the two nearest electric interconnections.

Site and Lease Selection

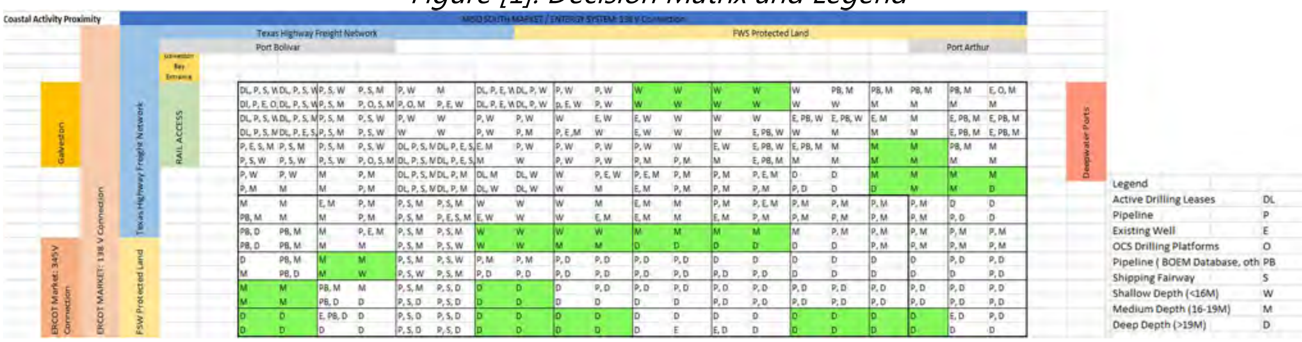
Two primary physical concerns for the farm are wind speed and water depth. Available data showed a relatively constant wind speed of 7.5 m/s throughout the given lease area. A slight increase in average speed (.1 m/s) was found towards the western and southern-most plots. This proved to us that other siting factors, such as existing land use and proximity to onshore infrastructure, may play a more critical role in the decision-making process than the wind resource. The lease area is situated in an area of the Gulf of Mexico (GOM) with relatively shallow water, at an average depth of roughly 20m. The southernmost plots show the deepest waters, up to 25m at their deepest points. Available scans do show some smaller-scale variation within the plots of the water depth, but in general, this location is an area of shallower water surrounded by deeper water in the south and east.

The oil and gas (O&G) industry has been active in the GOM for nearly a century, and consequently there exists a significant accumulation of O&G infrastructure in the lease area. The infrastructure must be largely avoided in the construction of the farm, as the farm's construction processes could interfere with the operation of the equipment. A series of pipelines cross and connect within the lease area, connecting drilling platforms with refineries in Houston. These pipelines are concentrated in the northwest corner of the lease area but extend southwest and south through the site as well. The northwest corner also contains multiple active site leases for (what is assumed to be) O&G use. Drilling wells are dotted throughout the site but are most heavily concentrated on the Northern half of the area. 4 plots contain major drilling platforms, 179, 176, 206, and 170. The major non-O&G use considerations are shipping lanes and protected reef areas. Luckily, shipping fairways seem to follow the major pipelines that cross the site, and a larger area of shipping fairway exists just northwest of the lease area, outside of the mouth of Galveston Bay. Additionally, the closest protected reef area, the Flower Garden Banks, is far southeast of the gridded area.

To investigate where critical construction and operation infrastructure might be located onshore to support the farm, we analyzed transportation infrastructure and interconnection locations. For transportation infrastructure, the main comparison is between the north side of Galveston Bay (the Bolivar Peninsula up through Port Arthur) and the South Side (Galveston Island). Both sides have access to major highways, but only the Southside has rail access. In Galveston Bay, the Port of Houston has access to both major highways and railroads. Regarding transmission access, The Bolivar Peninsula and Port Arthur are part of the Eastern Interconnection while Galveston and most of Houston are part of the ERCOT Interconnection. Galveston Island is connected to ERCOT through a double-circuit 138kV line across the Causeway Bridge, and the Bolivar Peninsula is connected to the MISO South region through a single-circuit 138kV line that runs up through Stowell and the 138kV Port Arthur system. 345kV interconnection would only be available inland in League City, or further South in Lake Jackson. Considering the onshore environment and areas to potentially avoid building a transmission line through, much of the land directly north of the lease area is protected forest or wildlife refuge, particularly the large McFaddin and Anahuac National Wildlife Refuges.

Much of the information had been taken from online ARCGIS maps overlaid over the competition leasing area. This data was combined with onshore considerations in a spreadsheet to produce a graphic decision matrix of possible options. The matrix can be seen in Figure [1]. A full list of online GIS sources used can be found in the GIS References description.

Figure [1]: Decision Matrix and Legend



Turbine Selection

One of the most defining aspects of the Galveston site, aside from the low water depths, is the relatively modest wind speeds, mostly class 2. Lower wind speeds require larger turbine rotors with lower specific power ratings. Research indicates that turbines designed for the conditions near the Galveston site would have a specific power of ~280 W/m^2 [1]. These reference designs have a hub height of 130m and a rotor diameter of 213m. However, these are only reference models, and many large offshore turbines have been developed already for European North Sea markets. Some available data about these turbines is shown in comparison in Figure [2]. All turbines considered are pitch-regulated variable speed models designed for class 1 winds. As can be seen from the comparison, the only turbine that has a specific power rating close to the necessary value is the 12MW GE Haliade model with a blade length of 222m. This is within the reasonable specific power range for the GOM and is the turbine that has been chosen for the rest of the project. It should also be said that none of the turbines considered are designed specifically for the lower wind speeds seen in the site region, and it is possible more bespoke turbines would be available in the future.

Figure [2]: Turbine Comparison

Turbine	Rated Power (MW)	Swept Area (m^2)	Specific Power (W/m^2)
Vestas V236-15MW	15	43742	342.9
SG-14-222 DD	14	39000	358.9
GE Haliade-X 12MW [13]	**12**	**38000**	**315.8**

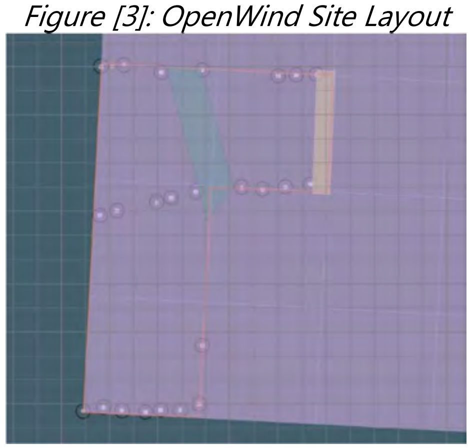
Farm Design

Given the available information cataloged in the decision matrix, the bottom left corner of the lease area was chosen as a location for the wind farm. The wind resource is slightly better in this area, and there are larger areas of water with few pieces of existing infrastructure. The benefit of choosing emptier plots is that each piece of land can be used to its full energy capture potential, maximizing return on investment for the price of the lease. It was also important to us to choose a set of contiguous plots, given that construction over too spread-out of an area could prove expensive. The area does present slightly deeper water than other parts of the grid, up to 5 m deeper than the average, but this difference is subtle compared to its other positive attributes. This location is the closest feasible build location to the Galveston area and the entrance to Galveston Bay, which the team determined was an overall better construction port and primary interconnection location. Galveston has rail and highway access, and less protected land than the other proposed onshore locations. Additionally, the much larger Port of Houston would be available if needed. Other site locations closer to Galveston Bay were full of existing pipelines and shipping freeways, which could make construction difficult or even impossible.

As far as the size of the farm is concerned, the general plan for the site was a farm of 200-300MW. Through cost analysis and various simulations, we believe this farm size optimizes well between the increased construction cost of a larger farm and the larger power production. Given that this would likely be the first offshore development in the region, lenders and investors may be hesitant to support a larger project without concrete evidence that similar sites have survived severe storms. The simulations showed that a farm of this size would require roughly 4 plots of land. Plots 292, A63, and 263 were determined to be completely free of problematic infrastructure and shipping freeways, and plot 264 is mostly free of existing obstacles. They were chosen as the plots to be used for the farm, as they provided a contiguous and clear area in which to construct the farm while aligning with the other benefits of construction in the lower corner of the lease area. Given the 220m rotor diameter of the chosen turbine, a sufficient hub height must be chosen. The team believes a 130m hub height would present the best optimization between a stronger wind resource and increased construction costs. With this hub height, the correct foundation type must be identified to support the structure. Jacket-style foundations have been chosen for this project. They are the standard in the O&G industry due to their optimized weight to strength ratio in the sandier Gulf soils. They are also simple to install relative to other foundation systems, such as monopiles, due to their ability to be floated out to sea. Ease of installation, lower cost, and overall strength make them the ideal choice for the Galveston location [2].

The plot locations were loaded into OpenWind alongside a wind resource file for the location. A site boundary was placed around the chosen plots (292, A63, 264, 263), and space was delineated where the plots intersected with a pipeline and shipping lanes to form a complete project boundary. Layout optimization for different amounts of turbines was performed to minimize array losses and maximize energy production. A 10MW reference turbine was used for analysis. 7% array loss was determined to be the acceptable maximum value [3], and 24 turbines could be arranged in the site without increasing the array loss beyond this value. This brings the farm to a nameplate capacity of 288MW with the 12MW GE turbines. The layout of the site is shown in Figure [3] with the overlaid plot grid and site boundaries. Also, shown in Figure [3] is the chosen offshore substation location, in the upper left corner of the site.

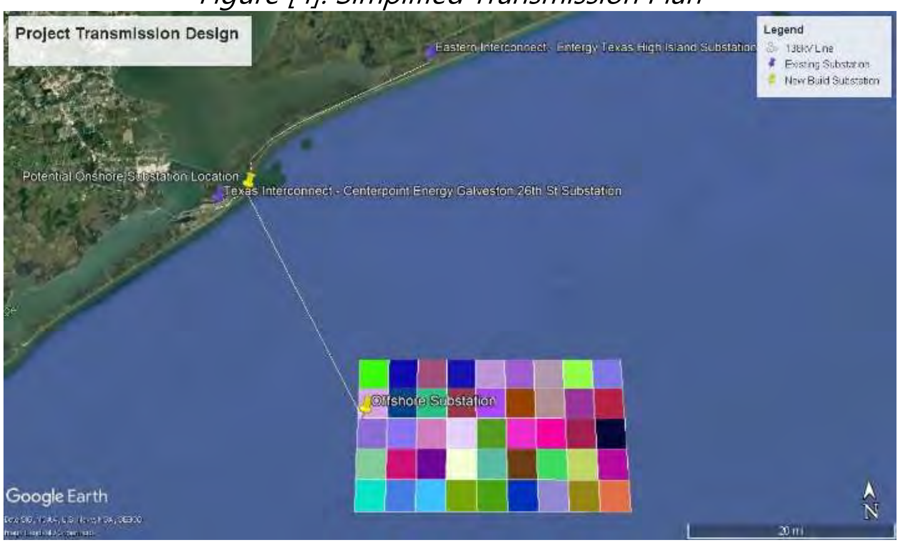
Figure [3]: OpenWind Site Layout



Transmission Design

The onshore substation would be located on Galveston or Pelican Island, and transmission would be designed to connect the farm to both the Eastern and Texas interconnections. CenterPoint Energy's existing 26th Street 138kV substation in Galveston would be expanded for interconnection to ERCOT. Transmission lines need to be built to connect the wind farm to the substation, and then to connect the substation to the 138kV line on Galveston Island and the 138kV line on the Bolivar Peninsula. The MISO interconnection point would be at the newly expanded High Island Substation [4]. The project is under the generally accepted "critical distance" (50km) from a transmission interconnection that would necessitate the use of HVDC technology, so the export cables from the offshore farm would be AC. However, the project is also far enough from shore that the transmission voltage would need to be higher than typical collector system voltages (34kV), so an offshore transformer and substation would be required [5]. Thus, the export cables would be at the interconnection voltage of 138kV. Onshore, switchgear would be required, especially when considering interplaying between interconnections, but not another large transformer. The system can be seen in a simplified illustration in Figure [4].

Figure [4]: Simplified Transmission Plan



Environmental Considerations

Since the United States does not currently have any legislated guidelines on the environmental impacts of offshore wind, the project will adhere to current European ordinances and areas of concern. Two factors that will affect the farm are wildlife impact and pollution. Many birds have migratory paths that pass through the Gulf of Mexico, necessitating countermeasures to avoid impacts. Promising countermeasures include raising the cut-in speeds to around 5.0 m/s [6], employing market-available tools such as Merlin Advanced Avian Monitoring System to stop turbines while large flocks fly through the farm, as well as using ultrasonic sound boxes to prevent bats from hanging around. The farm's placement is not close enough to the nearest reef, the Flower Garden Banks reef, to cause significant issues. In fact, local marine ecosystems might benefit from the wind farm as studies have shown that the hard structures provide artificial reefs which positively impact local fish and reef-building creatures [7]. Apart from the immediate benefits to the environment, we could also see significant benefits to the local fishing industry. The increased habitat area would see significant gains in marine wildlife populations, thus reducing the pressures on existing populations allowing for greater production by fisheries. For this project, the main sources of pollution that must be mitigated are construction, noise, and transportation. In terms of pollution directly from construction processes, the team expects these to be minimal in comparison to previous large-scale O&G construction projects in the Gulf of Mexico. The Haliade X is largely pre-assembled on land and shipped out, leaving only final assembly and mounting to be done on the ocean. A more pressing concern would be the damage done to local ecosystems by noise pollution in both the initial installation phase as well as in the long term. One of the major concerns in the installation phase is the long-term effects of using pile drivers to hammer in the jacket systems on marine ecosystems. However, studies have shown that the effects are relatively short-term, and fish and wildlife typically increase to higher levels than before operations [7]. The number of decibels the wind farm produces is regulated under U.S. law, however, as the Haliade was initially designed for use in Europe, it must comply with the much more stringent laws surrounding noise pollution [8]. Another very significant source of pollution for this project will be the transportation of materials. It is expected that most components will be transported using more energy-efficient methods such as trains, largely due to the large size of the components. The selection of installation vessels will also impact our overall carbon footprint, it is expected that the selection of the *Charybdis* and the use of specialized O&M vessels would reduce the number of ships necessary to install and operate the farm, thus reducing the overall pollution produced by the project. In the long term, proper foundation maintenance will be important to eliminate polluting rust and other environmental concerns such as scour at the base of the foundation. It is also vital to ensure that cable materials are chosen correctly to prevent both electrical losses to the project as well as pollution. A lead extruded sheath is the only currently accepted sheathing to prevent water intrusion and special care to select non-magnetic armoring to prevent both losses in efficiency, as well as causing magnetic fields that might affect marine species.

Tax Considerations

Wind farms are allowed to take advantage of either the Production Tax Credit (PTC) or the Investment Tax Credit (ITC). The PTC provides a tax credit based on hourly production, while the ITC gives a one-time credit of a percent of investment costs. Currently, neither has been extended up to 2030, but we will assume for this project that the most recent government actions will be extended similarly through 2030. The PTC would garner a credit of 1.5 cents/kWh, while the ITC would garner a single credit of 30% of the total investment at the start of the project [9].

Energy Production

As mentioned previously, the site was designed and simulated in OpenWind to calculate losses due to wake effects. The OpenWind simulation yielded a gross energy production of 530 GWh, but there were many discrepancies between the OpenWind simulation and the actual farm design that could not be rectified. First, the turbines used in the simulation were rated for 10 MW, while the farm was specified with 12MW turbines. Second, the data used in the simulation seemed to have a lower average wind speed than other data sources indicate for the region, it had an average wind speed of around 7 m/s while other sources show an average closer to 7.5 m/s. Third, the data was for a hub height of 100m, rather than the 130m for the hub height needed for the turbines. To rectify the differences, different scaling factors were applied to the net energy production of the farm from OpenWind. First, the total production was scaled up to a 12MW turbine rating from a 10MW rating at (12/10) = 1.2. While this may not take into account the different power curves of the different turbines, it can capture the generally higher production seen at each wind speed along the curve. A wind speed power law calculation was done to calculate the wind speed at a height of 130m over a height of 100m, producing a factor of (with an alpha of .143 for offshore calculations) 1.038, which was cubed to produce a scaling factor of 1.119. Finally, the generally low average wind speed of the data was scaled up to the 7.5 m/s seen from other sources, producing a factor when cubed of 1.229956. This led to a net production of 875.4GWh, which was closer to what we expected from SAM and NREL calculations and data.

Risk Analysis

The project faces some risks inherent to all offshore construction projects, and some unique to its location. Environmental risks such as hurricanes, one of the main risk factors unique to the site, would be a major consideration and would necessitate the procurement of insurance. It would be a major responsibility of the developer and insurer to decide whether to insure the project against the full replacement cost or insure it against some portion of that loss based on probabilistic studies. Other risk types must be analyzed as well, beyond those that threaten the structural sustainability of the plant in operation. Although construction risk is generally lower for wind projects than other energy projects, it is still the riskiest period of the time for the project for lenders. Project lenders might try and mitigate construction risk by ensuring that reserves for construction cost overruns are funded before construction begins, or by asking for periodic updates on the completion of the project that they can review themselves. From the perspective of the project sponsor and developer, consistent communication with EPC contractors, the O&M contractor, and lenders throughout the construction process can ensure that.

Additionally, although transmission basis risk will likely be avoided due to the dual-market system, and risk due to exposure to low electricity prices will be minimized, there is always the risk of the farm not producing planned quantities of electricity due to seasonal changes in weather trends. This resource risk can result in a shortfall in revenue that can make it difficult for the project to service debt. Oftentimes non-PPA projects such as this one will engage in weather or price-related hedges to ensure a constant revenue stream. Given that the dual-market design already acts as a hedge of sorts against price changes, this project can enter into an agreement with an insurer known as a Proxy Revenue Swap (PRS) to hedge against weather-related changes in output which could impact production and revenue [10]. In these agreements, the farm owner would receive a fixed payment from the insurer in exchange for calculated revenue amounts and a fee, which can greatly firm the revenue stream and ensure that the project can continually service its debt.

Project Analysis

Market Analysis and Revenue Calculation

The Galveston and Houston areas are unique in that they are close to the border between two electric interconnections and power markets, the ERCOT market and Texas Interconnection, and the MISO Market as part of the Eastern Interconnection. Because only limited power can flow between the two regions (through a DC link), power prices on the MISO side are generally higher than in other portions of the MISO market, as power can only flow in from the North and East to supply the region’s load. This creates a unique opportunity for a generator in the area to take advantage of these high prices by interconnecting within this pocket. But there are advantages to the ERCOT market as well. While power prices are generally lower than in the MISO region, the lack of a market capacity construct in ERCOT means that there are usually several days in the year with relatively higher day-ahead and real-time prices than in either region. The ERCOT market is heavily dominated by wind power in Northern Texas, and if a generator was facing a different wind regime than these farms (possible if it was offshore), it may be in a very good position to capture revenue from the price spikes seen when wind elsewhere in the state is not producing.

The transmission tie lines of this farm have been designed to take advantage of the price spikes in the ERCOT region and the generally higher prices of the MISO South area. Lines will connect the system to substations on both the Eastern and Western interconnection. Because the marginal production cost of wind is very low, we can assume for revenue calculation that wind would participate in the day-ahead wholesale market for either region and choose to operate hourly in whatever region sees the higher day-ahead price. It is unknown if the other generators that participate in multiple markets perform this kind of hourly switching, but it should be technologically possible with the right breaker and bus arrangement at interconnection points. Two separate sets of data were used to calculate revenue and ensure that this transmission arrangement would be profitable. First, historical day-ahead hourly Locational Marginal Price (LMP) data from the MISO Houston Node and the ERCOT Houston Load Zone were pulled from internet sources for 2012 and compared to see if there was a price disparity between the two that oscillated between both sources. Analysis of the data showed an average price of $2.5/MWh higher than the average for either region if the highest hourly value was chosen between both markets. Second, the same calculation was performed with data from the NREL Cambium study for 2030 in the mid-case for renewable growth. Data for the p67 and p66 load zones were compared, and the same conclusion was reached. Participating in both markets and choosing the one with the higher day-ahead hourly price would lead to increased revenue opportunities. The average price of the combined sets was 5.4 $/MWh higher than the p67 load zone (ERCOT Houston) average and 3.4 $/MWh higher than the p66 load zone (MISO Texas).

Analysis of both data sets also showed negligible periods of time with the price at or below zero with this tactic, which could signify very low curtailment for the farm due to transmission constraints or wind overproduction. The farm is interconnected at points in either interconnection without other generation on the same line, so curtailment due to transmission constraints would be unlikely, as the farm could only reduce loading on the lines by serving the local load. This is a very positive sign as far as the revenue of the farm is concerned, but it does also signify that there would be very limited periods where the farm would be able to participate in ancillary markets, such as ERCOTs Regulation Service Up and Down Markets or MISO's Spinning or Supplemental Reserve Markets. Thus, it was assumed for revenue calculation that the farm would primarily capture revenue through the sale of energy only. One input was made to revenue calculation, and that was an overall 4% increase in average energy price seen due to the interconnection point of the wind farm at the end of long transmission lines without any generation. The farm's production would only be relieving congestion on lines, rarely causing it, so it could potentially capture higher prices through the congestion component of the day-ahead Locational Marginal Price (LMP). 4% was seen as a conservative estimate for this increase, during the summer months when the load on Galveston Island is high it could be even more as the farm serves the local load and relieves congestion on the Tiki Island-West Galveston 138kV line. Finally, a 2% yearly increase in average price was added to the revenue data, to account for inflation in wholesale power prices.

Revenue calculation was done through the SAM Merchant Plant model. It would be equally valid to assume that the plant could operate through a PPA framework, given the wide variety of potential power buyers in Houston, Galveston, and Port Arthur. However, the farm is designed to take advantage of high power prices between markets, and thus a PPA framework would largely negate that benefit. The combined Cambium study data for the two regions, in which the higher hourly price was chosen, was input back into the tool's energy market data input after analysis, assuming negligible curtailment, leading to a yearly revenue of 33.9M$.

Installation Vessel Selection

Several variables, mainly the Jones Act of 1920, influence the fact that the vessels chosen for the construction of the farm must be US-flagged. Foreign ships can and have been used, but they must be used as 'feeder' vessels and have equipment brought to them at sea by Jones Act-compliant ships. The most critical vessel for the construction of a turbine is the vessel that lifts the nacelles and blades of the turbines for installation, which requires the most precise lift and most stability during lifting. Generally, these vessels, known as Wind Turbine Installation Vessels (WTIVs), are equipped with the capability to jack up out of the water. Several organizations have chartered a vessel with this capability known as the *Charybdis* for the construction of a farm off the east coast; it will be the first US-flagged ship designed for 12MW+ wind turbine installation [11]. Ideally, this vessel would be available for the project and could be used for both the difficult nacelle and blade lifts as well as foundation installation.

However, because the water in the GOM is not especially deep, it would be more cost-effective to utilize a different kind of heavy lift vessel for the jacket foundation and transition piece installation. A heavy-lift cargo vessel could perform this type of work, and significant cargo capacity would be useful during the jacket installation process. A number of ships in the USOcean fleet could potentially be cheaper than the *Charybdis,* and could still have the lift capacity necessary to perform some of this installation, and are all US-flagged [12]. The *Ocean Grand* and *Ocean Glory* are the largest, with twin 450MT cranes on each. Other specialized ships may be needed for other parts of the construction process, including the laying of undersea cables, the carrying of project cargo, and offshore substation construction. A subsea cable plow and cable installation vessel could be necessary to install the export cables, but it would also be possible to reduce costs by laying the cables directly on the ocean floor. A previous ruling confirmed that this process would not need to be performed by a US-flagged ship [13], and thus a foreign vessel like the *CS Cable Venture* could be used [12]. Additionally, a Houston company is constructing a US-flagged vessel designed to transport and deposit rocks on the seabed to support turbine foundations and cables [14]. This vessel, while still unnamed, will be US-flagged and could be useful in the project construction. For O&M operations, an unnamed ship has been recently commissioned for servicing wind farms on the east coast [15]. This ship has a variety of specialized features including hydraulic gangways and modular storage, deck use, and an on-site workshop, and would ideally be used for O&M operations out of the Galveston port.

Port Selection and Activities

Ports in Texas have decades of experience in the manufacturing and construction of large, complex offshore structures, mainly for the Oil and Gas industry. The development of a large offshore farm would demand adequate port infrastructure for construction, staging, and continued operation and maintenance (O&M). As far as O&M activities are concerned, an operational facility would need to be close to the site location to allow easy access for maintenance. O&M activity would not require costly upgrades to the port itself and would merely need to accommodate the use of smaller vessels to transfer maintenance crew out to the site. Thus, a facility in the Galveston or Texas City ports would be viable.

Specific activities that these ports would have to perform mainly revolve around the staging process and loading of the ships. If the factories were in the port, it would facilitate a lot of these actions but in the cases when they aren't in Galveston, initially we would see the prefabricated components of the Haliade turbine arrive, because of the size of the components, they would likely arrive by train, and be stored in nearby warehouses. Towers will begin to be assembled onshore from the pieces it was transported in. Another critical step that must be done at the port is loading the jacket foundations which will be performed similarly to the rest of the turbine, just earlier in the process of installation and without the use of the *Charybdis*. Once it is deemed that enough components have arrived for effective loading of the *Charybdis*, a crane will position itself to load Self-Propelled Modular Transports (SPMTS) which will move the components to a point where the cranage system (likely two sets of 600-ton cranes) can effectively maneuver the components onto the *Charybdis*. It is important to note that this loading process can take several hours per component and will need to be done a multitude of times throughout the installation of the wind farm, thus proper training of staff is imperative and docking regulations revised [16]. With the *Charybdis* loaded, it will depart from port ready to install the towers, nacelles, and blades. Finally, the port would be continually used for O&M operations, however, these can likely be done out of any port and likely will have to be done out of more than one port if there are multiple projects in the GOM region.

For construction and staging, one of the most critical variables is the ground bearing capacity of the port itself. Reports recommend that the ground bearing capacity is over 10 tons per square meter. Most US ports have ground bearing capacity in the range of 5-10 tons per square meter [16]. Due to the high weight and relatively small footprints, components such as the Haliade nacelle weigh as much as 600 tons and have a footprint of about 226 square meters placing a pressure of 2.26 tons per square meter [17], however, nacelles can be stored on a supporting system decreases the necessary bearing capacity. The components (blades, nacelle, tower, and jackets) of the large Haliade turbine would weigh on average 12.1 tons per square meter. Most ports are not designed to handle such heavy cargo, in addition, cranes in many can only lift a few tons. These components also require very large ships to transport them from the storage and staging site to the final installation site. Reports indicate that suitable ports would ideally not have Horizontal Clearance nor Air Draft Restrictions, thus it is likely that there would need to be significant upgrades done to any port [18].

While completing all these same upgrades would be ideal, the closest port with the fewest necessary upgrades must be considered. Ideally, the port would be situated in Galveston Bay as it is very close to the proposed site. Thanks to the large cruise port, there are few restrictions on the Air Draft and Horizontal Clearance and any such restrictions could be waived, the draft restrictions are also relatively deep allowing for the large ships required. This would likely leave reinforcing the deck to be the only major upgrade done. Storage will also be a major consideration given the staging area needed for turbine components. Analysis has indicated that Galveston has significant potential to operate as a construction and staging port for offshore wind construction due to the reduced necessity for deck upgrades [17], but storage improvements would be needed given the limited floating storage availability. Galveston will be chosen as the primary staging and construction port for the project, but other ports, particularly Texas City or even Freeport, could be used as a secondary staging location.

Initial Capital Cost

Many factors play into the final cost of the completed project, and the team tried to understand as many of them as possible as they developed an estimate for the total capital cost of the project. NREL's SAM tool was used for project analysis, which has nearly 250 different inputs that come together to produce a finalized project cost. Many of the inputs had to be adjusted and changed, both as research on typical values became clearer, but also to produce a viable project cost that could yield a description of a financially solvent project. While not every input can be discussed in this document, the main cost estimates that we have researched and used in the calculation are discussed below, and how they are reflected in system parameters. Some farm parameters that play into installation cost are shown below, from design decisions and analysis.

Figure [5]: Selected Installation Cost Parameters

Parameter	Value	Parameter	Value	Parameter	Value
Substructure	Jacket	Interconnect Voltage	169kV	Array Cable Voltage	64kV
Anchor	Suction Pile	Distance to Landfall	50km	Vessel Strategy	Primary (WTIV)
Max. Water Depth	30m	Distance to inst. Port	53km	Distance over Land	45km

The SAM tool we used to calculate project financials includes many cost inputs, and below are shown some cost inputs that we have found to play a major role in total project installation cost, and for which we have researched values. Of particular note is the turbine capital cost, reports have shown a cost of 1301 $/kW for Atlantic coast projects [19], but we assume a slightly lower cost due to the necessarily lower rated power for GOM turbines, and future cost reductions in offshore turbine technology.

Figure [6]: Selected Installation Costs

Parameter	Value	Parameter	Value	Parameter	Value
Turbine Cost	1100 $/kW	Cable Burial Rate	130	Environmental Compliance Cost	3M$
Substation Design Cost	4.5M$	Crane Rate	19800	Met Tower Inst. Cost	1.5M$
Substation Fab. Cost	14.5k$	Quayside Docking Rate	3000	Site Assessment Cost	$410000
Jacket Lattice +Pile Cost Rate	6930	Cable Rack Cost	1M$	Number of Feeder Barges	2

The final installation cost for the site is shown below.

Figure [7]: Final Installation Costs

Cost Component	Cost($/kW)	Rated Capacity (kW)	Cost (M$)
Turbine Cost	1100	288000	316.8
BOS Cost	5193	288000	1495.68
Total $	**6293.32**	**288000**	**1812.48**

Financing

The setup of the project as a merchant independent power producer, rather than as a seller through a Power Purchase Agreement (PPA), exposes the operating company to a level of merchant price risk. The signing of a PPA with a creditworthy entity offers a level of assurance to lenders of continued profitability, and the lack of one could keep the project from ever getting off the ground. The dual-market merchant arrangement of the plant does present potential for improved revenue stability, and the uncertain future of global natural gas markets may guarantee a high floor in ERCOT wholesale electricity prices, but it may not be enough for the project to secure financing from commercial lenders. Thus, new financing options may need to be found.

The Department of Energy's Loan Programs Office (LPO) may be able to provide some of this financing, as it offers debt financing for technologically innovative large-scale energy projects. Concerning large-scale renewable energy projects, LPO provides access to capital for projects that would be genuinely innovative in their space through the Title 17 Innovative Energy Loan Guarantee Program. In order to prove that the project is innovative, we would argue that the dual-market interconnection setup, alongside the fact that the project would likely be the first offshore wind farm in the Gulf Region and would require different foundation and turbine designs than have been seen in Europe and will be seen in the Atlantic, qualifies it for the financing. Even if the LPO limited its financing of the project below what is needed, their presence as part of the lender group could encourage commercial lenders to invest as well. The LPO also provides in-house legal, technical, and environmental support to projects, which would be useful as the developer navigates the BOEM lease process.

A major piece of funding needed for the project is a term loan, offered at some ratio of available cash flow to the debt service interest payments that would be necessary (DSCR). Our research indicates that, without the LPO being involved, this project might see a DSCR as high as 1.4 [20], but we believe that they would be willing to offer lower DSCR conditions given their mission and goals. DSCR is often calculated by lenders based on mid and worse-case production and revenue scenarios. Other major types of project funding, like sourcing it from the bond market, offer more complex tax situations and would generally not be used in this kind of situation. Construction loans are also an important portion of funding for offshore wind development. They are over a shorter-term period and are often slightly cheaper than the longer-term loans over the life of the project. If LPO funding was available, it is possible that the construction loan could be converted into a longer-term loan upon completion of project construction and commercial operation. Even if LPO only agreed to provide the term loan, their presence in the project might sway other investors into providing the necessary construction loans needed for the project during construction.

Assumptions

NREL SAM Software was used for financial modeling and analysis, and the inputs to the software are cataloged below as a way of describing the system model.

Considering the analysis of operating costs, research was performed to find out what typical offshore farms in Europe see in operational costs, as well as estimates for future farms in North America [21]. From the research, it was assumed that the project would see \$100/kW-yr in fixed capacity-related costs, and \$20/kWh in variable generation costs, with a 3% escalation rate. The estimates were placed between European statistics and North American estimates, as the lower water depths and wind speeds could lead to cheaper maintenance than the North American Atlantic Coast estimates, but the North American industry hasn’t reached the scale that the European markets have, to bring down the operational costs too much.

As far as depreciation is concerned, most assets in renewable projects qualify for the Modified Accelerated Cost Recovery System (MACRS). We have assumed that most of the project (95%), qualifies for 5-yr MACRS, while the 3% qualifies for 15-yr MACRS and 2% is non-depreciable. MACRS is very beneficial during the early life of the project, as it provides useful tax deductions that can offset taxable income early in the project’s life. It was assumed that all of the project elected for ITC and claimed the 20% bonus depreciation for projects in service in 2026 (the latest date available).

Regarding the loans that the project would receive, we will continue with the assumption that the unique project design would qualify it for assistance from the DOE LPO. Thus, it might qualify for a lower DSCR for the term loan than otherwise might be possible given the site conditions. We have assumed a DSCR of 1.3, over a tenor of 18 years, and at an interest rate of 3.75%. The interest rate of LPO loans is calculated from a combination of the treasury rate for loans over the same period, and a credit-based spread that is usually under 200 basis points. With long-term treasury rates hovering around 2.2% [22], we estimated that the credit based-spread would apply at 155 basis points, yielding the interest rate of 3.75%. We also assume $450000 in closing costs for the debt and a 2% fee upfront. For the construction loan, we will continue with similar assumptions, and assume an interest rate 50 basis points lower than the term debt [21], or 3.25%. We will give a conservative estimate for the portion of the project construction costs funded by the construction loan, at 70%, and assume a 1% up-front fee for the loan as well.

For other general financial parameters, we assumed an insurance cost near 1% of the total installed cost [21] and assumed that the sales tax of 6.25% seen for most goods in Texas would apply to the direct costs in the installation. We assumed a salvage value of roughly 1% of project installation costs [23]. We have assumed an inflation rate over the project period of 2.5% [24], and a real discount rate of 6.4%. Property tax was assumed to be assessed only on the onshore (or within state waters) portion of developments, roughly 3% of project costs, at a 2% rate. It is common for project lenders to require reserves to be set aside for debt service or O&M costs, and we have assumed reserves of 10 months of operating costs to satisfy potential requirements from lenders.

Cash Flow

Cash flow analysis of the simulated project showed a farm that was not profitable under the planned 2030 operational conditions. A reduced cash flow statement for the 25-year operational life of the project is shown below. The Levelized Cost of Energy for the project sits at 198.9/MWh, which is higher than NREL estimates for the site.

Figure [8]: Reduced Cash Flow Statement

Year	0	1	5	10	15	20	25
Production (GWh)	876.8	876.8	876.8	876.8	876.8	876.8	876.8
Revenue (M$)	0	35.1	38.0	42.0	46.4	51.2	74.6
Property Tax Value (M$)	0	1359.4	1359.4	1359.4	1359.4	1359.4	1359.4
Total O&M (M$)	0	74.1	82.8	96.4	113.8	135.8	164.1
EBITDA (M$)	0	-38.994	-44.9	-54.5	-67.4	-84.7	-89.5
Cash Flow from Operating (M$)	0	-18.551	-26.2	-39.06	-58.8	-83.0	-87.4
Cash Flow from Investing (M$)	-1849.2	-1.184	-1.4	-1.7	-2.1	-4.3	136.8
Cash Flow from Financing (M$)	1849.2	10.2	16.6	27.9	44.3	0	0
Total After-Tax Returns (M$)	-2375.6	-1791.4	-1661.8	-1665.0	-1671.8	-69.8	67.7

Optimization

While we were confident in our research on cost estimates, and method of estimating revenue for the project, we wanted to adjust the cost estimates and revenue in order to describe the conditions that would be necessary for the project to become profitable. We believe the main reason for the project's lack of profitability is that the operation as a Merchant Plant keeps it from seeing the higher PPA prices that may be possible if an offtaker wanted to purchase offshore wind energy for their own CER or REC reasons. Thus, after adjusting all installation cost estimates to the extreme lower end of what might be possible in the future, we looked at what the wholesale price of power might have to be for the project to be profitable as a Merchant Plant. Adjustments include a 15-30% increase in the rate of installation with no accompanying increase in cost, a 50-80% reduction in engineering management and design costs, and a slight reduction in O&M costs. This would only be realistic if the design and construction contractors completed the project at a steep discount. An improved reduced Cash Flow statement for the site is shown below. The LCOE for this project sits at 137.8$/MWh, much lower than the previous version of the project.

Figure [9]: Reduced Cash Flow Statement

Year	0	1	5	10	15	20	25
Production (GWh)	876.8	876.8	876.8	876.8	876.8	876.8	876.8
Revenue (M$)	0	105.4	114.1	126.0	139.078	153.6	169.54
Property Tax Value (M$)	0	1123.8	1123.8	1123.8	1123.8	1123.8	1123.8
Total O&M (M$)	0	63.4	68.8	76.5	85.6	96.3	108.8
EBITDA (M$)	0	42.0	45.3	49.4	53.5	57.3	75.7
Cash Flow from Operating (M$)	0	25.1	30.9	39.3	49.1	58.5	77.1
Cash Flow from Investing (M$)	-1577.3	-1.4	-1.5	-1.7	-2.0	-2.0	90.7
Cash Flow from Financing (M$)	1577.3	-14.4	-19.3	-26.6	-35.3	0	0
Total After-Tax Returns (M$)	-1098.5	552.285	28.8	3.1	1.9	44.2	151.6

This situation would require power prices 3 times higher than the NREL Cambium estimates for the region in 2030, at an average of $160/MWh assuming the yearly 2% increase. We know that the combination of changes made to project cost and revenue estimates may make it unrealistic, but we believe they may represent the most feasible path to profitability for the project. We also know that there may be benefits and potential revenue sources that estimates could not capture that would improve profitability, such as other payments for the production of green energy, or payments made to this farm by other new farms in the GOM for use of its transmission tie lines.

Auction Bid

Given the fact that we were unable to find a realistic way to make the farm a reasonable investment, it is not likely that we would recommend a bid on the lease. However, with our more extreme assumptions of installation costs and future power prices, we could develop a bid price for the 23,160-acre lease area. Lease prices as high as $9000/acre were seen in some regions on the Atlantic Coast [25], but our estimate was much lower, at around $2100/acre for the four sites, with a total lease price of $50M. The cash flow statement above reflects this price in the installation cost and LCOE metrics. We arrived at this lease price after the development of the more extreme model, by comparing the financial output parameters of the tool under different price scenarios, and aiming to find a competitive price that would still give the project a positive internal rate of return by the end of the project.

GIS References

Type	Name	Link
ArcGIS Online Source	Texas-Louisiana Continental Shelf Bathymetry - Gulf of Mexico (GCOOS)	https://gisdata.gcoos.org/maps/0dd0fb1fcd764451b4dc22af5f02cb1e/explore
ArcGIS Online Source	TxDOT Texas Highway Freight Network	https://gis-txdot.opendata.arcgis.com/datasets/txdot-texas-highway-freight-network/explore
ArcGIS Online Source	USDOT North American Rail Lines	https://data-usdot.opendata.arcgis.com/datasets/north-american-rail-lines/explore
ArcGIS Online Source	Gulf of Mexico BOEM & BSEE Layers	https://www.arcgis.com/home/item.html?id=f568a0ea58f841f284dd84fabd93dbb3
ArcGIS Online Source	Major Hurricane Tracklines	https://www.arcgis.com/home/item.html?id=248e7b5827a34b248647afb012c58787
ArcGIS Online Source	Federal Lands	https://www.arcgis.com/home/item.html?id=5e92f2e0930848faa40480bcb4fdc44e
ArcGIS Online Source	BSEE US GOM Active Leases	https://www.arcgis.com/apps/webappviewer/index.html?id=5eb6a6a1f75b4501b3d14f41f043815a
ArcGIS Online Source	BSEE US GOM Pipelines	https://www.arcgis.com/home/item.html?id=446f760c682e4750ab6910523b77ff91
ArcGIS Online Source	Shipping Fairways	https://www.arcgis.com/home/item.html?id=7ba696c12aa34f2f8c19c96c4a70091f
Online Mapping Tool	U.S. Energy Infrastructure Map	https://atlas.eia.gov/apps/all-energy-infrastructure-and-resources/explore
Online Mapping Tool	Depth Map: Gulf of Mexico	https://usa.fishermap.org/depth-map/gulf-of-mexico-tx-fl
Online Mapping Tool	Galveston Zoning Tool	https://www.galvestontx.gov/601/Planning-Development-Division
Online Mapping Tool	NREL WindProspector	https://maps.nrel.gov/wind-prospector/

Ref. 1

Data File	Vortex Wind Resource Grid File	Locally Saved

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