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TRIDENT WIND COLLABORATIVE

Project Development Report Milestone

PREPARED FOR

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COLLEGIATE
WIND COMPETITION
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JMU
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Project Development Report

Neptune's Breath Wind Farm Development

By Trident Wind Collaborative (TWC)

James Madison University (JMU)

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Abstract

Trident Wind Collaborative (TWC), launched at James Madison University in 2022, presents *Neptune's Breath* Wind Farm sited offshore in the Gulf of Mexico (GOM), United States. The annual energy yield of this wind power plant is 9,199 GWh at a Levelized Cost of Energy (LCOE) of 101 USD/MWh while sourced from the second-highest-rated wind resource in the Gulf and with minimal environmental impact as suggested in Figure A. Our project features a novel business model through which a power purchase agreement (PPA) is established with AirProducts, Inc. (AP), with wind energy supplied to their hydrogen production facilities built out along the Gulf Coast. The Infrastructure Investment and Jobs Act (IIJA) (Public Law 117-58 also known as the "Bipartisan Infrastructure Law") mandates for the U.S. Department of Energy to launch major clean hydrogen initiatives, thus addressing climate concerns as well as the rising prices of natural gas, and simultaneously provides AP an opportunity to produce a greener hydrogen product [1].

1.0 Opportunity

The Trident Wind Collaborative (TWC) proposes the first offshore wind farm in the GOM off the coast of Galveston, Texas. *Neptune's Breath* wind farm will become one of the nation's largest offshore wind farms in the nation, with the deployment of 175 Vestas 236-15 MW wind turbines across 216 square miles of contiguous ocean lease-space. TWC anticipates that the power generated by *Neptune's Breath* will enable the production of *green* hydrogen which is produced without processes that involve fossil fuels, and thus will promote the growth of this important form of sustainable energy. The offtaker that can accept all the power produced by *Neptune's Breath*, and utilize it to produce a green hydrogen product, will earn themselves both a business and an environmental advantage.

Galveston Bay and adjacent Trinity Bay present an exciting opportunity to partner with AP, the principal business of which is to supply gasses and chemicals for industrial purposes. AP already owns and operates two hydrogen production facilities that surround the larger bay area, with additional facilities connected through a 180-mile pipeline. As part of their initiative, the company boasts that this pipeline "connects our existing Texas and Louisiana systems, [uniting] 22 hydrogen plants and 600 miles (965 km) of pipeline, with a total capacity of over one billion SCFD (1.3 million Nm3/hr)" [2].

AP is at present building a new facility in Texas City, adjacent to the where we propose to land our export cable. Shown as yellow pins in Figure 1, are the three facilities that border water. Each of these facilities requires large quantities of electric power to produce a large quantity of chemicals and gas products. Given the significance of climate change and critical importance of developing mitigation strategies, large corporations have advocated for greater access to power generated from renewable sources. Further, in response to the Infrastructure Investment and Jobs Act (IIJA), the U.S. Department is implementing major clean hydrogen initiatives [3]. It is good business for TWC and AP to position themselves to respond to these initiatives.

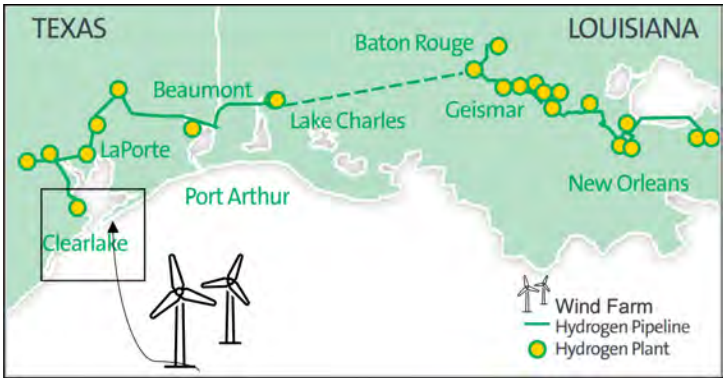


Figure 1: Map of the coastal region showing AP facilities and hydrogen pipeline along the Texas Gulf Coast. The black square represents the area covered shown in greater detail in Figure 2.

The partnership between TWC and AP will impact both companies favorably. The construction of AP's new facility in Texas City area is intended to be served by a new natural gas-fired generation station, but TWC is negotiating with AP to abandon those plans and instead partner on the *Neptune's Breath* wind project. Such a move, away from natural gas and toward a renewable solution, would enable AP to avoid locking into a fossil fuel-based energy source for decades, a scenario for which a finite number of resources will become more inaccessible and expensive over time as well as contribute additional greenhouse gas to our environment.

2.0 Site Description and Energy Estimation

A preliminary assessment of the wind resource in the Gulf was conducted initially by analyzing wind data accessed from Galveston Airport. It was determined that winds are predominantly southerly during at least seven months each year [4]. Average annual wind speeds of at least 7 m/s at a height of at least 90 meters present the optimal conditions for developing offshore wind farms [5]. The site selected by our team meets these criteria, as the average annual wind speed was estimated at between 7.5 and 8 m/s [6]. It is critical to ensure that infrastructure deployed is able to withstand the effects of salt water and remain in a safe operating condition over a long period. At depths of 10 meters, the winter water salinity rates for our proposed area range between 3.25 and 3.325% and during the summer between 3.15 and 3.2%. The average winter water temperature within our area is between 15.5 and 16 ℃ and during summer between 28 and 29 ℃. The average winter air temperature in our area is 20.5℃ and during summer around 30 ℃. The temperature variance determines the nature of insulation to be used in the turbines. Mechanical and electrical mechanisms associated with the turbine are designed to operate within a prescribed temperature range in order to operate at full capacity. If the range is exceeded then the lifespan of the turbine can decrease significantly. If air near the turbines contains salt in fine droplet form, they can induce corrosion. Droplet size, volume conductivity, and position of the droplets relative to conducting material can impact insulating materials [7].

2.1 Site Selection and Characteristics

The project boundary is defined by the blue single-hatched area in Figure 2, an area that presents several attributes that suggest a highly suitable location for this venture. This site projects an average annual wind speed between 7.5 and 8 m/s and accounts for 216 contiguous square miles of open ocean that lie between primary shipping lanes [8] as denoted with yellow lines in Figure 2. This area does not overlap with any other spaces in which offshore structures such as oil rigs (represented with green dots) already exist [9] and avoids conflict with mooring fields for tankers (black shaded region) and the area of ship traffic congestion (purple line). The only time during construction that operations may impact ship traffic is while cable is laid through the area. Further, this region is sufficiently distant from the coast to avoid interrupting established fishing grounds [10]. It is apparent that the broader region within which our area resides coincides with a low-floor airspace military training zone [11]; however, given the large number of gas and oil rigs that are already present in this region, it is assumed that it will be feasible to engage with the Department of Defense Clearinghouse to secure permission to build out a wind farm.

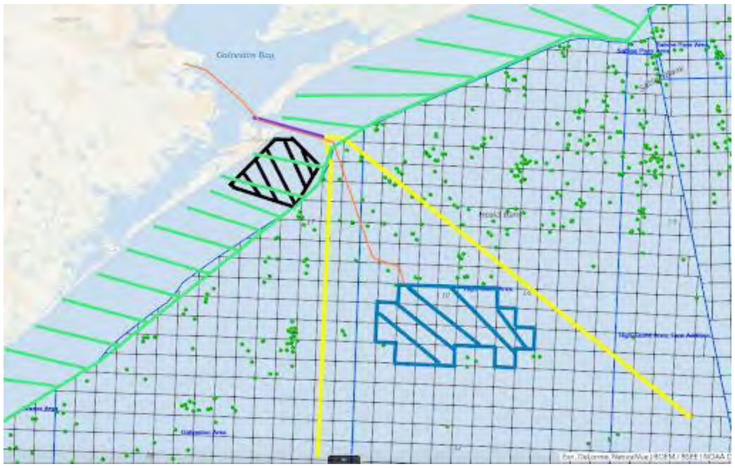


Figure 2: Outline of lease area (blue), shipping lanes in yellow, and oil rigs in green dots.

The Port of Galveston is available for staging, operation, and maintenance, and is close enough to our project site to provide necessary support (less than a day's sail away). The Port of Galveston features an access channel width of 165 meters, water depth of 12.2 meters, unrestricted overhead clearance, and a quayside of 225 meters. As of 2013, this port has been updated to accommodate large-scale offshore wind projects [12].

Data Sources and Modeling

Our first step toward characterizing the wind resource in our area was to identify and access relevant wind data. Initially we acquired data from the National Buoy Data Center in a location that was nearest to our lease space [13]. The variables in the buoy data set included only average wind speed, temperature, and wind directions in increments of one hour. The absence of standard deviation values proved to be a major hurdle in modeling. Since wind power is the cube of wind speed, it is crucial to include standard deviation values that are derived from non-averaged values of wind speed [14].

The company, Vortex, was contacted to provide a more robust wind data set. Vortex "uses a supercomputer cluster to run a non-linear flow model (WRF) that scales large atmospheric patterns (NCAR-NCEP, ECMWF and NASA) down to fine spatial resolutions (SRTM), generating modeled wind resource data suitable to be used where and when no measurements are as yet available" [15]. The Vortex data set specific to our site included standard deviation values and ten minute intervals, thus prompting a shift from the original buoy dataset to the Vortex dataset. The turbine power curve was estimated by scaling up the default Vestas V136-3.45 MW Class IIIA turbine to 15 MW, and the thrust curve data was retrieved from the NREL 15 MW offshore reference turbine [16]. Thrust coefficient data points (red line) were available as shown in Figure 3 between 0 and 25 m/s. After the turbine data was loaded, turbine layout was determined next.

Furrow wind modeling software was utilized to estimate the annual energy yield at our site, driven by meteorological and turbine performance described previously. The Furow software calculated our wind resource throughout our intended area of deployment, showing that the prevailing winds are from the southeast as seen in the wind rose presented later in this section. The wind resource layer was informed by the wind speed values and standard deviations and atmospheric parameters obtained from Vortex. Furrow was then used to calculate the annual energy yield and capacity factor for our wind farm. Results follow below.

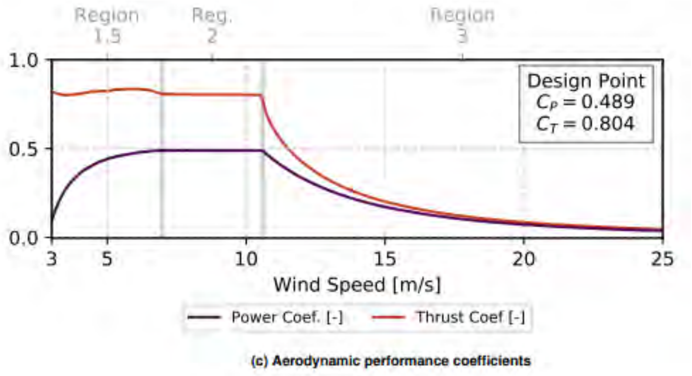


Figure 3: Power and thrust coefficients for NREL 15 MW offshore reference turbine.

2.2 Wind Power Plant Design

Foundation Type

In terms of choosing foundation type, it is important to ensure that the structure is capable of supporting vertical loads (e.g. weight and density of the turbine) and horizontal loads (e.g. force of the wind, ocean currents, and waves impacting the turbine) associated with each wind turbine. We selected a jacket foundation given its economic attractiveness, structural rigidity, and opportunity for it to enhance marine ecosystems. The first consideration is the geological characteristics of the seabed; in the Gulf we are dealing primarily with clay and concentrations of silt in neighboring locations, as visualized in Figure 4. The health of local marine life is also an important consideration when determining the optimum foundation for a turbine. Jacket structures in particular have more usable surface area compared to monopiles and "provide the most habitat for species to colonize and become established...which could provide greater amounts of habitat opportunities than could monopiles, tripod, tri-pile, jack-up, suction bucket, and gravity foundations" [17].

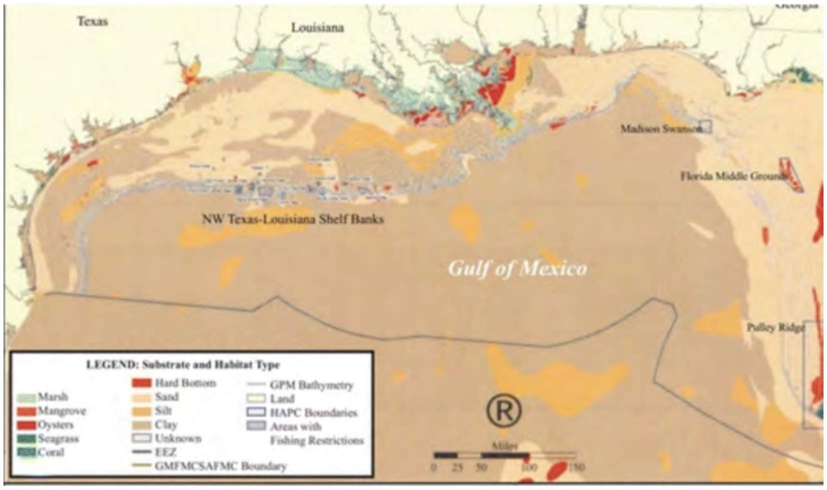


Figure 4: Map of seabed geology and habitats.

Wind Turbine

The Furow software required specific turbine details including rated capacity, hub height, rotor diameter, cut-in speed, cut-out speed, low-temperature shut down, high-temperature shut down, and thrust and power curve. The TWC team selected the Vestas V236-15.0 MW wind turbine. This model has a swept area of 43,742 square meters with a blade length of 115.5 meters. This model of wind turbine enables capacity factors as high as 60% in highly favorable wind conditions. Another advantage of this model is that it projects a lifetime of 25 years and can withstand wind speeds up to 50 m/s. Finally, each wind turbine may generate as much as 80 GWh per year [18]. Our project assumes a hub height of 150 meters to optimize wind energy conversion.

Site Design

Our turbine layout was oriented in a manner that considers that the prevailing wind direction is out of the southeast at 157.5 degrees. The 175 Turbines intended for this project will be installed along a two-dimensional grid that aligns with this direction. The number of turbines is the largest number that could be accommodated within our specified lease area as depicted in

Figure 5. In terms of spacing, each turbine is no closer than 1,652 meters side-to-side or front-to-back. This spacing helps reduce losses from park and the wake effects, thus enabling maximum energy capture. This distance was calculated by applying a rule of thumb method of multiplying the turbine diameter (236 m) by 7. According to the Wind Farm Planning Handbook, "A wind-farm layout must take into account that turbines have substantial 'wakes', which interfere with each other depending on wind direction and spacing. The general rule of thumb for spacing (the '5r-8r rule') is five times rotor diameter abreast and eight times rotor diameter downwind" [19]. Several turbines that were initially intended were later removed in order to avoid infringing on airspace outside the lease area as well to avoid any potential military or future wind farm development complications.

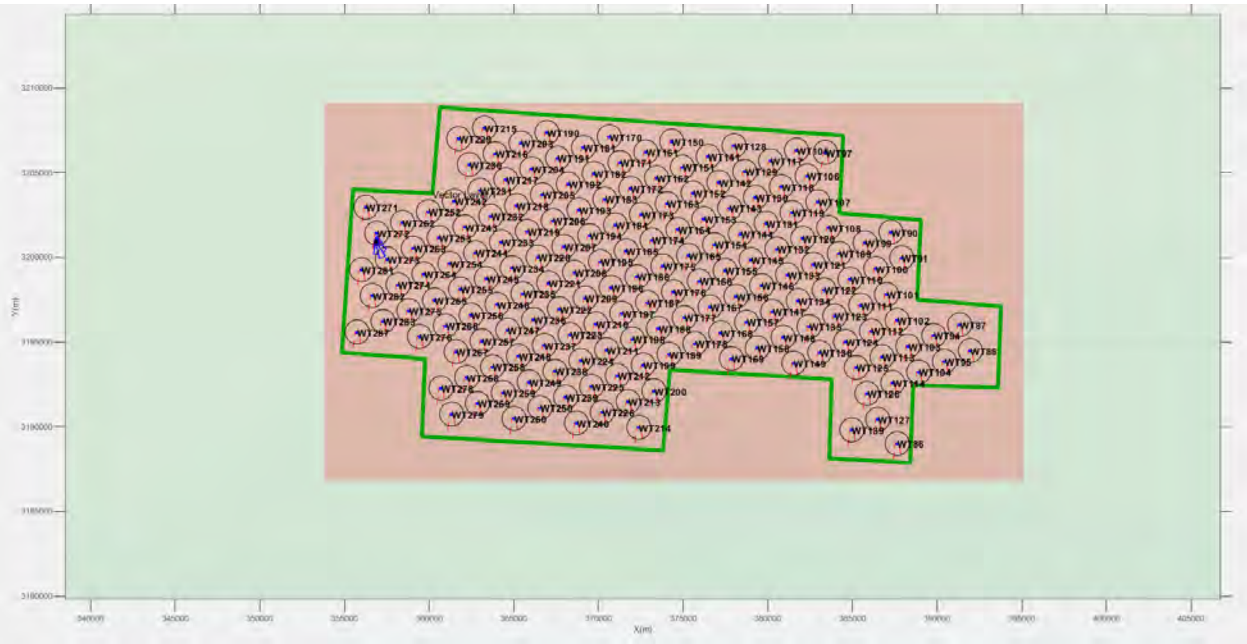


Figure 5: Turbine layout oriented to 157.5° prevailing wind direction within the calculated wind resource area (red) generated.

Operations and Controls

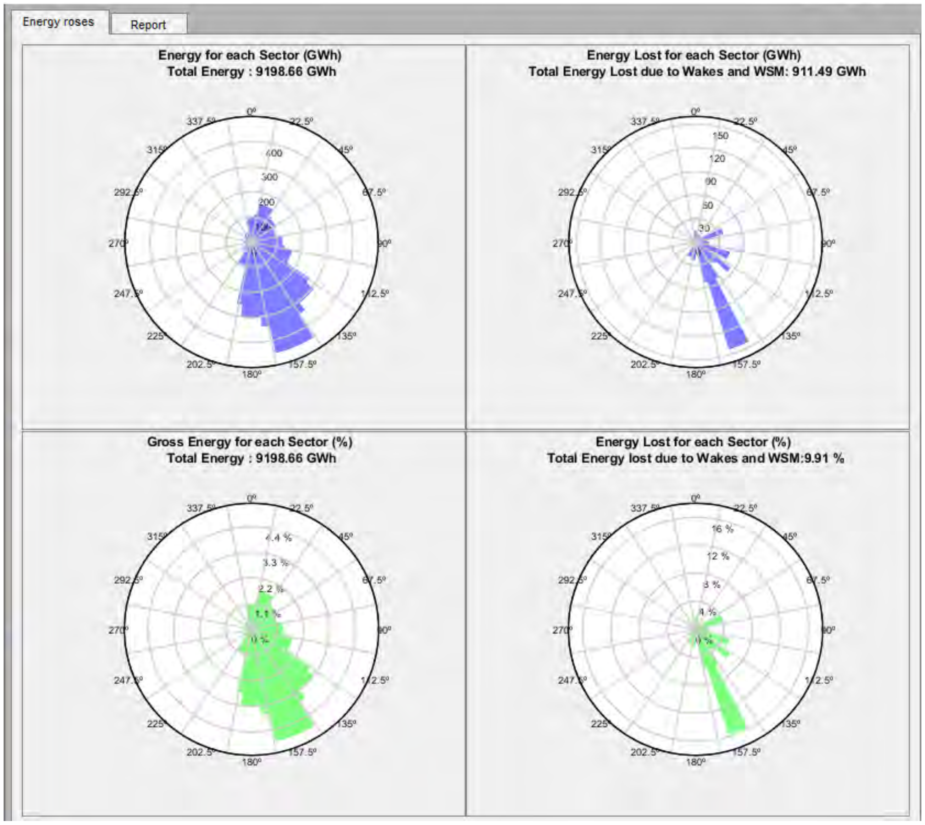
The optimization of energy output is heavily dependent on not only positioning, but controls of the turbines within our lease area. The implementation of wake-steering methods involves the "misalignment of upstream turbines with the wind direction to deflect wakes away from downstream turbines, increasing net wind plant power production" [20]. The effect of wake steering benefits is amplified by the fact that our offshore wind farm has a less turbulent source of wind compared to typical onshore sites. Specifically, "an increase in percentage AEP (annual energy production) gain is expected with decreasing turbulence intensity because wakes dissipate at a slower rate with stable, lower turbulence atmospheric conditions, resulting in more opportunities for wake steering to mitigate wake losses" [20]. Moreover, similar wind farms have seen increases in power production of "7% and 13% for moderate wind speeds near the site annual average and up to 47% for low wind speeds" [20].

Energy Yield

Table 1 presents meteorological conditions and projected energy yield as derived from our Furow analysis as informed by the Vortex data set described previously. The results of this analysis as depicted in Figure 6 suggest that the majority of energy generated is associated with winds from the prevailing direction. The annual energy yield projected is 9,198,654 MWh.

Table 1: The atmospheric conditions and energy yield of our designated wind farm.

Atmospheric Conditions		Energy Yield	
Hours per Year	8760	Total Capacity Installed [MW]	2625
Wake Model	Jensen	Number of turbines	175
Air Density [kg/m^3]	1.2	Gross Yield [MWh]	9198659.4
Mean Free Wind Speed [m/s]	7.6	Gross Capacity factor [%]	40
Mean Wake Affected Wind Speed [m/s]	7.1	Gross Full load hours	3504.6
Ambient TI [%]	9.2	Array Efficiency [%]	90.1
Total TI [%]	10.1	Net Yield [MWh]	8287166.8
		Net Capacity Factor [%]	36
		Net Full load hours	3157



Energy for each Sector (GWh)
Total Energy : 9198.66 GWh

Energy Lost for each Sector (GWh)
Total Energy Lost due to Wakes and WSM: 911.49 GWh

Gross Energy for each Sector (%)
Total Energy : 9198.66 GWh

Energy Lost for each Sector (%)
Total Energy lost due to Wakes and WSM:9.91 %

Figure 6: The total energy yield is 9,198.66 GWh using the Jensen wake loss model as shown in the wind roses above.

2.3 Permitting and Logistics

There are several major stakeholders involved in the permitting process. The most important is the Bureau of Ocean Energy Management (BOEM) which has jurisdictional authority in federal waters and follows a four-phase process that includes *planning analysis*, *leasing*, *site assessment*, and finally *construction and operation*. For the first two phases, there are two major groups involved in this project: Wind Energy Transmission Texas, LLC (WETT) and Electrical Reliability Council of Texas (ERCOT). Both cooperate to ensure that all protocols are met and operating guides regarding transmission processes are addressed. In addition, WETT is overseen by the North American Electric Reliability Corporation (Texas RE) [21].

Once these groups have developed a plan, BOEM must approve the company's Site Assessment Plan (SAP) and then the Construction and Operations Plan (COP) which contains thorough descriptions of all the activities that will take place both on and offshore. It will also include all direct and indirect socioe-conomic and environmental impacts that may result from the implementation of this project [22].

Permitting

At the same time that BOEM is assessing the project, there are also federal, state, and local permitting processes that occur. The federal statute, EPAct 2005, was a turning point for offshore wind, as it officially granted legal permission for offshore wind projects to develop and laid out guidelines for developers to follow.

Federal permitting for offshore wind is addressed in 43 U.S.C. §1337(p)(1) [16] which entrusts the issuance of federal permits for offshore energy activity under the jurisdiction of the Secretary of the Interior. The DOI follows Section 388 which "authorized the Secretary of the Interior, in consultation with other federal agencies, to grant leases, easements, or rights-of-way on the OCS for certain activities...over 'the production, transportation, or transmission of energy from non-hydrokinetic renewable energy projects on the OCS' [23]."

For state permitting, the cables will fall under state regulation per the Coastal Zone Management Act (CZMA) [24]. Onshore tie-in locations fall under state and local onshore permitting. The tie-in location for this project will be at the La Porte substation which rests in La Porte, Texas, thus their permitting regulations will be followed [25].

The project also must pass guidelines within the National Environmental Policy Act (NEPA), which entails environmental regulations and thresholds that must be met associated with the Endangered Species Act, Marine Mammal Protection Act, and the Migratory Bird Treaty Act.

In addition to the SAP and COP, BOEM must approve the company's Facility and Design Report (FDR), and the Fabrication for Installation Report (FIR). The site location must also be approved by the U.S. Department of Defense (DOD) and Federal Aviation Administration (FAA). From here, the National Oceanic and Atmospheric Administration (NOAA) and Advisory Council on Historic Preservation, NOAA Fisheries, and the U.S. Fish and Wildlife Service (USFWS) must ensure that the project meets the demands of several environmental acts. The Environmental Protection Agency (EPA) is also a part of this environmental approval process as well as the U.S. Army Corps of Engineers (USACE). Finally, the U.S. Coast Guard (USGS) must approve the project for navigational lighting and aircraft detection lighting systems [26].

Transportation

Several types of vessels are utilized for offshore development. Requirements include six to eight turbine installation vessels. Feeder vessels transport heavy cargo such as turbine structures and blades to installation sites. In a shallow water system, these vessels can self-elevate and provide their own support. In deeper waters, these vessels are engineered to act as heavy-lift vessels. Liftboats, acting as additional service and feeder support vessels, are mainly utilized in shallow waters. As we expect to approach more shallow waters, it becomes important to understand the limitations of our vessels and the need for support vessels.

For laying and burying cables, a trenching vessel and field development vessel are utilized. To further assist with the transmission, an array cable laying vessel connects individual turbines to the offshore substation, while an export cable laying vessel is used to connect the offshore to the onshore substation. Finally, an additional vessel is responsible for positioning of the offshore substation. Additionally, crew member vessels are equipped with "walk-to-work gangways" and can house at least 40 personnel.

On average, vessels cost around $180,000 per day to use, so it is important to keep in mind that the duration of the project construction phase could make this a costly expense over long periods of time. This estimate does not include stresses and costs of ensuring compliance with the Jones Act, which could cause a 1.4% increase in costs [27]. There is in fact only one vessel, now under construction, that will be compliant with this act, it is Dominion's Charbydis which has an anticipated construction cost of USD 500 million in 2022 dollars [28].

Transmission and Interconnection

Our lease area extends 62 miles offshore with easy access to and from ports. The team has chosen our onshore interconnection point to be at La Porte substation which presents a maximum capacity of 165 MW [29]. We chose this interconnection site due to the numerous benefits that exist within a close vicinity of the substation. The site is conveniently located within close range of two ports, Galveston and Texas City, thus enabling an efficient and cost-effective interconnection option.

At maximum generation, *Neptune's Breath* will introduce a surplus of power at the La Porte substation. To negate the challenge of excess energy that might require shedding we will develop and implement a hydrogen offtake plan in coordination with AP, which has the capacity to receive any excess power available and convert it into green hydrogen. AP, located along the shore of Trinity Bay, is in an ideal position to partner with TWC on this project, given its proximity both to our intended point of interconnection site as well as the ports that will support this project.

2.4 Potential Impacts and Mitigation Strategies

Important environmental surveys will be conducted which include: benthic, pelagic, ornithological, and marine life surveys. Second, a coastal process survey will be conducted using meteorological station structures with attached sensors. This survey will consider the potential for erosion and sedimentation being caused by the wind farm on the coastline itself. Additionally, seabed surveys analyze and track all conditions occurring on the seafloor, and all its stable and variable characteristics. Finally, human impact studies will examine how nearby coastal communities will be affected by the offshore wind farm [30].

There are three categories in the avian community that are observed: bats, local birds, and migratory birds. Bats are especially consistent in emerging at dusk just before or after the arrival of a storm system [31]. For local birds, the coastal region has observed endangered species of local waterfowl such as the Brown Pelican [32]. There are 73 species of trans-Gulf migratory birds, although several bird deterrent technologies have been considered to mitigate the risk to these migratory bird species [33].

In the aquatic zone, the most heavily impacted ecosystem will likely be the infaunal benthic community. Once cable construction efforts conclude, the new, structured, sea floor from our foundations will support the building of a stronger epifaunal benthic community and a new shellfish habitat. This will lead to a stronger ecosystem with greater biodiversity, and an estimated effect of up to a 60 fold increase in the availability of food within the wind farm region for fin-fish and other organisms when compared to the indigenous infauna community [34]. When considering the construction aspect of the project, the predicted habitat loss is expected to be negligible and recover quickly once the project is completed. The scale of the habitat destruction from the decommission phase of the project depends largely on whether the sub-structures of the turbines are left in place or removed. If left in place, the reefs that have grown over the lifetime of the project will be left behind and maintain the ecosystem they created. If removed, it could lead to large-scale reef destruction, and in turn lead to greater habitat destruction. Special considerations must be made during both of these phases of the project, as large vessels increase water turbidity and block sunlight which can lead to habitat destruction.

According to historical trends, a “direct hurricane hit” is only likely to impact the Galveston area every 9.3 years. Yet on average, the Galveston area will be hit by the “clean side” of a hurricane at least every 2.6 years [35]. In this case, part of the hurricane has already made landfall, and rotates counterclockwise to come down from the northeast and hit the Galveston area with less force. Hurricane season in Texas ranges from the beginning of June to the end of November. It is key to note that the peak wind speed generated from hurricanes can reach over 150 mph, which is survivable by the wind farm. Turbines use anemometers to measure wind speed and cut out when it surpasses 55 mph. Hurricane season also has an effect on wave height, typically contributing to its peak in the months of August and September. Data collected over 50 years suggests that the average wave height in our area is at about 10 meters on average, and could reach but not exceed 13 meters [35].

While the end result of this project is likely to have a positive impact on the surrounding communities, throughout the drafting process of the proposed wind farm design, there have been many considerations of risks and flaws that could potentially plague site design. In an offshore wind space, there are potential risks that need to be addressed in order to make a project feasible; factors such as the existence of military training routes or MTRs, shipping lanes, other existing semi-permanent structures like oil rigs, the incorporation of an Aircraft Detection Lighting System or ADLS, weather patterns, and the obstruction of natural habitats and protected wildlife. Our project will be meticulously designed in order to address as many of these risks as possible, so that the risk of a full-scale buildout could be de-escalated as much as possible.

One potential risk of our site is the existence of a low floor airspace military training zone [35]. The existence of flight routes within the planned space does inherently incorporate some risk, because certain areas of the project then have to be permitted by the DOD. The DOD does not have to grant permission to our request to place turbines in their airspace, which suggests that coordination with them is essential to ensure compliance with any and all requests pertinent to constructing large, rotating structures in that area. One thing that does help to relax the aforementioned risk is the existence of numerous gas and oil structures already present in those very same MTRs.

The size of the selected turbine selected, the Vestas 236-15MW, extends as high as 800 ft as each blade projects upward vertically. One large risk is the visibility of turbines, especially during nighttime flight training. In order to mitigate this risk, it is important that during the installation of turbines bearing such a large vertical footprint, the implementation of an Aircraft Detection Lighting System is incorporated. Any and all turbines that exceed a height of 700 ft must be equipped with lights, both at the mid-mast and the highest point of the nacelle. Red wavelength LEDs should flash 30 times per minute or once every two seconds in the infrared light spectrum, with wavelengths of 800 to 900 nanometers to ensure compatibility with night vision goggles used by pilots.

Finally, the issue of "NIMBY" does not apply. The distance from the northern tip of Galveston Island to the wind farm is roughly 62 miles and the wind farm will not be visible from nearby coastal lands along the GOM.

2.5 Plan for End of Project Life

The cost of the decommissioning accounts for 2-3% of the total capital, half of this goes to removing the foundation and must be escrowed by the developers in the early stage to guarantee that it can be decommissioned cost-effectively [36]. The first step in decommission involves de-energizing the turbines from the grid. Next, a heavy lift vessel is transported to the location, and reversed installation techniques are applied. Recycling methods for turbine blades are in development, this impacts the overall sustainability of turbines. The blades are made to withstand hurricane-force winds and are made of fiberglass, so they cannot be crushed or repurposed in as straightforward a manner as other turbine components which are manufactured from steel, aluminum, copper, and other materials. There are some alternatives available to decommissioning such as repowering or refurbishment in which drivetrain and rotor elements are rebuilt. This approach may double the lease time from 20-25 years to 40-50 years. As for the subsea cables, the current recommendation is to maintain them anchored to the seabed floor because removal processes can cause serious damage to neighboring environments, as well as increase the cost of decommission.

3.0 Financial Analysis

Our financial analysis was calculated using the System Advisory Model (SAM) software with calculations and conformations generated through Furow and Excel® analyses. Our financial analysis is influenced by the information listed in the previous sections as well as the current global and domestic energy market dynamics, precedents set by recent domestic offshore wind projects, and a detailed analysis of AP strategy and the economics of their hydrogen business vis-a-vis recent increases in gas prices.

3.1 Cost Analysis

The estimated capital expense for *Neptune's Breath* is 3216.23 $/kW (Turbine capital & soft costs = 1859.67 $/kW, Balance of System costs = 1,007.98 $/kW, lease costs = 348.58/kW). The data for this estimate is derived from SAM-estimated cost of a 600-MW wind farm comprising 8-MW Turbines set to 2022 dollars [36]. Wind farms achieve strong economies of scale when increasing the size of a wind farm and the size of turbines used in the project; implying that an increase in one or both of these aspects will push cost/kW down. TWC was not able to find data to document the exact economies of scale for our proposed wind farm, but we compensated for this by estimating the cost elasticity of turbine size and factoring that into our initial capital costs.

Our analysis led to the estimation of annual operating expenses at $90/kW/yr [36]. A downward trend in estimates of these costs going forward was also seen and suggests that annual operating expenses will fall below $80/kW/yr by 2030. However, once a project has begun operation, the $/kW/yr is expected to increase gradually as equipment ages. To account for the increase in maintenance over the years as well as the downward trend in market $/kW/yr, TWC's model used a conservative escalation rate of 2.5% per year.

3.2 Business Economics and Financing Plan

The financial structure of the investment in *Neptune's Breath* project is a partnership with flip debt between the developer (TWC) and the investor (AP). Pre-flip, the investors receive 80% of the project cash and 70% of the tax benefits. Post-flip, this is to become 20% of project cash and 30% of tax benefits. The structure of the debt incurred by the developer will have 1.5% of the total debt paid upfront, with the remainder being paid out over 20 years with a 5% annual interest rate. The *Neptune's Breath* project will also take advantage of two key federal incentives to aid the project financially: a $0.02/KWh production tax credit (PTC) and the 50% first-year federal bonus depreciation as enabled by the Economic Stimulus Act of 2008. AP is not only being sought as an investor in *Neptune's Breath* project, but also the PPA partner with TWC. This PPA will be set at 0.11 $/kWh in the initial year of the project with a 4% annual escalation rate and will provide energy to operate AP's new Texas City anhydrous ammonia plant.

Before the development of *Neptune's Breath* project, AP had intended to construct a combustion turbine plant to meet their power needs at the new Texas City plant. Gas used for energy generation has a capacity weighted average LCOE of 0.1238 $/kWh [38] which requires a cost to AP of 0.0138 $/kWh more than the 0.11 $/kWh PPA deal with TWC. Not only would shifting investment from building a natural gas-fed and powered hydrogen plant into the wind-powered and fed (water being the feedstock) project save money for AP, it would allow them as well to market their various hydrogen products (with a focus on anhydrous ammonia produced by the Texas City plant) as 100% green products. This would enable them to charge higher prices for these goods, as green products have a noticeable mark-up in prices compared to non-green substitutes.

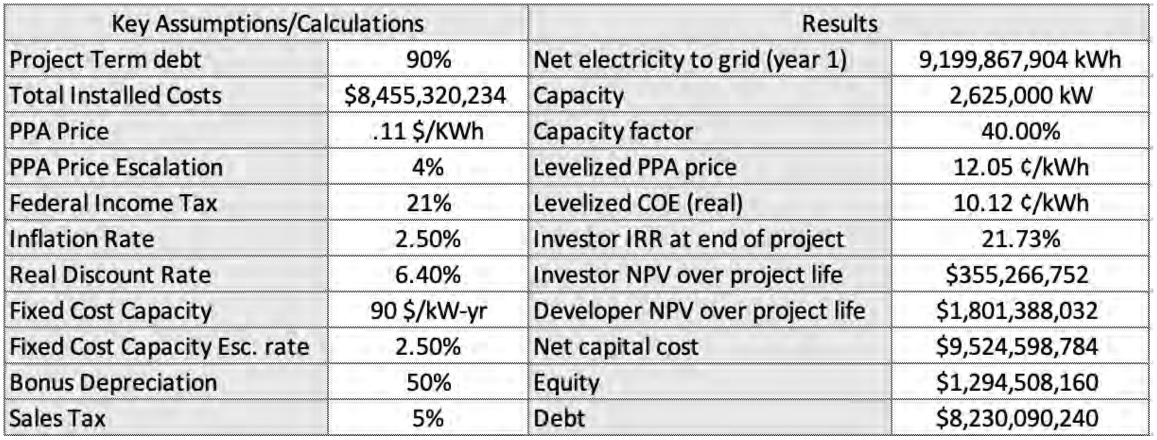
The escalation rate of the PPA is set at 4% to account for two main factors. The first factor is to account for rising natural gas prices, which stems to an extent from the current war in Ukraine (there has been a 40.15% increase in natural gas prices since the conflict began [45]). The second factor is to account for the trend of rising PPA prices seen over the past several years [39].

3.3 Financial Projections

When looking at the project's lifespan as a whole, it's observed that over the first 20 years of the project, TWC as the developer will net $4.2 Billion in after-tax returns. However, the lease is for 33 years which has the potential to allow for at least 13 more years of energy production. Over this extended time frame, there will be additional costs as O&M will be more expensive and repowering efforts may likely need to be undertaken. Yet, the plant would generate an additional $4.79 billion for TWC over the 21-25 years of the project alone. Thus the *Neptune's Breath* project has a strong chance of being an economically viable project well past its original 20-year lifespan.

As SAM was utilized we considered key assumptions and ran calculations informed by knowledge procured through online sources, experts in the field, and current economic standings. The development of a wind farm in the GOM provides unique challenges financially, as one has not yet been built in this region. Certain assumptions such as inflation rate and real discount rate were already provided in SAM while other significant parameters such as fixed cost capacity and its escalation rate were based on financial data procured from previous offshore projects.

Table 2: Key Assumptions and Results of SAM analysis.



Key Assumptions/Calculations		Results	
Project Term debt	90%	Net electricity to grid (year 1)	9,199,867,904 kWh
Total Installed Costs	$8,455,320,234	Capacity	2,625,000 kW
PPA Price	.11 $/KWh	Capacity factor	40.00%
PPA Price Escalation	4%	Levelized PPA price	12.05 ¢/kWh
Federal Income Tax	21%	Levelized COE (real)	10.12 ¢/kWh
Inflation Rate	2.50%	Investor IRR at end of project	21.73%
Real Discount Rate	6.40%	Investor NPV over project life	$355,266,752
Fixed Cost Capacity	90 $/kW-yr	Developer NPV over project life	$1,801,388,032
Fixed Cost Capacity Esc. rate	2.50%	Net capital cost	$9,524,598,784
Bonus Depreciation	50%	Equity	$1,294,508,160
Sales Tax	5%	Debt	$8,230,090,240

Our SAM generated our financial summary that included our “After Tax Cash Flow” as seen in *Figure* 7. Our greater initial influx of capital from years 1-10 can be attributed to our leveraging the Federal PTC at $0.02/kWh. Our flow is then reduced in year 11 after the federal PTC runs its course and the upward trend in cash flow continues through Year 20 when we see our largest revenue influx of the project.

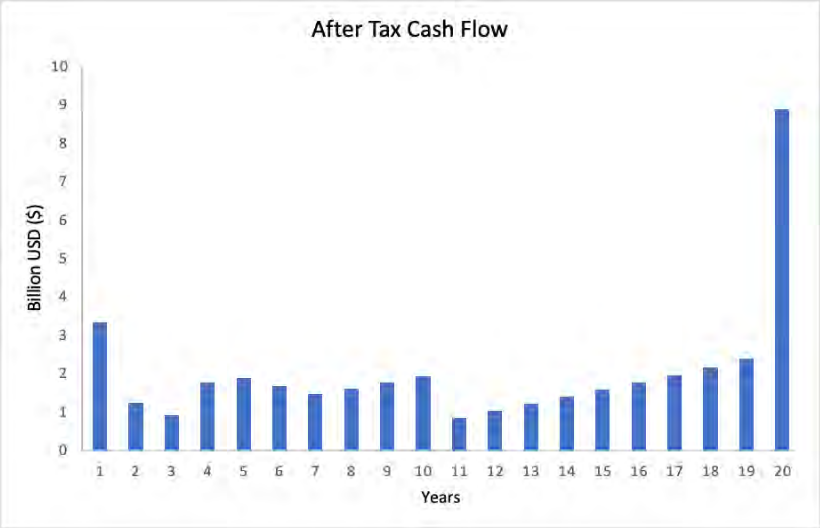


Figure 7: Neptune’s Breath “After Tax Cash Flow.”

4.0 Optimization Process

The main challenge when using the Furow software was the wind turbine placement optimizer function was not working correctly. This resulted in the need for manual placement of the wind turbines within Furow, and the inability to have efficient wake-loss reductions through the optimizer function. Using data analytical tools in Furow, we verified the SAM financial outputs by ensuring that important factors such as annual energy yield and capacity factor correlated with Furow calculations and results.

The optimization of our SAM analysis occurred through a repetitive three-step process: *research*, *step adjustments*, and *output analysis*. Research consisted of broadening TWC's understanding of the SAM model and data collection. The adjustment phase is when all data were standardized (adjusted to 2022 prices). The output analysis phase is where the TWC team analyzed the bankability of the project and looked to see that output results were reasonable. As for applying the net annual energy yield that Furow calculated to our SAM analysis, TWC was able to characterize the wind resource by applying a Weibull distribution in such a way that the SAM model would predict the identical net annual energy yield as did Furow.

5.0 Auction Bid

The maximum bid that TWC is willing to pay for the required leasing area is $915,010,560. This bid price was determined by considering the lowest of the prices per acre associated with the recent auction in the New York Bight ($6,619) and multiplying it by the total area of the *Neptune's Breath* project (138,240 acres).

The first reason why TWC chose to base its bid on the lowest end of the New York Bight auction range is that the Texas energy market is not as supportive of an offshore wind farm as is the case in New York. Some other challenges include that our capacity factor is 36% whereas some of the New York bids claimed to reach 40% according to BOEM [40]. The average wind speed in the New York Bight auction is 8.5 m/s which is 0.9 m/s higher than our 7.6 m/s [41]. Another consideration is that the 62-mile distance from shore may require an additional offshore substation to reduce transmission losses which will add to the total cost. The relatively low water depth makes the seabed more dynamic which introduces additional risk [42]. There are additional risks as the first offshore wind developer in a new region. As seen in the CVOW project off the coast of Virginia Beach, two turbines were installed as a pilot study in June 2020 to accurately depict how economically viable a future commercial project will be by first monitoring how two such turbines perform and interact with the local ecosystem, thus informing future development [43]. Our team chose a conservative estimate for the bid price per area because of the risks addressed above.

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Appendix

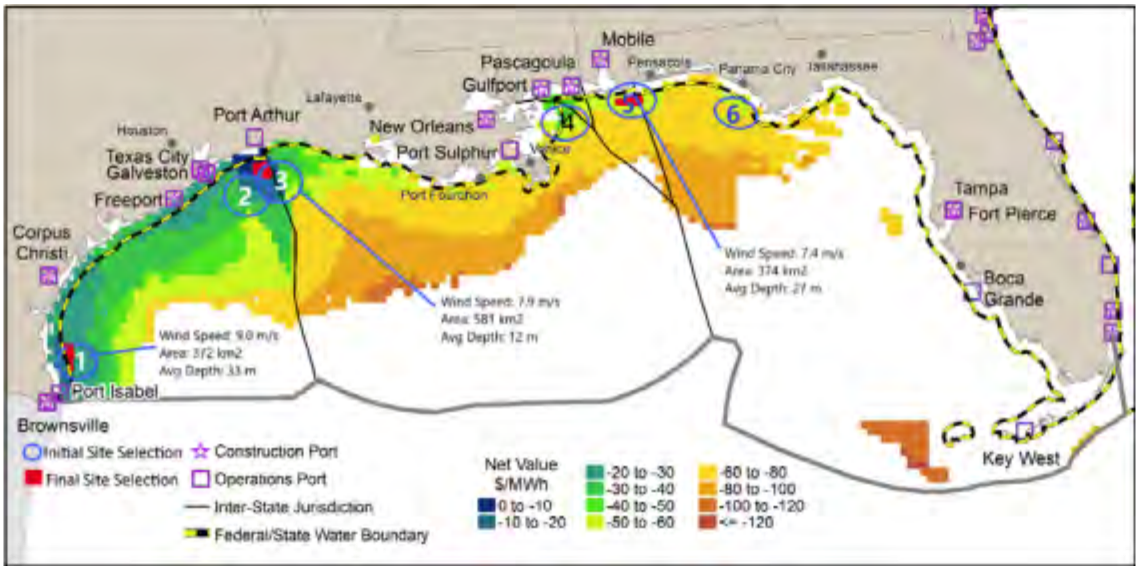

Figure A: The results of the net value regional GOM analysis, which shows that regions with locally high electricity prices (i.e., LACE) and lower LCOE have the highest net value

References

[1] *Bipartisan Infrastructure Law—Fact Sheets | Federal Highway Administration*. (n.d.). Retrieved April 24, 2022, from https://www.fhwa.dot.gov/bipartisan-infrastructure-law/fact_sheet.cfm

[2] *Industrial Gas Pipeline Supply*. Air Products. (2022). Retrieved April 22, 2022, from https://www.airproducts.com/supply-modes/pipeline#overview

[3] "Doe establishes bipartisan infrastructure law's $9.5 billion clean hydrogen initiatives," *Energy.gov*. [Online]. Available: https://www.energy.gov/articles/doe-establishes-bipartisan-infrastructure-laws-95-billion-clean-hydrogen-initiatives. [Accessed: 24-Apr-2022].

[4] "Weatherspark.com," *Texas Gulf Coast Regional Airport Climate, Weather By Month, Average Temperature (Texas, United States) - WeatherSpark*. [Online]. Available: https://weatherspark.com/y/146040/Average-Weather-at-Texas-Gulf-Coast-Regional-Airport-Texas-United-States-Year-Round. [Accessed: 29-Nov-2021].

[5] Horwath, Sarah, et al. Comparison of Environmental Effects from Different Offshore Wind Turbine Foundations. U.S. Department of the Interior Bureau of Ocean Energy Management Office of Renewable Energy Programs, Aug. 2021, https://www.boem.gov/sites/default/files/documents/environment/Comparison-Environmental-Effects-Different-OWT-Foundations-2021.pdf.

[6] "NREL," *The wind prospector*. [Online]. Available: https://maps.nrel.gov/wind-prospector/. [Accessed: 29-Nov-2021].

[7] "Weatherspark.com," *Texas Gulf Coast Regional Airport Climate, Weather By Month, Average Temperature (Texas, United States) - WeatherSpark*. [Online]. Available: https://weatherspark.com/y/146040/Average-Weather-at-Texas-Gulf-Coast-Regional-Airport-Texas-United-States-Year-Round. [Accessed: 29-Nov-2021].

[8] L. A. of the World, "U.S. Vessel Traffic," Redirect. [Online]. Available: https://livingatlas.arcgis.com/vessel-traffic/#@=-91.018,28.009,7&time=201903&sublayer=Fishing. [Accessed: 29-Nov-2021].

[9] ArcGIS web application. (n.d.). Retrieved December 18, 2021, from https://bobson.maps.arcgis.com/apps/webappviewer/index.html?id=9c82bd4a9ef541f0bf32dfa107173c21

[10] Low-level military airspace in the US (feb ... - acq.osd.mil," *Low Level Military Airspace in the U.S.* [Online]. Available: https://www.acq.osd.mil/dodsc/downloads/20160408_R2508_RAIMORA_Nationwide_MTR_Review_01_v7.pdf. [Accessed: 21-Feb-2022].

[11] C. Elkinton, A. Blatiak, and H. Ameen, "Assessment of ports for offshore wind

development in the United States," *Assessment of Ports for Offshore Wind Development in the United States (Technical Report) | OSTI.GOV*, 21-Mar-2014. [Online]. Available: https://www.osti.gov/biblio/1124491 [Accessed: 29-Nov-2021].

[12] NOAA US Department of Commerce, Natural Data Buoy Center, 08-Nov-1996. [Outline]. Available:https://www.ndbc.noaa.gov/. [Accessed: 24-Apr-2022].

[13] Bensason, D., Simley, E., Roberts, O., Fleming, P., Debnath, M., King, J., Bay, C., & Mudafort, R. (2021). Evaluation of the potential for wake steering for U.S. land-based wind power plants. *Journal of Renewable and Sustainable Energy*, *13*(3), 033303. https://doi.org/10.1063/5.0039325

[14] *Wind Resource Data for Wind Farm Developments | Vortex FDC*. (n.d.). Retrieved April 22, 2022, from https://vortexfdc.com/?gclid=Cj0KCQjwmPSSBhCNARIsAH3cYgZzt6JAKvuV2pWBCl4QR6432OCArnNNAOrmKb3EeibkvIYo1ceeHmsaAmSNEALw_wcB

[15] Gaertner, Evan, Jennifer Rinker, Latha Sethuraman, Frederik Zahle, Benjamin Anderson, Garrett Barter, Nikhar Abbas, Fanzhong Meng, Pietro Bortolotti, Witold Skrzypinski, George Scott, Roland Feil, Henrik Bredmose, Katherine Dykes, Matt Shields, Christopher Allen, and Anthony Viselli. 2020. Definition of the IEA 15-Megawatt Offshore Reference Wind. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5000-75698. https://www.nrel.gov/docs/fy20osti/75698.pdf

[16] Horwath, Sarah, et al. Comparison of Environmental Effects from Different Offshore Wind Turbine Foundations. U.S. Department of the Interior Bureau of Ocean Energy Management Office of Renewable Energy Programs, Aug. 2021, https://www.boem.gov/sites/default/files/documents/environment/Comparison-Environmental-Effects-Different-OWT-Foundations-2021.pdf.

[17] Vestas. (2021). *V236-15.0 MW™*. Vestas US. Retrieved April 18, 2022, from https://us.vestas.com/en-us/products/offshore/V236-15MW

[18] Williamson, A., Lawrence, A., Short, R., Grey, C., New South Wales, Department of Energy, U., and Sustainability, & Sustainable Energy Development Authority. (2002). *NSW wind energy handbook*. Sustainable Energy Development Authority.

[19] *Regulatory*. (n.d.). Wind Energy Transmission of Texas. Retrieved April 24, 2022, from http://www.windenergyoftexas.com/regulatory

[20] *U.S. offshore wind permitting | RPS*. (n.d.). Retrieved April 24, 2022, from https://www.rpsgroup.com/insights/energy/us-offshore-wind-permitting-the-sap-the-cop-

and-the-regulatory-process-in-between/

[21] Vann, A. (n.d.). Wind Energy: Offshore Permitting. Wind Energy, 4-15 (2021).

[22] Simpson, M. K., Cole, T., Joyce, D. P., Stewart, C., Amodei, M. E., Jenkins, E. H., Virginia, W., McCOLLUM, B., Pingree, C., Kilmer, D., Israel, S., Lesstrang, D., Benjamin, D., Gray, J., Bina, B., & Richmond, K. (n.d.). *KEN CALVERT, California, Chairman*. 1149.

[23] "Utility Construction," Municode Library. [Online]. Available: https://library.municode.com/tx/galveston/codes/code_of_ordinances?nodeId=PTIICOCI_CH31PUUT_ARTVIUTCOPURI-W. [Accessed: 30-Nov-2021].

[24] "Bird Repeller-A Review," *ResearchGate*. [Online]. Available: https://www.researchgate.net/publication/331310794_Bird_Repeller-A_Review. [Accessed: 29-Nov-2021].

[25] C. Grabow, *Cato.org*, 02-Aug-2021. [Online]. Available: https://www.cato.org/commentary/jones-act-inflicts-costly-burden-us-offshore-wind. [Accessed: 24-Apr-2022].

[26] WPED Staff, "Dominion Energy will allow Ørsted to use its Jones Act-qualified offshore install vessel on additional projects," Windpower Engineering, 01-Jun-2021. [Online]. Available: https://www.windpowerengineering.com/dominion-energy-will-allow-orsted-to-use-its-jones-act-qualified-offshore-install-vessel-on-additional-projects/. [Accessed: 02-Dec-2021].

[27] Austin, TX, New Electric Generating Plants in Texas, 1–18 (2014). Austin, Texas; Public Utility Commission of Texas.

[28] "Wind Energy Facts," *Impacts on benthos and fish*. [Online]. Available: https://www.wind-energy-the-facts.org/impacts-on-benthos-and-fish.html. [Accessed: 29-Nov-2021].

[29] Texas Parks and Wildlife, "Hoary bat (lasiurus cinereus)," *RSS*. [Online]. Available: https://tpwd.texas.gov/huntwild/wild/species/hoary/. [Accessed: 29-Nov-2021].

[30] Texas Parks and Wildlife, "Eastern red bat (lasiurus borealis)," *RSS*. [Online]. Available: https://tpwd.texas.gov/huntwild/wild/species/eastred/. [Accessed: 29-Nov-2021].

[31] Texas Parks & Wildlife. (n.d.). *Trans-gulf migrants*. TPWD. Retrieved December 13, 2021, from https://tpwd.texas.gov/huntwild/wild/birding/migration/transgulf_migrants/.

[32] Texas Parks and Wildlife, "Silver-haired bat (Lasionycteris noctivagans)," *RSS*. [Online]. Available: https://tpwd.texas.gov/huntwild/wild/species/silverhair/.

[Accessed: 29-Nov-2021].

[33] C. M. Appendini, A. Torres-Freyermuth, P. Salles, J. López-González, and E. T. Mendoza, “Wave climate and trends for the Gulf of Mexico: A 30-yr wave hindcast,” *AMETSOC*, 15-Feb-2014. [Online]. Available: https://journals.ametsoc.org/view/journals/clim/27/4/jcli-d-13-00206.1.xml. [Accessed: 29-Nov-2021].

[34] E. Topham and D. McMillan, “Sustainable decommissioning of an Offshore Wind Farm,” *Renewable Energy*, 02-Nov-2016. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0960148116309430. [Accessed: 29-Nov-2021].

[35] Stehly, T., & Duffy, P. (2022). 2020 Cost of Wind Energy Review. *Renewable Energy*, 77.

[36] Musial, W., Spitsen, P., Beiter, P., Duffy, P., Marquis, M., Cooperman, A., Hammond, R., & Shields, M. (2021). *Offshore Wind Market Report: 2021 Edition*. 119.

[37] “Home: Industrial gas supplier, *Air Products*. [Online]. Available: https://www.airproducts.com/.[Accessed: 24-Apr-2022].

[38] “Levelized Costs of New Generation Resources in the Annual Energy Outlook 2022,” p. 26, 2022.

[39] “North American Renewable Energy Prices Skyrocket Nearly 30% in One Year, Threatening Corporate and Federal Net Zero Ambitions.” https://www.leveltenenergy.com/post/q1-2022-ppa-prices-north-america (accessed Apr. 24, 2022).

[40] “New York Bight Wind Energy Area Summaries - BOEM,” 29-Mar-2021. [Online]. Available: https://www.boem.gov/sites/default/files/documents/renewable-energy/state-activities/NYBight-Wind-Energy-Areas-Summary.pdf. [Accessed: 24-Apr-2022]. https://www.boem.gov/sites/default/files/documents/renewable-energy/state activities/NYBight-Wind-Energy-Areas-Summary.pdf

[41] “Why is the United States' East Coast an optimal location for offshore wind?,” *Offshore Renewable Energy*, 17-Mar-2020. [Online]. Available: https://web.uri.edu/offshore-renewable-energy/ate/why-is-the-united-states-east-coast-an-optimal-location-for-offshore-wind/. [Accessed: 24-Apr-2022].

[42] C. Jones, S. McWilliams, G. Engelmann, A. Thurlow, and J. D. Roberts, “Offshore wind sediment stability evaluation framework.,” *Offshore Wind Sediment Stability Evaluation Framework. (Conference) | OSTI.GOV*, 01-Jun-2018. [Online]. Available:

https://www.osti.gov/servlets/purl/1529208. [Accessed: 24-Apr-2022].

[43] A. P. Steger, “Video shows marine life flourishing around wind turbines off Virginia Coast,” *13newsnow.com*, 15-Oct-2021. [Online]. Available: https://www.13newsnow.com/article/tech/science/environment/marine-life-wind-turbines-virginia-coast/farm. [Accessed: 24-Apr-2022].

[44] “Air Products’ U.S. gulf coast hydrogen network,” *airproducts.com*. [Online]. Available: https://microsites.airproducts.com/h2-pipeline/pdf/air-products-us-gulf-coast-hydrogen-network-datasheet.pdf. [Accessed: 24-Apr-2022].

[45] “Natural gas - 2022 Data - 1990-2021 Historical - 2023 Forecast - Price - Quote - Chart.” https://tradingeconomics.com/commodity/natural-gas (accessed Apr. 24, 2022).