May 2023

MAX VENTUS

Project Development Report

James Madison University
Collegiate Wind Competition 2023

Project Development Team

Isabella Lindblad	Project Development Lead	lindblis@dukes.jmu.edu
Everett McConville	Siting & Modeling Lead, Offtake Analysis	mcconvec@dukes.jmu.edu
Peter Fyffe	Finance Lead	fyffepd@dukes.jmu.edu
Alex Garcia	Hydrogen & E-methanol Research	garciaav@dukes.jmu.edu
Lorelai Lamoureux	Transmission Design	lamourlq@dukes.jmu.edu
Sidney Roth	Permitting & Incentives Lead	rothsk@dukes.jmu.edu
Colin Hill	Cybersecurity	hill2cp@dukes.jmu.edu
Francheska Sacoto	Environmental Management	sacotofg@dukes.jmu.edu
Melanie Leon	Market Analysis	leon3mm@dukes.jmu.edu

Featured Industry Mentors & Faculty Advisors

Chett Chiasson	Executive Director at Port Fourchon
Lacy McManus	Executive Director of Future Energy
Margarita Patria	Principal at Charles River Associates
Ralph Kurth	Senior Principal at Stantec
Alexander Reumert	Project Associate in Power-to-X at European Energy A/S
Robert Sherwin	Managing Partner at EAPC Wind Energy Services
Zachary Batts	Green Fuels Technology Manager at Apex Clean Energy
Dr. Keith Holland	Professor of Engineering
Dr. Jonathan Miles	Professor of Integrated Science and Technology

JMU JAMES MADISON UNIVERSITY

COLLEGIATE WIND COMPETITION
U.S. DEPARTMENT OF ENERGY

Table of Contents

Executive Summary

MaxVentus Collective has developed the site analysis, construction timeline, offtake strategy, financial analysis, optimization process, and auction bid associated with the development of a 322-MW offshore wind power plant off the coast of Louisiana. Lease blocks ST143, ST167, and ST168 were identified as those that are available areas and are likely to cause the least impact on the natural environment, sensitive species, and neighboring industries. Site characteristics and financial projections warrant the incorporation of twenty-three Siemens Gamesa 14-222 DD turbines into the site design. Energy generated by this offshore project will be used to power an onshore Power-To-X facility that produces e-methanol fuel modules for vessels at Port Fourchon. This project is attractive to investors

considering the total Capital expenditures of $3,663,487,657 billion dollars and total yearly revenue of $205,040,000 million dollars. MaxVentus has outlined a maximum bid price of $75 million dollars ($5,000 per acre, 15,000 total acres) for the lease blocks we have identified. The site design was visualized and manipulated using the modeling software Furow (by Solute) and the financial analysis was facilitated by System Advisory Model (SAM) developed and supported by NREL.

1.0 Site Selection and Design

Site identification from offered lease blocks required assessments of ocean activities, atmospheric characteristics, environmental sensitivities, and financial opportunities in order to develop an environmentally conscious, energy-efficient, financially-viable project. The lease blocks selected proved to be advantageous when considering shipping traffic, existing infrastructure, active oil and gas leases, access to Port Fourchon, and seafloor characteristics. Research on these factors pertains particularly to Lease Blocks ST143, ST167, and ST168 are visualized in Figure 1.

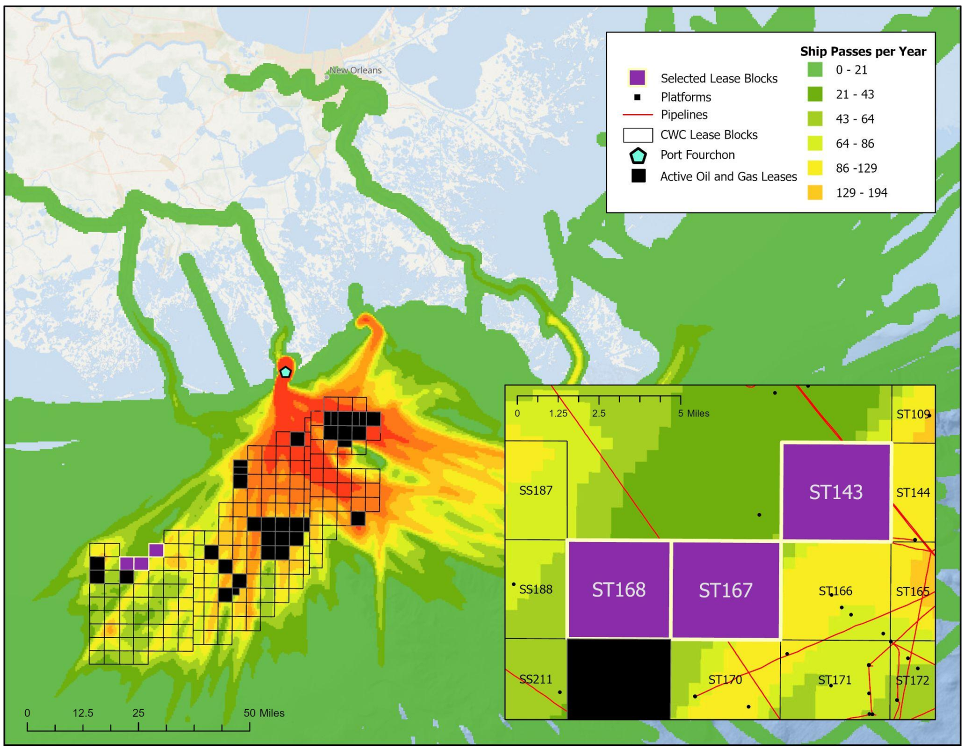

Figure 1. Map showing selected lease blocks in the South Timbalier area with additional siting concerns

1.1 Ocean Activities

To properly evaluate the least disruptive lease blocks available, shipping, fishing, and oil and gas production account for most of the activities visible in the kernel density map [Figure 1]. This map was created using ArcGIS Pro to run the kernel density tool on Automated Identification System (AIS) data from 2019 [1], [2]. Lease blocks ST167 and ST168 experienced approximately 50 ship passes during 2019, thus avoiding the high-density traffic to the east. Lease blocks ST143, ST167, and ST168 are located along the northern edge of the available lease area. Transmission cables can be installed from this location to Port Fourchon without interfering with neighboring wind energy leases.

1.2 Environmental Impacts

The development of this project was conducted in a manner to avoid significant biological communities and species migratory routes during project construction, operations, and maintenance. Endangered species off the Louisiana coast include the Kemp's Ridley Turtle, Leatherback Turtle, Hawksbill Turtle, Sperm Whale, and Rice's Whale [3]. Threatened species in the area include the Green Sea Turtle, Loggerhead Sea Turtle, Gulf Sturgeon, Oceanic Whitetip Shark, and Giant Manta Ray [3]. Most Essential Fish Habitats (EFH) do not intersect with any available lease blocks [4]. Bird species migratory routes are present in the project site; however, none are categorized as endangered or threatened. In order to acquire approval from BOEM, MaxVentus must outline a Habitat Conservation Plan (HCP) [5]. Through this plan MaxVentus has committed to NOAA and local conservation organizations that, should an incidental take event occur, MaxVentus will replenish the ecosystem with the same but limited number of animals lost during project construction and operation. Further to promote environmental mitigation, the construction teams will utilize detection technologies to slow vessel movement and reduce impacts on any animals detected.

1.3 Risks and Fatal Flaws

Impact-producing factors (IPF) is a term used by BOEM that identifies critical cause-and-effect relationships between renewable energy projects and affected resources, including but not limited to physical, biological, economic, or cultural resources [6]. IPF relevant to this project include extreme weather events, ecological loss, political administration change, rising inflation rates, and supply chain challenges. In order to mitigate hurricane impacts on this wind project, project construction will commence outside of the expected hurricane season (June through January) and installed turbines will incorporate systems to furl blades and otherwise self-protect prior to hurricane conditions. Anemometers and other weather-monitoring devices will be installed on turbines to monitor wind speeds and preparations will be made in advance of extreme weather events [7]. Excluding hurricane conditions, average wave heights in the Gulf of Mexico (GoM) are not considered an IPF [7].

For an offshore wind project to receive approval from BOEM, the project must follow the Renewable Energy Program Regulations (30 CFR 585, Section H), which outlines if the selected lease areas include endangered or threatened species [6]. BOEM must consult with state and federal wildlife agencies to identify specific conditions for the project to proceed [6]. If environmental consultants conclude that project development will lead to detrimental ecological losses then BOEM will not issue permits and project development will be terminated. This project’s design attempts to avoid ecological harm and MaxVentus does not anticipate project termination on these grounds.

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

Technical and high-investment operating costs are susceptible to unexpected price changes. In order to mitigate construction and operational risks, MaxVentus has identified Munich RE’s offshore EPC cover insurance as a means to address the uncertainty associated with variable costs [8]. Through Munich RE’s insurance solution, MaxVentus will be covered against unexpected costs related to O&M and supply chain disruptions [8]. Also, given the selected wind turbine for this project (Siemens Gamesa 14-222 DD) is manufactured overseas, technical insurance is required under a European entity.

1.4 Resource Assessment

Wind resource data were obtained from the company Vortex, which specializes in providing clients with high-resolution wind resource data. 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” [9]. A Large Eddy Simulation (LES) data set was used for this resource assessment which combines the WRF and LES models to calculate wind data at a specific height and location in 10-minute intervals over one year. Wind resource data is generally calculated or measured for a period longer than one year, to capture enough data for adequate analysis. However, due to computational costs, LES uses an optimization process to select a rolling one-year window that is representative of a larger 20-year period [10]. This one-year window includes 10-minute interval results for a period of 365 days that offers the best representation of the long-term data at the selected site. The representative one-year window falls between March 3, 2010 and March 3, 2011. The geographic center of selected Lease Blocks ST143, ST167, and ST168 was used for this resource calculation. The reference height used for calculations was 140 meters which coincides with the hub height of the selected turbine model. Results were downloaded from the Vortex website into a .txt file that was then loaded into Furow for further analysis. As revealed during analysis, wind speeds are typically highest during the winter and spring seasons in the region. The average annual wind speed calculated in Furow was 6.82 m/s at the 140-m hub height of the turbine. This data informed the proceeding decisions explained in Section 4.0.

1.5 Turbine Technology

MaxVentus selected the Siemens Gamesa 14-222 DD offshore wind turbine in part to the favorable supply chain characteristics. Although the Vestas V236-15.0 MW turbine has a greater swept area, blade length, and rated power, it is not as suitable for this project given the low average wind speeds of the site. Critical design features that aided the selection of the Siemens Gamesa turbine include IntegralBlade® technology and RecyclableBlade, High Wind Ride Through (HWRT), and Power Boost features. HWRT stabilizes energy output to slowly decrease, automatically, the power output when wind speeds surpass 25 m/s. Power Boost and HWRT features have the potential to increase capacity to as high as 15 MW. As determined by the resource assessment, average wind speeds are significantly lower during the summer and fall seasons. The low cut-in speed of 3 m/s enables turbines to generate power during these seasons regardless. This turbine utilizes IntegralBlade® technology, where each fiberglass-reinforced epoxy blade can be cast in one piece and separated and recycled at its end-of-life [11]. Siemens Gamesa is developing the first US blade-finishing facility in Portsmouth, VA, which would effectively reduce finishing costs and promote the types of domestic manufacturing outlined in the Inflation Reduction Act [12]. Further plans for Siemens Gamesa to develop other manufacturing facilities in Portsmouth have been confirmed by Cathie J. Vick Chief Development and Public Affairs Officer for the Port of Virginia. The specifications of this turbine are summarized in Table 1. The generated power curve for the SG 14-222 DD to enter into the turbine database in Furow applied turbine data extrapolated from a 15-MW power curve based on NREL's 15-MW reference offshore turbine from 2020 [13]. It is assumed that the application of this power curve produces more conservative energy projections as compared to the SG 14-222 DD, since it holds the record for most power produced by a turbine in 24 hours with 359 MWh [14]. All of these conditions aid in the project's optimization process and financial analysis

Table 1. Selected turbine specifications.

Siemens Gamesa 14-222 DD Turbine					
Rated Power	Rotor Diameter	Hub Height	Cut-in Speed	Cut-out Speed	Wind Class
14000 kW	222 m	140 m	3 m/s	25 m/s	IEC I,S

1.6 Foundation Structure

MaxVentus identified an appropriate foundation to provide vertical load support weight and lateral support of the entire turbine structure at the hub height of 140 meters. Alternative possible foundation types were evaluated for cost-effectiveness, reliability, and environmental impact. Site characteristics encourage the installation of jacket foundation structures when considering the threats of hurricanes. Jacket foundations consist of a lattice-truss structure with four legs that are welded together providing lateral support [15]. Compared to the common monopile or other suction caisson designs, jacket foundations have the smallest ecological footprint and largest surface area limiting the effects of habitat loss due to foundation installation while providing the most habitat during operation [15]. With the prominence of the oil and gas industry in the GoM, the proximity to the fabrication of steel support structures significantly decreases costs allowing these structures to be financially feasible [16].

1.7 Wind Farm Design

This project will feature 23 SG 14-222 DD offshore wind turbines, bearing a total installed capacity of 322 MW. Nine turbines will be placed in each of the Lease Blocks ST168 and ST143, and five in ST167. The wind farm layout is shown in Figure 2. The turbines are situated in a grid formation across the square lease blocks, with an alignment rotation of 2° counterclockwise to minimize wake effect energy losses. The layout is designed to maximize the number of turbines and power generation and minimize cabling distances. An eddy viscosity wake effect model was calculated by simulating 10 m/s winds from the wind farm's average dominant wind direction of 122° (southeast) in order to better understand the nature of wake losses. As seen in Figure 2, only minimal "waked" wind was experienced by WT3 and WT6 out of the entire fleet for this model. Turbine spacing was set to 1800 m which equates to more than eight 222-m rotor diameters between each turbine. Between five and twelve rotor diameters between turbines is a common practice among European offshore wind farms [17]. Although turbine separation radii extend beyond the lease blocks, blades fall entirely within the border. The offshore substation was placed at a location that is central within the wind farm, thus allowing for shorter collection system cable lengths. In some cases, offshore wind farms refrain from building the offshore substation at a central location due to vessel access risks associated with repairs and maintenance [17]. However, the lease blocks we selected fall along the perimeter of the CWC auction area, and this allows for ease of access to the substation and therefore bypasses vehicle access risks.

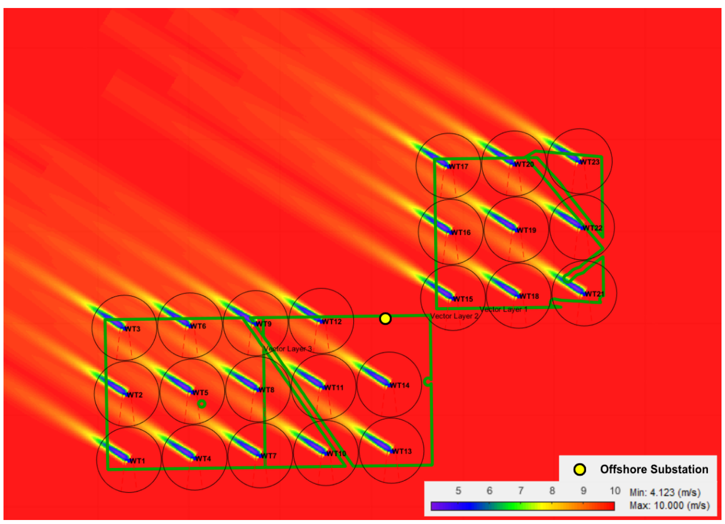

Figure 2. 23 SG 14-222 DD turbines displayed overtop of average wind direction wake effect raster ST143, ST167, and ST168 in Furow wind farm layout in blocks.

1.8 Energy Estimation

Furow modeling software was used to calculate the energy yield estimation of the wind farm. Total losses were set at 15.5% as this was the number defined for an offshore wind reference site by NREL in their 2021 Cost of Wind Energy Review [18]. The projected annual net energy yield of the 322-MW wind farm is 933,000 MWh with a net capacity factor (NCF) of 33.3%. This energy projection is likely conservative as the turbine power curve used for this model serves only as a proxy for that of the record-breaking SG 14-222 DD [14].

1.9 Transmission Design

The transmission system will be necessary for the interconnection of the wind farm's offshore substations and wind turbines to the offtake strategy which includes an e-methanol production plant as well as the onshore electric grid. The array cable technology is easily scalable to be able to match the size of offshore wind projects and can be trenched into the sea bed to protect the integrity of the cables. The array cable system diagram illustrates the means for transmission of power to the point of interconnection including, but not limited to, export cables, array cables, substations, and the Point of Interconnect [19], [Figure 3].

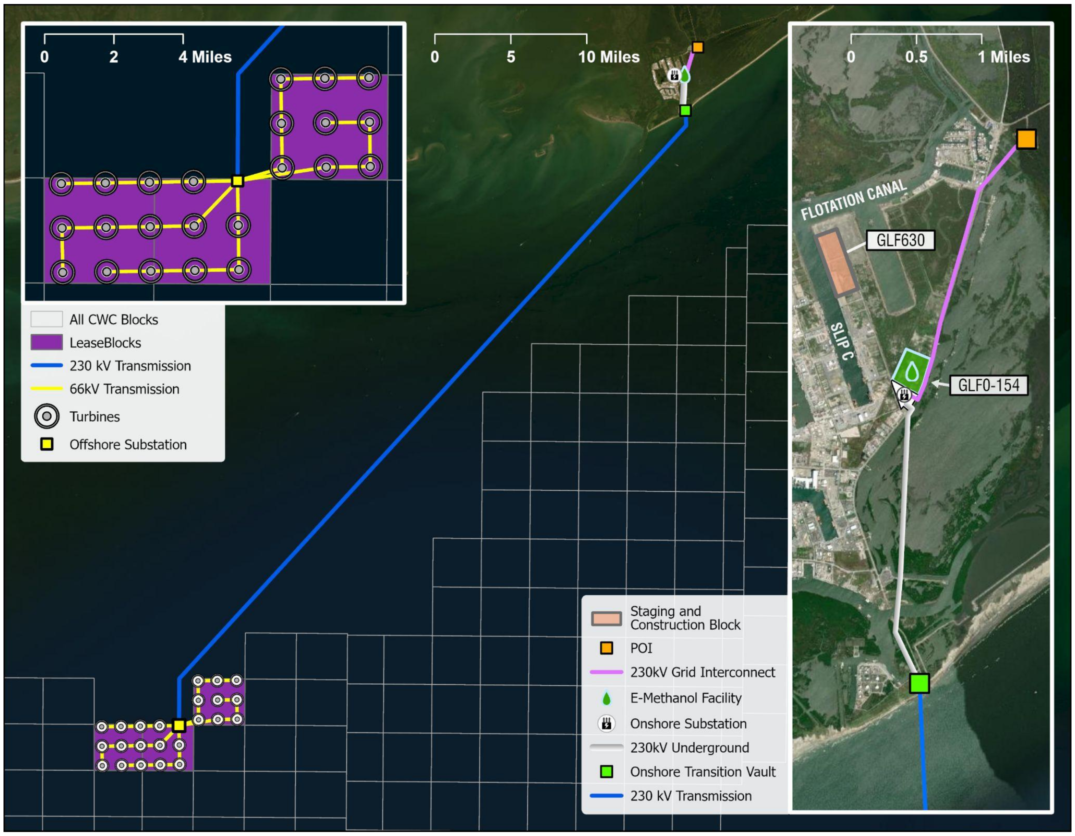

Figure 3. Map showing the export transmission design and infrastructure from each turbine

Through consultation with Ralph Kurth, a transmission expert at Stantec, it was determined that the transmission of electric power via the submarine cables would be in the form of alternating current (AC) because of the relation of the wind farm location to shore. These technical aspects of the transmission design would result in the optimization of the layout of the cables in a manner that maintains the financial feasibility of this project and maximum energy production [17]. Kurth was instrumental in assisting the transmission design by determining necessary components, providing cost estimates, and identifying manufacturers as seen in Table 3. The single-line diagram of the transmission system from turbines to the e-methanol facility and the point of interconnect is seen in Figure 4. Essential suppliers for the wind farm design include Siemens Energy and GE corporations to provide substation equipment, Prysmian and LS Cable companies for supplying submarine and land cables and Kiewit for the installation and construction processes. The acquisition of submerged land leases will be required for implementing submarine array cables, and consultation with myriad federal agencies including but not limited to the National Oceanic and Atmospheric Administration (NOAA), the U.S. Army Corps of Engineers (USACE), the Bureau of Ocean Energy Management (BOEM), and the U.S. Department of the Interior, will be required [20], [21].

To determine the necessity of reactive compensation elements associated with High Voltage Alternating Current (HVAC), preconstruction engineering assessments will need to be performed. The design of the array cable system will avoid exclusion zones in which any form of construction is prohibited, obstructions or obstacles present on the sea floor from previous infrastructure or marine habitation, and minimize damage to the sea floor during the cable-burying process. The design will also be impacted by the location of the wind turbines and their proximity to the substations. A design consideration that will impact the entire system is the prevention of overlapping cable crossings which would risk the potential for cable thermal overloading [22].

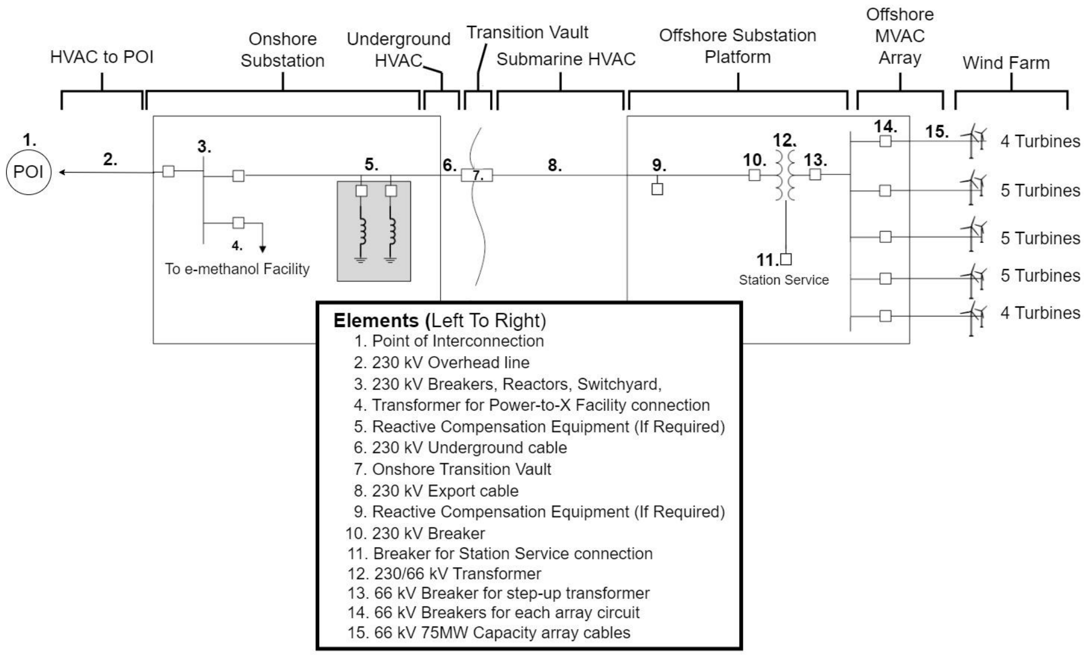

Figure 4. Visualizes transmission design from wind farm to point of interconnect.

2.0 Site Preparation and Development

The framework for the development of this wind farm required outlining appropriate post-acquisition assessments, identifying required regulatory and environmental permits, outlining construction and operations plan, implementing necessary cybersecurity measures, understanding the decommissioning process, and creating a rough project schedule.

2.1 Site Assessment Plan

Prior to project installation procedures, geophysical, geotechnical, meteorological, and biological surveys will be conducted [23]. These surveys will happen over five years before, during, and after construction [23]. Surveys will measure impact-producing factors of the proposed wind farm, including emissions and pollution, discharge, noise, strikes and collisions, bottom disturbances, and coastal land use/modification [23]. The surveys will determine the severity of impact-producing factors. The most critical impact-producing factors are noise, strikes, collisions, and bottom disturbance without protective measures, resulting in significant biological and benthic impacts as described by BOEM [23]. A solution for the proposed wind farm, to mitigate noise and vessel strikes, includes enacting a vessel traffic buffer around the project area [24]. For the project area, a 10-mile vessel traffic buffer would be adequate to lower impact-producing factors from major to negligible. In order to reduce bottom disturbances, when constructing a turbine, jack-up legs points of contact will fall within a 300-m radius of the turbine installation spot [25].

2.2 Permits Required

Louisiana state waters extend three nautical miles (nm) from the coast while federal waters extend to the point where the Louisiana gulf-ward boundary ends, up to 200 nm from the coast [26]. The selected lease blocks are 46 nm away from Port Fourchon; therefore, acquiring state permits for project development is not necessary [26]. Federal agencies will facilitate the acquisition of permits for the wind farm. BOEM requires projects to develop various plans including a site assessment plan, technical design report, and O&M outline [Table 2]. The Environmental Protection Agency (EPA), National Oceanic and Atmospheric Administration (NOAA), and U.S. Fish & Wildlife Service (USFWS) require projects to consider predicted impacts on the environment and protected species [Table 2]. The U.S. Department of

Defense (DoD), U.S. Coast Guard (USCG), and Federal Aviation Administration (FAA) require the development of plans that ensure no disruption to military or aviation activity [Table 2]. Acquiring all of these required permits will take between 0 to 2 years [27].

Table 2. Portrays agencies that administer relevant permits for project construction and development

	Site Acquisition & Technical Aspects	Environmental Impacts	National Security
Federal Agencies			
Requirements & Compliance Acts	- Secure commercial lease for offshore energy development - Site Assessment Plan (SAP) - Facility and Design Report (FDR) - Construction and Operations Plan (COP) - Fabrication and Installation Report (FIR)	- National Historic Preservation - Magnuson-Stevens Fishery Conservation and Management Act - Endangered Species Act - Marine Mammal Protection Act - Migratory Bird Treaty Act - Clean Water Act → air quality, water quality, and pollution prevention permits	- Sitting consultations and negotiations - Navigational Lighting Permit

2.3 Construction and Operations

Port Fourchon currently offers a 169,968 square meters lease area (GLF630) which MaxVentus will utilize for onshore construction and staging procedures for upwards of two years [28]. The selected turbine model (SG 14-222 DD) warrants 79,000 square meters which does not surpass the area of the available lease area. The selected lease area (GLF630) is 42 acres with 2,300 feet of waterfront access with a monthly rent cost of $163,000 dollars ($3.912 million dollars for two years). These financial parameters were provided by Chett Chiasson Executive Director at Port Fourchon.

The staging area will consist of turbine blades, mooring equipment, and electrical cables will be arranged and placed onto Dominion's Charybdis for installation [28]. Docking for all O&M vessels will require space at a separate harbor from the identified staging lease block (GLF630) [28]. All O&M vessels must comply with regulations outlined in the Jones Act, which mandates that cargo shipped between United States ports be carried by ships that are flagged in the U.S. and manned by an American crew. By utilizing Dominion's Charybdis, MaxVentus would be in compliance with the Jones Act and intends to advance project operations accordingly.

Dominion's Charybdis jack-up vessel will be utilized for offshore project construction, installation, and significant repairs [29]. Charybdis has extendable "legs" that drive into the sea floor to lift the vessel out of the water for stabilization. Once out of the water, Charybdis's onboard crane will support the construction of turbines. Although European-developed installation vessels are more established, the cost of a non-US sea installer vessel is estimated to be approximately a $250 thousand dollars daily fee [30]. These equipment prices paired with the substantial scale repairs are not financially feasible for this project [28].

For cable installation, the Bahamian Siem Dorado cable installer vessel will be used [30]. For standard repairs extending beyond twenty-four hours, the first Jones Act-compliant service operation vessel (SOV), Eco Edison, will be used. Eco Edison will be equipped with safe and innovative access methods, such as a "walk to work" gangway and accommodations on board to support more than 40 technicians [30]. For common repairs, MaxVentus will use the British windcat MK1 crew transport vessel (CTV) as needed to transport trained crew members to and from the turbines.

As part of the project's offtake strategy, MaxVentus will construct a 15-hectare e-methanol Power-to-X Facility (PtX) with an onshore substation in Port Fourchon's GLF0-154 lease area seen in

Figure 3. Through consultation with Chett Chiasson, the total cost of lease block GLF0 will be $929,649 dollars. The PtX facility will contain components for hydrogen and methanol loops in the e-methanol production process as well as auxiliary system components as seen in Figure 5. Hydrogen loop components will include a water treatment facility, a power supply Siemens Silyzer 300 Electrolyzer, a hydrogen conditioning facility, and hydrogen pressurization tanks. Methanol loop components will include, direct air capture units, carbon conditioning and pressurization units, a Syngas gas compression unit, a methanol synthesis facility, and e-methanol bunker storage and offtake. Methanol auxiliary systems will include heating and cooling management systems, instrumentation and control units, and various pipes needed for transport [Figure 5]. MaxVentus plans for a two-year construction of all aspects of the wind farm, PtX facility, and preparation areas due to financial considerations [Figure 6].

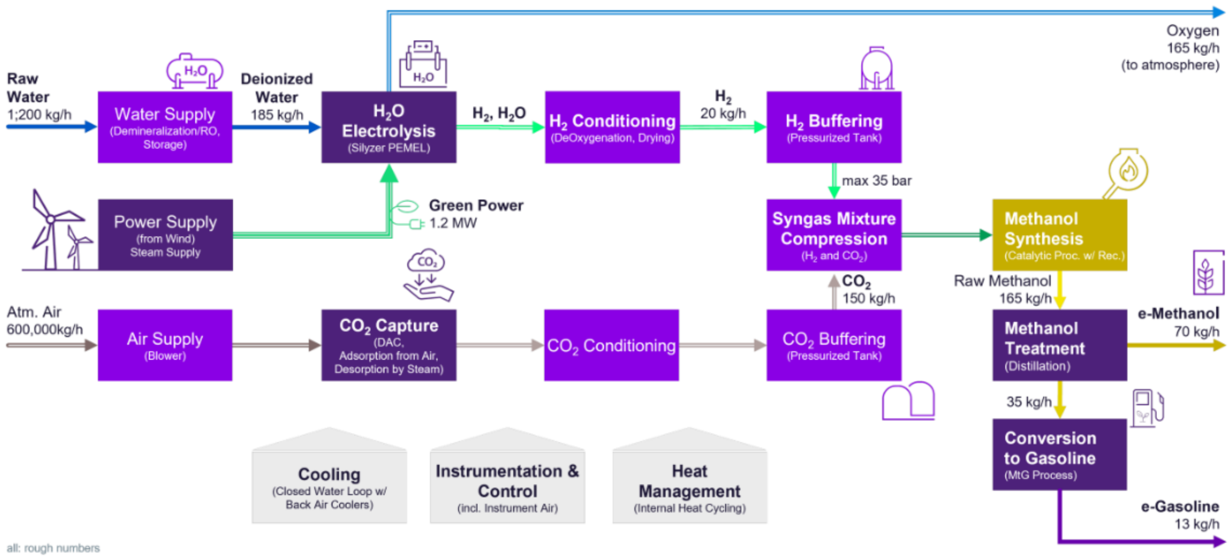

Figure 5. E-methanol Power-to-X facility components and processes. Figure developed by Siemens Energy.

2.4 Cybersecurity

The Federal Energy Regulatory Commission (FERC) facilitates interstate electricity transmission by ensuring reliable, safe, secure & economically efficient energy for consumers at a reasonable cost [31]. FERC's Office of Energy Infrastructure Security supplies expertise and direction to mitigate potential cybersecurity threats and physical attacks on energy-generating facilities [31]. FERC offers Critical Infrastructure Protection (CIP) standards that guide the industry on how to manage cybersecurity and physical risks [31]. The North American Electric Reliability Corporation (NERC) under FERC creates and enforces mandatory reliability standards [31]. NERC has adopted these mandatory CIP standards for the protection and security of critical cyber assets supporting the power grid.

DoE's Office of Energy Efficiency & Renewable Energy has identified and outlined how projects can ensure security against physical and cyber attacks. After evaluating the proposed cybersecurity measures, the most suitable option for the project would be to install a firewall. This strategy is essential to facilitate secure control system data access, filter external requests, and permit Virtual Private Network (VPN) access to stop potential cyberattacks. Implementation of a firewall is necessary in order to prevent external action or access to the internal local area network which connects to the wind turbines and transmits critical data [31]. Given that power produced by this wind farm will be supplied to the e-methanol production facility and not fed directly into the grid, there are limited grid reliability concerns.

2.5 Decommission Plan

Decommissioning obligations enforced by BOEM mandate an allotment of two years to remove all facilities, projects, cables, pipelines, and obstructions, and to clear the seafloor of all obstructions created by activities on the lease, including a project easement or grant, to a depth of 15 feet below the mud line (30 CFR §585.433, §585.910) [32]. Within 60 days after the removal of any facility, cable, or pipeline, a final notice must be submitted to BOEM verifying site clearance that provides a summary of removal activities and a description of any environmental mitigation measures (30 CFR §585.912) [32]. Although landfilling turbine blades is currently the most cost-effective solution to manage equipment that is removed from service, MaxVentus has committed to supporting blade recycling procedures.

2.6 Project Timeline

The projected timeline for initiating, operating, and performing the decommissioning processes is demonstrated in Figure 6 below. Overall, the project is anticipated to require approximately nine years to implement, with an overall lifetime of 25-35 years, and a two-year decommissioning process [33].

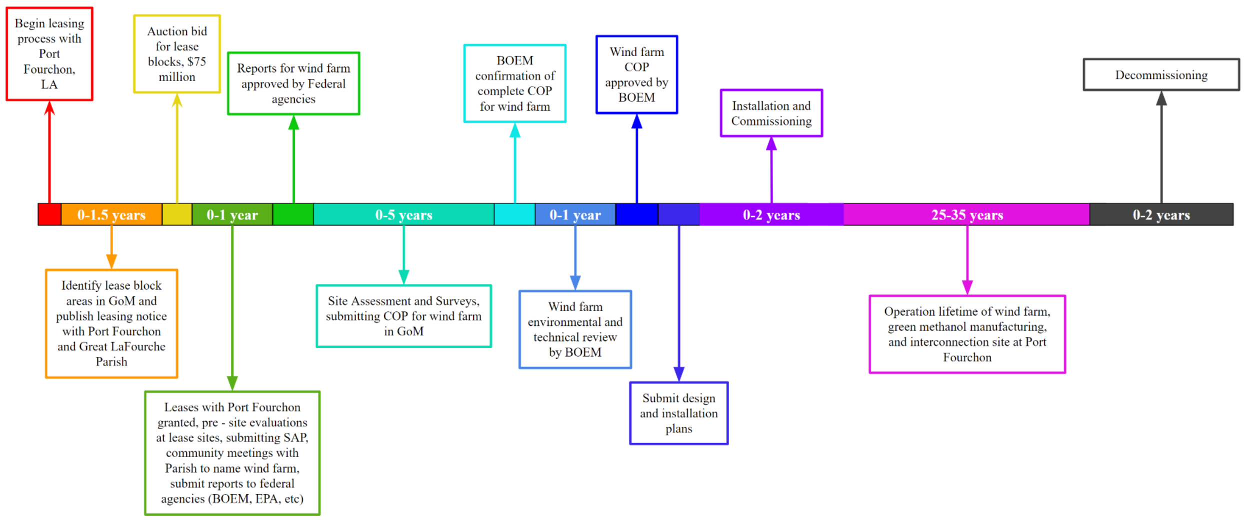

Figure 6. Timeline visualizing general project development sequence.

3.0 Offtake Strategy

In an effort to avoid the challenges of upgrading the current transmission infrastructure in the Louisiana coast region of MISO, MaxVentus has identified a unique and innovative offtake solution that will optimize financial opportunities as well as benefit the industries at Port Fourchon. Port Fourchon is identified as the port with the highest demand for, and highest number of vessels (460) with electrification potential in the country [34]. Given that global shipping accounts for 3% of total greenhouse gas emissions, shipping companies have made plans to transition to cleaner sources of fuel [35]. For instance, Maersk has ordered 19 vessels with dual-fuel engines able to operate on e-methanol [36]. Granted these opportunities, MaxVentus has developed plans to use the generated power from the developed wind farm to power an e-methanol production facility which will offer a cleaner fuel option for vessels. Port Fourchon's central location in the GoM and well-supported infrastructure allow for an energy addition of wind and e-methanol. Chett Chiasson, Executive Director at Port Fourchon, has confirmed with MaxVentus has personally confirmed the viability of this project concept and reiterated the Port's interest in e-methanol.

MaxVentus intends to utilize the electrical power produced from the wind farm to power an e-methanol production facility through the use of the PtX facility constructed and operated by MaxVentus. Produced e-methanol will then be sold to Martin Energy Solutions. This business model follows the growing trend of interests, investments, and fuel purchase agreements pertaining to the procurement of e-methanols by large end-user companies such as Maersk and Shell [36], [37]. MaxVentus believes that, based on investments in shipping and fuel offshore wind coupled with an e-methanol PtX facility offers a profitable business strategy. This belief is influenced by Maersk fuel purchase agreements with other methanol-producing companies such as European Energy, SunGas renewables, and CarbonSink LLC, demonstrating that the demand for e-methanol production is present and profitable [36], [38], [39].

3.1 E-Methanol Production

E-methanol is the combination of green hydrogen and sourced carbon. MaxVentus will create in-house green hydrogen through PEM Electrolysis. As seen in Figure 5, the production of e-methanol requires Max Ventus to source three components: generated electricity, ultrapure water, and carbon. MaxVentus will provide 322 MW of electrical power for the PtX facility to produce e-methanol. Water will be sourced from the GOM and then pumped through a Siemens water desalination plant to produce ultrapure water (PH 7.00) for electrolysis [40].

To produce the green hydrogen needed for e-methanol, MaxVentus will perform electrolysis utilizing Siemens' Sliyzer- 300 PEM Electrolyzer [41]. During MaxVentus' PEM electrolysis, ultrapure fresh water (7.00 PH) will be pumped through the electrolyzer unit to create at a rate of 15 liters of water to produce one kilogram of green hydrogen [42]. When water is combined with MaxVentus' electricity, the Slilyzer-300 electrolyzer will electrochemically split and recombine hydrogen and oxygen molecules to produce green hydrogen. The use of Siemens' Sliyzer-300 PEM Electrolyzer is cost-effective for MaxVentus as electrolyzer units have been cost-optimized for higher scaled operations [43] Other important parts of the production facility that will be needed for production and risk management include Core electrolyzer stacks, Arrays, Tanks, Pumps, Heat Exchangers, Rectifiers, Compressors, Purification unit and cooling systems, Water demineralization, Fire and gas safety systems, and an EPC pod. Green Hydrogen production releases a byproduct of pure oxygen which can be collected and sold at adequate market value [44].

After electrolysis, green hydrogen will be combined with sourced carbon. MaxVentus will source carbon via direct air capture (DAC). By using direct air capture, MaxVentus avoids complicated and costly methods of transporting carbon from outside sources which outweighs the low concentration of carbon sourced through this method [45]. MaxVentus still has further research questions on the process including capital expenditures and power usage of the direct air capture system that will have to be answered in future development processes.

Through consultation with a European Energy Power to X Associate, Alexander Ruemert, to produce methanol, 1.4 kg of carbon will be needed per kilogram of methanol. The sourced carbon will then be combined with green hydrogen to create e-methanol fuel in a heat-intensive process known as methanol synthesis [46]. The final product of the heat-intensive process is a liquid fuel that has similar properties as gasoline thus allowing for easy storage and transportation [46]. MaxVentus will have bunker storage for e-methanol where produced e-methanol can be picked up by Port Fourchon fuel suppliers such as John. W. Stone and Martin Energy Services to be delivered to end users as identified by Port Fourchon executive director Chett Chiasson. Chett Chiasson was critical in determining the offtake solution by explaining the current infrastructure of the port, availability for offshore wind development, and demand for alternative fuel sources for vessels.

3.2 Facility Design

MaxVentus will invest and construct a PtX facility in Port Fourchon in lease block GLF0. Total capital expenditures for the PtX facility will total circa 1.55 billion dollars based on a capital investment of 1.4 billion euros for Esbjerg's PtX facility [47]. The investment will be funded by MaxVentus, loans, and outside investment from companies such as Martin Energy Services. Based on consultation with Mr. Ruemert, Of the total capital expenditure, 60-80% will go towards procurement costs while 20-40% will go towards installation. Alexander Ruemert also stated that installation costs will also decline as the industry further develops.

3.3 Fuel Purchase Agreement

Chett Chiasson, Executive Director at Port Fourchon, has identified essential energy providers that would be interested in purchasing the e-methanol vessel fuel modules to sell to shipping companies including John W. Stone Oil Distributor, Martin Energy Services, and other liquid natural gas (LNG) providers. Identified direct purchasers of this e-methanol would include Eddison Chouest Offshore, Harvey Gulf International Marine, Oceaneering, and Hornbeck Offshore Services. Based on general statistics and guidance provided by Alexander Ruemert of European Energy, and in collaboration with Mr. Chiasson, MaxVentus will enter a fuel purchase agreement with Martin Energy Services for $1,200 per ton of e-methanol.

4.0 Financial Analysis

The financial analysis was conducted using SAM software with calculations and conformations generated through Furow and Excel® analysis. The following research was informed by details noted in Sections 4.1-4.6 as well as the current global and domestic energy market dynamics, precedents set by recent domestic offshore wind projects, and demand for alternative fuel options for vessels docking at Port Fourchon.

4.1 Financial Potential

A commercial-size offshore wind project in the Gulf of Mexico, where wind resources are not as favorable as in other areas and the industry is only beginning to launch, is financially feasible only with access to economic incentives. These can come in the form of Investment Tax Credits (ITC) or other economic mechanisms discussed in financing strategies. As explained in Section 3.0, the growing demand for alternative fuel sources such as e-methanol in Port Fourchon promotes the following business model.

4.2 Investment Incentives

President Biden's National Climate Task Force has ambitious goals for the United States which cannot be realized without the adoption of renewable energy, and this requires agencies to work toward a net-zero emissions economy by 2050 [48].The adoption of renewable energy has been incentivized in particular by recent federal legislation, notably the Inflation Reduction Act (IRA) and the Infrastructure Investment and Jobs Act of 2021 (IIJA), through which billions of dollars are being invested to advance renewable energy deployment and manufacturing through tax credits, loan programs, and grants [49], [50]. President Biden's Justicy40 Initiative sets a goal for 40% of the benefits from federal investments in climate change and clean energy to benefit communities that are "marginalized, underserved, and overburdened by pollution," [51]. The area of Port Fourchon qualifies as a disadvantaged community under federal criteria as an energy community tied to petroleum.

We intend for project construction to be initiated prior to January 2025 so it would meet all apprenticeship and wage requirements, thus this project will qualify for a 30% Federal Investment Tax Credit (ITC). This would be supplemented by an additional 10% credit for meeting domestic production requirements and another additional 10% credit in light of the project's location in a disadvantaged energy community.

Louisiana is ranked fourth in the U.S. for offshore wind potential and has identified a shift to clean energy as its primary strategy to achieve net-zero emissions by 2050, with a prioritization placed on achieving 5 GW of offshore wind generation by 2035 [52]. The economic opportunity provided by offshore wind is of particular interest to the state government, given that a single offshore wind project could create more than 4,500 jobs during its lifetime [52]. Louisiana is also interested in green hydrogen, with southern Louisiana, led by the Greater New Orleans Development Foundation, receiving approximately $50 million for H2theFuture. The project's funding will go toward transitioning the regional hydrogen sector to green hydrogen [53].

The project will likely also qualify for the DoE Loans Program Office (LPO) Title 17 Innovative Clean Energy Loan Guarantee Program which was authorized by the Energy Policy Act of 2005. Projects eligible for Title 17 loan guarantees must meet certain innovation, emissions, location, and repayment prospect requirements. This wind farm will employ existing commercial technologies in combination with new and significantly improved technologies, helps reduce anthropogenic GHG emissions, is located in the U.S., and provides a reasonable prospect of repayment. The new and improved technologies employed by this project are the Siemens Gamesa 14-222 DD turbine which is not currently installed in the U.S. and the production of e-methanol powered by the wind farm. These project characteristics achieve eligibility requirements to receive a Conditional Commitment and a Loan Guarantee Agreement from the DoE LPO [54].

4.3 Required Capital

MaxVentus found that estimating the initial capital cost of the entire project is a complicated task involving many factors that were analyzed by the team to develop the estimate of the total capital cost of the project. Of the hundreds of inputs used in SAM, we mostly used general assumptions confirmed by industry mentors, default model values, or those acquired from publicly available sources and adapted to fit the model. Given the developing and proprietary nature of the industry, confidential information from private companies could not always be obtained. MaxVentus combined researched values, industry estimates, and results from SAM to estimate the total capital cost at $3.66 billion (Net capital cost of the wind power plant, $2.1 B; Capex of PtX, $1.54 B; Offshore lease, $75 M; Port lease, $4.8 M).

Through early engagement with the LPO, a Title 17 Part I submission for basic eligibility was submitted and returned in under 60 days. Upon acceptance of eligibility, Part II of the application was submitted for further evaluation of the project in terms of risk allocation, creditworthiness, technical relevance and merit, technical approach, work plan, construction plan, and legal, environmental, and regulatory factors. It is expected MaxVentus application will move forward considering technological significance as well as socioeconomic factors in achieving DoE's policy objectives, including (i) job quality, (ii) responsible contractor standards, (iv) underserved or disadvantaged community hiring goals, and (v) creating quality jobs, spurring economic revitalization, remediating environmental degradation, and supporting energy workers in communities, whose members are or were engaged in providing, or have been affected by the provision of, energy-intensive goods and services. Following Part II, the LPO conducts legal, technical, financial, market, and insurance due diligence, and reviews compliance with federal environmental laws [54]. During this time term sheet negotiations are conducted and Bank of America (BofA) is presented as a co-lender in conjunction with the Federal Financing Bank (FFB). The FFB is the only lender for which DoE can guarantee 100% of the principal and interest on a loan under 1703 Regulations [55]. Negotiations of construction loans are drawn for both FFB and BofA. The project and agreed negotiations are presented for credit approval to the internal Project Review Committee, external Interagency Review and internal Credit Review Board review. Upon review and approval by the Secretary of Energy, LPO issues a Conditional Commitment. Lastly, a loan guarantee is executed.

4.3.1 CAPEX & OPEX

The primary driving factors that affect the capital cost of a wind project are the turbine cost and the balance of systems cost. SAM provides an estimation of turbine costs that is generous, although outdated, so research into

Equipment	QTY	Unit Cost	Total
Offshore Substation			
Offshore Platform	1	$80,000,000	$80,000,000
66 kV Breakers	6	$200,000	$1,200,000
66 kV buswork, arrestors, switches, etc.	1	$1,000,000	$1,000,000
Station Service	1	$1,000,000	$1,000,000
Protection, Control, and Communication	1	$2,000,000	$2,000,000
230kV/66 kV Transformer	1	$14,000,000	$14,000,000
		Subtotal	$99,200,000
Export Cable			
230kV Submarine Cable (mi)	50	$3,700,000	$185,000,000
66kV collection Cable (mi)	31	$2,400,000	$74,400,000
Joint Vault	1	$500,000	$500,000
230 kV Onshore Cable (mi) (includes splices, ductbank/trench, etc.)	2	$6,000,000	$12,000,000
		Subtotal	$271,900,000
Onshore Switching Station			
Site works/civil	1	$10,000,000	$10,000,000
230 kV Reactors (150 Mvar)	2	$2,100,000	$4,200,000
230 kV Breakers	3	$300,000	$900,000
230 kV buswork, arrestors, switches, etc.	1	$1,600,000	$1,600,000
Station Service	1	$800,000	$800,000
Protection, Control, and Communication	1	$1,800,000	$1,800,000
		Subtotal	$19,300,000
Interconnection			
230 kV transmission Line to POI (mi)	2	$2,200,000	$4,400,000
Modifications at Port Fourchon	1	$3,000,000	$3,000,000
		Subtotal	$7,400,000
		Transmission System Total Costs	**$397,800,000**

Table 3: Transmission Cost breakdown provided by Ralph Kurth, Principal at Stantec

offshore per MW cost of turbines and the Coastal Virginia Offshore Wind project using the same turbine model, lead to the assumption of $1,700.07/kW [56]. The balance of systems cost generated by SAM using values based on the location of the project, installation procedures, and generic model values is $4028/kW. To better account for the cost of the project and evaluate SAM's results other estimations for portions of the BOS cost were researched individually. Cable and substation infrastructure and installation costs based on the layout were presented to us by Ralph Kurth at $397.8M. This estimation aligns with SAM's calculations as cable infrastructure is expected to be approximately 15% of a project's total capital cost. Due to the limits of SAM, the own analysis of PtX capital investment resulted in 1,544,459,000 USD (dollars) and is included in the total capital cost.

The analysis determined a general O&M cost of $111/kW-yr [18][57]. A conservative escalation rate of 5% was applied to this cost to cover increased wear and tear due to the region as turbines age and unexpected disruptions from this.

4.4 Assumptions

Every parameter used in SAM can not be discussed in depth in this document, although specifications mentioned earlier were included as well as the assumptions following. Losses and uncertainties were left to the default model values as they were calculated and implemented in the Furow analysis. The estimated energy production was matched using the same turbine characteristics and an adjusted maximum capacity of the turbine. The insurance rate was assumed as 1.25% of installed cost, greater than the typical 1% rate, due to variable weather conditions in the GoM. Assumed sales tax basis, % of total equipment cost to be 24% as that is the amount of equipment acquired near the area. Federal income tax of 21% and Louisiana income tax of 8%. Assessed percentage of installed cost for property tax 0.1234% as this is the price of the leases per year. Louisiana state property tax rate of 0.34%. Louisiana state and parish sales tax rate of 9.85% in Lafourche parish. A generous net salvage value of 5% was assumed because of the IntegralBlade® technology.

For depreciation, a large majority of the project qualifies for the Modified Accelerated Cost Recovery System (MACRS) and a renewable energy project. We have assumed that most of the project (85%), qualifies for 5-yr MACRS, while the 12% qualifies for 15-yr MACRS and 3% is non-depreciable. MACRS is a valuable tool in the early stages of the project as it offers valuable tax benefits that can offset taxable income early on. With regard to the loans required for the project, we have assumed that the project's innovative design would make it eligible for support from the DoE LPO. The agreed negotiations are assumed, the FFB loan is drafted 70% of the capital investment with a twenty-year tenor and an interest rate of 3.5%. This loan is priced by 75 basis points above the benchmark 10-year Treasury rate [54]. The BofA loan is 30% of the capital investment with a six-year tenor and an interest rate of 4.5%. This loan is priced by 150 basis points above the benchmark 10-year Treasury rate. The financial projections assume a debt service coverage ratio (DSCR) of 1.5, over a period of 20 years, with a fixed interest rate of 4%. We also assume $450000 in closing costs for the debt and a 2.75% fee upfront.

Although we did not have a power purchase agreement we assumed a power price of between 15 and 20 ¢/kWh in order to receive a positive net present value showing the SAM analysis is viable [Table 4]. This relatively high price is acceptable in the situation as the further analysis of the Power-To-X facility and e-methanol fuel purchase agreement

Metric	Value
Annual AC energy in Year 1	932,679,800 kWh
Capacity	322,000 kW
Capacity factor in Year 1	32.00%
P90 AC Energy in Year 1	807,380,352.0 kWh
PPA price in Year 1	18.00 ¢/kWh
PPA price escalation	2.00 %/year
LPPA Levelized PPA price nominal	20.69 ¢/kWh
LPPA Levelized PPA price real	16.94 ¢/kWh
LCOE Levelized cost of energy nominal	19.88 ¢/kWh
LCOE Levelized cost of energy real	16.27 ¢/kWh
NPV Net present value	$69,577,184
IRR Internal rate of return	11.97 %
Year IRR is achieved	20
IRR at end of project	11.97 %
Net capital cost	$2,114,187,008
Equity	$1,207,983,360
Size of debt	$906,203,648
Debt percent	42.86%

Table 4: Metric outputs from SAM

By selling 93,200,000 kilograms of produced e-methanol at a mid metric price of $1200 per tonne, a price assumed by industry consultants, MaxVentus will have a yearly net revenue of 111,840,000 USD (dollars) per year [58]. However, MaxVentus has a power price of 0.20 cents per kilowatt hour or 300 dollars per megawatt hour, when producing 932,000 MW yearly, MaxVentus will pay 186,400,000 USD per MWh/yr. Maxventus' PtX Facility will be producing 93,200,000 kg of e-methanol yearly, with .75 kilograms of hydrogen being produced for every 6 kilograms of e-methanol. With a federal tax credit from the IRA of $3/kg of hydrogen produced that would be applied to the hydrogen production, MaxVentus would get a $34,950,000/yr tax credit. However, with consultation from Margarita Patria, a hydrogen energy economist, and principal at Charles River Associates, MaxVentus learned that her understanding of the IRA hydrogen tax incentives indicates that due to how recently the tax credits were created, there are loose definitions of where tax credits can be applied to. Based on this argument, MaxVentus believes that because produced e-methanol is the final product instead of green hydrogen, the $3/kg of H2 can and should be applied to the 93,200,000 kg/year produced. This would result in a 279,600,000 dollar tax credit and a net positive yearly revenue of 205,040,000 USD before factoring in MaxVentus's 3,663,487,657 USD total capital expenditures. Through the project development process, MaxVentus has learned that the industry itself cannot create new industries. Instead, federal and state governments must assist and incentivize new business ventures similar to ours as demonstrated prior in other industries [59]. Thus it is reasonable to conclude that applied federal and state tax incentives would make MaxVentus profitable.

5.0 Optimization Process

When developing a wind farm, the main goal is to decrease the costs of producing electrons while also increasing their value of them. This is done by sourcing the most cost-competitive materials and placing them in an area where they have the highest chances of success. During the research and development for this wind farm, MaxVentus was able to optimize the energy output, transmission system, offtake solution, and financial opportunities to reach closer to the main goal of increasing the profit margin for the electrons.

5.1 Furow Modeling

The utilization of Furow allowed us to take advantage of the wind resource data we acquired from Vortex to create a wind farm with maximum electric power output. The data analysis and visualization of the many different trends in the data was very insightful to the way we thought about the project. For example, seasonal, diel, and extreme fluctuations of wind were able to be tracked and understood by the team. Optimization was done by designing the wind farm so that the turbines could maximize their potential. Furow facilitates the efficient micro siting of wind turbines by allowing the user to input specifications for their layout grid. Then, the created grid was put through many iterations of the wake effect and energy yield tools to incrementally make adjustments to optimize the layout. The spacing of eight rotor diameters between turbines took advantage of both available spaces inside the chosen lease block and induced minimal wake effects on other turbines. During this phase of micro siting, we were able to improve the wind farm design so that it creates the most possible electrons in its given location, space, wind resource, and technological constraints. These steps were vital to many other factors that go into the project since the e-methanol and financial returns are functions of how many electrons the farm brings to shore.

5.2 Transmission Strategy

Fortunately the meetings and consultation with Ralph Kurth drastically improved the knowledge of offshore wind transmission systems. This knowledge was then used to choose the equipment necessary for the design of a single-line diagram and map the best route for this infrastructure to run through. Originally, the research suggested that High Voltage Direct Current (HVDC) cables might be best for the submarine export cable infrastructure compared to High Voltage Alternating Current (HVAC). By consulting about the project's details with Mr. Kurth, we were able to consider several CapEx and logistical factors to determine that HVAC would be best. He also provided most of the information needed to estimate the total cost of the transmission system based on his experience in the industry and knowledge of the undisclosed monetary values of this infrastructure. The wind farm layout was designed in a way that decreases array cable distances by placing the offshore substation at a central location. Due to the unique offtake plan, a specialized transmission system was required in order to efficiently use electron production. Although the purpose of this production does not primarily serve the grid, it is connected with high voltage cabling so that in the case of the offtake facility experiencing problems, power could easily flow to the grid.

5.3 Offtake Solution

The offtake plan of producing e-methanol as a function of the wind farm's electricity production incorporates many additional factors and variables to the project. However, we recognized that this auspicious strategy is a scalable, mutualistic pairing between offshore wind and e-methanol production. Through research and consultation with multiple industry professionals from different aspects of expertise, this solution was justified and encouraged. Zach Batts from Apex Clean Energy gave us an understanding of the processes within green methanol production. Alexander Reumert from European Energy provided us with insight into the nascent PtX industry that has incredible potential to impact the Gulf of Mexico region. The knowledge and practice around e-methanol PtX is almost non-existent which made the meeting with Mr. Reumert important as we were then able to base the ideas and solutions around credible information that we could cite and rely on. Speaking with Port Fourchon's Executive Director, Chett Chaisson, allowed us to gain vital regional knowledge used in the plan. Since many pieces of the project are based out of his port for both construction and operation, he was able to clear up concerns about the end user and opportunity in the area. Each industry professional that consulted with us was impressed and recognized the viability of the offtake strategy. Although we feel it is hard to forecast the success of this unproven offtake strategy, it is based on acquired knowledge from the industry and was very well received by them by the end of the research.

6.0 Auction Bid

Given the findings from Section 4.0 and bid prices from previous BOEM lease area auctions, MaxVentus proposes a maximum bid price of $75,000,000 ($5,000 per acre for 15,000 total acres) for the selected Lease Blocks ST143, ST163, ST164. Final commercial lease agreements from the New York Bight auction ranged from $6,619-$10,486.28 per acre due to the high wind speeds measured and other favorable conditions for offshore wind development [60]. Provided the lower wind resource in the GoM than in the North Atlantic, auction bid prices are expected to be lower. BOEM announced on February 23, 2023, an auction of three lease area zones, OCS-G 37334, OCS-G 37335, and OCS-G 37336 with a total of 682,540 acres for the GoM [61]. The GoM Wind Energy areas have a minimum bid price of $50 per acre and an asking price of $50,000,000 for each zone [62].

References

[1] "MarineCadastre.gov," marinecadastre.gov. [Online]. Available: https://marinecadastre.gov/data/ [Accessed 4 December 2023]

[2] "ArcGIS Pro | 2D and 3D GIS Mapping Software," Esri.com, 2019. [Online]. Available: https://www.esri.com/en-us/arcgis/products/arcgis-pro/overview [Accessed 4 December 2023].

[3] N. Fisheries, "Threatened and Endangered Species List Louisiana | NOAA Fisheries," NOAA, Jul. 21, 2022. [Online]. Available: https://www.fisheries.noaa.gov/southeast/consultations/threatened-and-endangered-species-list-louisiana [Accessed 4 December 2023]

[4] "ArcGIS Hub," noaa.hub.arcgis.com. [Online]. Available: https://noaa.hub.arcgis.com/search?collection=Dataset [Accessed: May 04, 2023]

[5] "UNITED STATES DEPARTMENT OF THE INTERIOR Bureau of Ocean Energy Management Office of Renewable Energy Programs Guidelines for Providing Benthic Habitat Survey Information for Renewable Energy Development on the Atlantic Outer Continental Shelf Pursuant to 30 CFR Part 585," 2013 [Online]. Available: https://www.boem.gov/sites/default/files/uploadedFiles/BOEM/Renewable_Energy_Program/Regulatory_Information/Habitat%20Guidelines.pdf [Accessed: May 04, 2023]

[6] "National Environmental Policy Act Documentation for Impact-Producing Factors in the Offshore Wind Cumulative Impacts Scenario on the South Atlantic Outer Continental Shelf" [Online]. Available: https://www.boem.gov/sites/default/files/documents/renewable-energy/state-activities/Impact-Producing-Factors-in-the-Offshore-Wind-Cumulative-Impacts-Scenario-on-the-South-Atlantic.pdf [Accessed: May 04, 2023]

[7] Office of Energy Efficiency & Renewable Energy, "How Do Wind Turbines Survive Severe Storms?," Energy.gov, 2017. [Online]. Available: https://www.energy.gov/eere/articles/how-do-wind-turbines-survive-severe-storms [Accessed 4 May 2023]

[8] "Wind farm insurance: on- and off-shore | Munich Re," www.munichre.com. [Online]. Available: https://www.munichre.com/en/solutions/for-industry-clients/risk-transfer-solutions-for-on-and-off-shore-wind-power.html [Accessed 4 May 2023]

[9] "Wind Resource Data for Wind Farm Developments | Vortex FDC," VORTEX. [Online]. Available: https://vortexfdc.com/ [Accessed 4 May 2023]

[10] "LES JMU CWC O shore farm created for Evere Mcconville Rolling Window Report for run 581227," 2023 [Online]. Available: https://api.vortexfdc.com/data/581227/rep-4g1mzKBQZGrwbHrhhngbTGbWDgWuVJ-A/RollingWindow.LongTerm.Run_581227.pdf [Accessed: May 04, 2023]

[11] "Offshore Wind Turbine SG 14-222 DD I Siemens Gamesa." Siemens Gamesa, https://www.siemensgamesa.com/en-int/products-and-services/offshore/wind-turbine-sg-14-222-dd. [Accessed 2 December 2022].

[12] "Global leadership grows." Siemens Gamesa, 25 October 2021, https://www.siemensgamesa.com/en-int/newsroom/2021/10/offshore-blade-facility-virginia-usa. [Accessed 2 December 2022].

[13] "IEA Wind TCP Task 37 Definition of the IEA Wind 15-Megawatt Offshore Reference Wind Turbine Technical Report," 2020 [Online]. Available: https://www.nrel.gov/docs/fy20osti/75698.pdf [Accessed 4 May 2023]

[14] C. Shahan, "Siemens Gamesa Offshore Wind Turbine Prototype Breaks 24-Hour Output Record," CleanTechnica, Oct. 13, 2022. [Online]. Available: https://cleantechnica.com/2022/10/13/siemens-gamesa-offshore-wind-turbine-prototype-breaks-24-hour-output-record/ [Accessed: May 04, 2023]

[15] S. Horwath, J. Hassrick, R. Grismala, E. Diller, J. Krebs, R. Manhard. "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, Headquarters, Sterling. VA, Aug. 2021, https://www.boem.gov/sites/default/files/documents/environment/Comparison-Environmental-Effects-Different-OWT-Foundations-2021.pdf [Accessed 7 December 2022].

[16] BOEM, "Offshore wind in the US Gulf of Mexico: Regional Economic Site-Specific Analyses," 2020. [Online]. Available: https://espis.boem.gov/final%20reports/BOEM_2020-018.pdf [Accessed 29 November 2021].

[17] P. Beiter et al., "A Spatial-Economic Cost- Reduction Pathway Analysis for U.S. Offshore Wind Energy Development from 2015-2030," 2016 [Online]. Available: https://www.nrel.gov/docs/fy16osti/66579.pdf. [Accessed: May 04, 2023]

[18] T. Stehly and P. Duffy, "2021 Cost of Wind Energy Review," 2022 [Online]. Available: https://www.nrel.gov/docs/fy23osti/84774.pdf [Accessed: May 04, 2023]

[19] "MAINE OFFSHORE WIND ANALYSIS Offshore Wind Transmission Technical Review Report to the Maine Governor's Energy Office and Maine Offshore Wind Roadmap," 2022 [Online]. Available: https://www.maine.gov/energy/sites/maine.gov.energy/files/inline-files/Maine%20OSW%20DNV%20Offshore%20Wind%20Transmission%20Technical%20Review%20Final%20Report.pdf [Accessed: May 04, 2023]

[20] "Submarine Cables - Domestic Regulation," www.noaa.gov. [Online]. Available: https://www.noaa.gov/gc-international-section/submarine-cables-domestic-regulation [Accessed: May 04, 2023]

[21] "Lease and Grant Information | Bureau of Ocean Energy Management," www.boem.gov. [Online]. Available: https://www.boem.gov/renewable-energy/lease-and-grant-information [Accessed: May 04, 2023]

[22] X. Yi, M. Scutariu, and K. Smith, "Optimisation of offshore wind farm inter‐array collection system," IET Renewable Power Generation, vol. 13, no. 11, pp. 1990–1999, Jun. 2019, doi: https://doi.org/10.1049/iet-rpg.2018.5805. [Accessed: May 04, 2023]

[23] "Commercial and Research Wind Lease and Grant Issuance and Site Assessment Activities on the Outer Continental Shelf of the Gulf of Mexico Draft Environmental Assessment Bureau of Ocean Energy Management Gulf of Mexico Region" [Online]. Available: https://www.boem.gov/sites/default/files/documents/renewable-energy/state-activities/GOM-Wind-Lease-EA.pdf [Accessed: May 04, 2023]

[24] "State Activities | Bureau of Ocean Energy Management," www.boem.gov. [Online]. Available: https://www.boem.gov/renewable-energy/state-activities [Accessed: May 04, 2023]

[25] "Maryland Offshore Wind Project" [Online]. Available: https://www.boem.gov/sites/default/files/documents/renewable-energy/state-activities/US%20Wind%20Construction%20and%20Operations%20Plan%20Volume%20I.pdf [Accessed: May 04, 2023]

[26] "Boundaries (Saltwater/Freshwater and State/Federal) | Louisiana Department of Wildlife and Fisheries," www.wlf.louisiana.gov. [Online]. Available: https://www.wlf.louisiana.gov/page/boundaries [Accessed: May 04, 2023]

[27] "WINDExchange: Permitting and Zoning," windexchange.energy.gov. [Online]. Available: https://windexchange.energy.gov/projects/permitting [Accessed: May 04, 2023]

[28] A. Crowle and P. Thies, "Floating offshore wind turbines port requirements for construction," Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment, p. 147509022210784, Feb. 2022, doi: https://doi.org/10.1177/14750902221078425 [Accessed: May 04, 2023]

[29] "Dominion Energy Continues Development of First Jones Act Compliant Offshore Wind Turbine Installation Vessel," Dominion Energy MediaRoom. [Online]. Available: https://news.dominionenergy.com/2020-12-16-Dominion-Energy-Continues-Development-of-Firs

t-Jones-Act-Compliant-Offshore-Wind-Turbine-Installation-Vessel [Accessed: May 04, 2023]
[30] "Offshore Wind Support Vessels," www.dco.uscg.mil. [Online]. Available: https://www.dco.uscg.mil/OCSNCOE/Renewable-Energy/Support-Vessels/ [Accessed: May 04, 2023]
[31] "Roadmap for Wind Cybersecurity," 2020 [Online]. Available: https://www.energy.gov/sites/prod/files/2020/07/f76/wind-energy-cybersecurity-roadmap-2020v2.pdf [Accessed: May 04, 2023]
[32] "Supporting National Environmental Policy Act Documentation for Offshore Wind Energy Development Related to Decommissioning Offshore Wind Facilities" [Online]. Available: https://www.boem.gov/sites/default/files/documents/renewable-energy/state-activities/Decommissioning%20White%20Paper.pdf [Accessed: May 04, 2023]
[33] "Summary Report: Bureau of Ocean Energy Management's Offshore Wind and Maritime Industry Knowledge Exchange Offshore Wind turbine jackets for the Block Island Wind Project off Rhode Island (credit: Sid Falk, BOEM)," 2018 [Online]. Available: https://www.boem.gov/sites/default/files/renewable-energy-program/BOEM-Maritime-Meeting-Summary-FINAL-%281%29.PDF [Accessed: May 04, 2023]
[34] "The Maritime Fleet of the USA -the current status and potential for the future January 2022 -Rev 2.0" [Online]. Available: https://www.u-mas.co.uk/wp-content/uploads/2022/04/oc_jaf_final_report_20220119.pdf [Accessed: May 04, 2023]
[35] E. Müller-Casseres, O. Y. Edelenbosch, A. Szklo, R. Schaeffer, and D. P. van Vuuren, "Global futures of trade impacting the challenge to decarbonize the international shipping sector," Energy, vol. 237, p. 121547, Dec. 2021, doi: https://doi.org/10.1016/j.energy.2021.121547 [Accessed: May 04, 2023]
[36] "A.P. Moller - Maersk continues green transformation with six additional large container vessels," www.maersk.com. [Online]. Available: https://www.maersk.com/news/articles/2022/10/05/maersk-continues-green-transformation [Accessed: May 04, 2023]
[37] Shell, "New Energies," Shell.com, 2019. [Online]. Available: https://www.shell.com/energy-and-innovation/new-energies.html [Accessed: May 04, 2023]
[38] B. International, "Maersk and SunGas sign strategic green methanol deal," Bioenergy International, Jan. 02, 2023. [Online]. Available: https://bioenergyinternational.com/maersk-and-sungas-sign-strategic-green-methanol-deal/ [Accessed: May 04, 2023]
[39] CarbonSinkLLC, "CarbonSinkLLC," CarbonSinkLLC. [Online]. Available: https://carbonsinkllc.com/maerskpressrelease [Accessed: May 04, 2023]
[40] "Technologies for the automation and digitalization of desalination plants," siemens.com Global Website. [Online]. Available: https://www.siemens.com/global/en/markets/water/desalination-plants.html [Accessed: May 04, 2023]
[41] "Silyzer 300 Startup time: < 1 minute Dynamics: 0 -100% in 10% / s Minimum load: ≥ 40% Silyzer 300 The next paradigm of PEM electrolysis Silyzer 300 -PEM Module Array" [Online]. Available: https://assets.siemens-energy.com/siemens/assets/api/uuid:40d117f9-1b4f-4816-ae58-b47cf011d406/datasheet-pem-electrolyzer-17-5mw.pdf?ste_sid=29cd6c81e2d7b3b24ce2846d744f5c53 [Accessed: May 04, 2023]
[42] M. Matošec, "Water treatment for green hydrogen: what you need to know," Hydrogen Tech World.com, Oct. 27, 2022. [Online]. Available: https://hydrogentechworld.com/water-treatment-for-green-hydrogen-what-you-need-to-know [Accessed: May 04, 2023]
[43] "Workshop PtG/ PtL Large Scale PEM Electrolysis and Sector Coupling 8 th of March, 2021;

Ilona Dickschas" [Online]. Available: https://www.heattofuel.eu/wp-content/uploads/2021/03/6_Ilona-Dickschas.pdf [Accessed: May 04, 2023]

[44] T. Kato, M. Kubota, N. Kobayashi, and Y. Suzuoki, "Effective utilization of by-product oxygen from electrolysis hydrogen production," Energy, vol. 30, no. 14, pp. 2580–2595, Nov. 2005, doi: https://doi.org/10.1016/j.energy.2004.07.004 [Accessed: May 04, 2023]

[45] A. R. Dahiru, A. Vuokila, and M. Huuhtanen, "Recent development in Power-to-X: Part I - A review on techno-economic analysis," Journal of Energy Storage, vol. 56, p. 105861, Dec. 2022, doi: https://doi.org/10.1016/j.est.2022.105861.

[46] G. A. Olah, "Beyond Oil and Gas: The Methanol Economy," Angewandte Chemie International Edition, vol. 44, no. 18, pp. 2636–2639, Apr. 2005, doi: https://doi.org/10.1002/anie.200462121 [Accessed: May 04, 2023]

[47] "About the plant," HØST PtX Esbjerg. [Online]. Available: https://hoestptxesbjerg.dk/about-ptx/ [Accessed: May 04, 2023]

[48] The White House, "National Climate Task Force," The White House, Jan. 27, 2021. [Online]. Available: https://www.whitehouse.gov/climate/#:~:text=Reducing%20U.S.%20greenhouse%20gas%20emissions [Accessed: May 04, 2023]

[49] "BIPARTISAN INFRASTRUCTURE LAW - U.S. Senate Committee on Environment and Public Works," www.epw.senate.gov. [Online]. Available: https://www.epw.senate.gov/public/index.cfm/bipartisan-infrastructure-law [Accessed: May 04, 2023]

[50] "Inflation Reduction Act of 2022," Energy.gov. [Online]. Available: https://www.energy.gov/lpo/inflation-reduction-act-2022 [Accessed: May 04, 2023]

[51] The White House, "Justice40 Initiative," The White House, 2022. [Online]. Available: https://www.whitehouse.gov/environmentaljustice/justice40/ [Accessed: May 04, 2023]

[52] J. Edwards, "LOUISIANA CLIMATE ACTION PLAN CLIMATE INITIATIVES TASK FORCE RECOMMENDATIONS TO THE GOVERNOR STATE OF LOUISIANA," 2022 [Online]. Available: https://gov.louisiana.gov/assets/docs/CCI-Task-force/CAP/Climate_Action_Plan_FINAL_3.pdf [Accessed: May 04, 2023]

[53] "H2theFuture," U.S. Economic Development Administration. [Online]. Available: https://www.eda.gov/funding/programs/american-rescue-plan/build-back-better/finalists/greater-new-orleans-development-foundation [Accessed: May 04, 2023]

[54] "INNOVATIVE CLEAN ENERGY LOAN GUARANTEES," Energy.gov. [Online]. Available: https://www.energy.gov/lpo/innovative-clean-energy-loan-guarantees [Accessed: May 04, 2023]

[55] "LOAN GUARANTEE SOLICITATION ANNOUNCEMENT" [Online]. Available: https://www.energy.gov/lpo/articles/innovative-clean-energy-loan-guarantee-solicitation-current [Accessed: May 04, 2023]

[56] "Offshore Wind Market Report: 2022 Edition" [Online]. Available: https://www.energy.gov/sites/default/files/2022-09/offshore-wind-market-report-2022-v2.pdf [Accessed: May 04, 2023]

[57] T. Stehly and P. Duffy, "2020 Cost of Wind Energy Review," 2021 [Online]. Available: https://www.nrel.gov/docs/fy22osti/81209.pdf [Accessed: May 04, 2023]

[58] J. O. Mandra, "Counting the cost of going green: The steep price of switching to e-methanol," Offshore Energy, Mar. 30, 2023. [Online]. Available: https://www.offshore-energy.biz/counting-the-cost-of-going-green-the-steep-price-of-switching-to-e-methanol/#:~:text=The%20shipping%20consultancy%20is%20assuming [Accessed: May 04, 2023]

[59] "The Economics of Small Modular Reactors," 2021 [Online]. Available:

https://smrstart.org/wp-content/uploads/2021/03/SMR-Start-Economic-Analysis-2021-APPROVED-2021-03-22.pdf [Accessed: May 04, 2023]

[60] "New York Bight | Bureau of Ocean Energy Management," www.boem.gov. [Online]. Available: https://www.boem.gov/renewable-energy/state-activities/new-york-bight [Accessed: May 04, 2023]

[61] "Gulf of Mexico Activities | Bureau of Ocean Energy Management," www.boem.gov. [Online]. Available: https://www.boem.gov/renewable-energy/state-activities/gulf-mexico-activities [Accessed: May 04, 2023]

[62] "DEPARTMENT OF THE INTERIOR Bureau of Ocean Energy Management Proposed Sale Notice for Commercial Leasing for Wind Power Development on the Outer Continental Shelf in the Gulf of Mexico (GOMW-1)" [Online]. Available: https://www.boem.gov/sites/default/files/documents/renewable-energy/state-activities/BOEM_FRDOC_0001-0629.pdf. [Accessed: May 05, 2023]