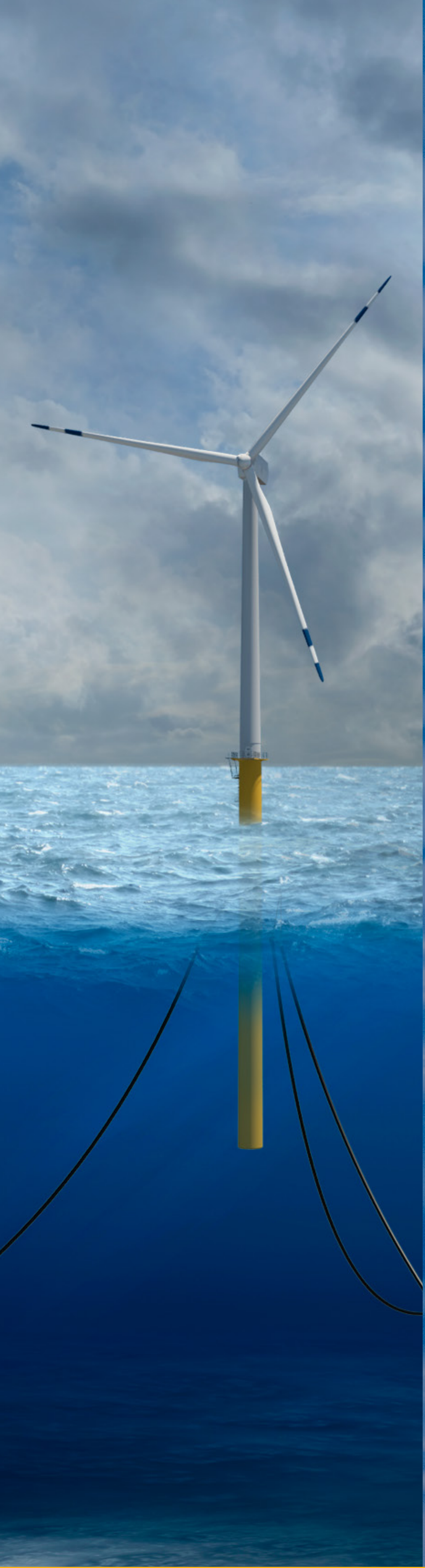

NEW YORK STATE

GREAT LAKES WIND ENERGY FEASIBILITY STUDY

NYSERDA Report 22-12

NYSERDA Report 22-12
NYSERDA Contract 123452
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Abstract

NYSERDA engaged three contractors to conduct the various analyses comprising this Great Lakes Wind Feasibility Study performed during February 2021 to May 2022. The Study focused on Lake Erie and Lake Ontario and consisted of data gathering, information synthesis, technical analysis, and development of recommendations for next steps to help New York achieve its ambitious Clean Energy Standard. The Study considered existing and emerging technologies for fixed and floating turbines, including icing considerations unique to the Great Lakes, new technology development timelines, geospatial conditions, resource assessment, regulatory processes, permitting requirements and risks, potential conflicts, costs and economic opportunities, electrical infrastructure, and overall cost-reduction pathways. Public engagement was facilitated by NYSERDA throughout the study and included public webinars and a public forum in 2021.

Acknowledgments

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Keywords

- Great Lakes
- Lake Erie
- Lake Ontario
- wind energy
- resource
- fixed bottom substructure
- floating substructure
- siting
- cost modeling
- economic development
- jobs
- environmental
- regulatory
- grid interconnection
- risks and benefits infrastructure, ports
- vessels
- permitting
- visual impact
- viewshed


Photo Credit: Getty Images

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Report 22-12d. Ports and Infrastructure

Report 22-12e. Substructure Options

Report 22-12f. Interconnection Feasibility Study

Report 22-12g. Cost Modeling and Cost Reduction Pathways

Report 22-12h. Economic Development and Workforce Opportunities

Report 22-12i. Environmental, Multi-User, and Risk Bnefit

Report 22-12j. Visual Impacts

Report 22-12k. Federal, State, and Utility Permitting Roadmap and Assessment

Report 22-12L. Stakeholder Report from Public Feedback Session

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Acronyms and Abbreviations

AEP	Annual Energy Production
AFDD	Accumulated FDD acronyms
CapEx	Capital Expenditure
CEHA	Coastal Erosion Hazard Area
COD	Commercial Operations Date
CWA	Clean Water Act
CZMA	Coastal Zone Management Act
DOS	Department of State
DPS	Department of Public Service
FAA	Federal Aviation Administration
FCR	Fixed Charge Rate
FDD	Freezing Degree Days
ft	feet
FTE	full time equivalent
GDP	Gross Domestic Product
GLW	Great Lakes Wind
JEDI	Jobs and Economic Development and Impacts
kWh	kilowatt hour
LCOE	levelized cost of energy
m/s	meters per second
MW	megawatts
NCF	Net Capacity Factor
NEPA	National Environmental Policy Act
NOAA	National Oceanic and Atmospheric Administration
NREL	National Renewable Energy Laboratory
NYISO	New York Independent System Operator
NYS	New York State
NYSDEC	New York State Department of Environmental Conservation
NYSERDA	New York State Energy Research and Development Authority
NYSOGS	New York State Office of General Services
O&M	Operation and Maintenance
OpEx	Operational Expenditure
ORCA	Offshore Regional Cost Analyzer
ORES	Office of Renewable Energy Siting
POI	point of interconnection
PSC	Public Service Commission
PUC	Public Utilities Commission
RNA	rotor/nacelle assembly
SEQRA	State Environmental Quality Review Act
SHPO	State Historic Preservation Office
THPO	Tribal Historic Preservation Office
USACE	U.S. Army Corps of Engineers
USCG	U.S. Coast Guard
USFWS	U.S. Fish and Wildlife Service
VIA	Visual Impact Assessment
W	Watt(s)

Executive Summary

In October, 2020, the State of New York Public Service Commission (Commission) issued an Order requiring the commencement of a feasibility study of Great Lakes Wind (GLW).[1]

In response, the New York GLW Feasibility Study described herein considered potential wind energy development in New York State waters of Lake Erie and Lake Ontario through a framework that balanced environmental, maritime, economic, and social issues with consideration of market barriers and costs. The Study consisted of data gathering, information synthesis, technical analysis, and development of recommendations for next steps to help New York State plan for potential future GLW development, as it works toward meeting its Clean Energy Standard mandates.

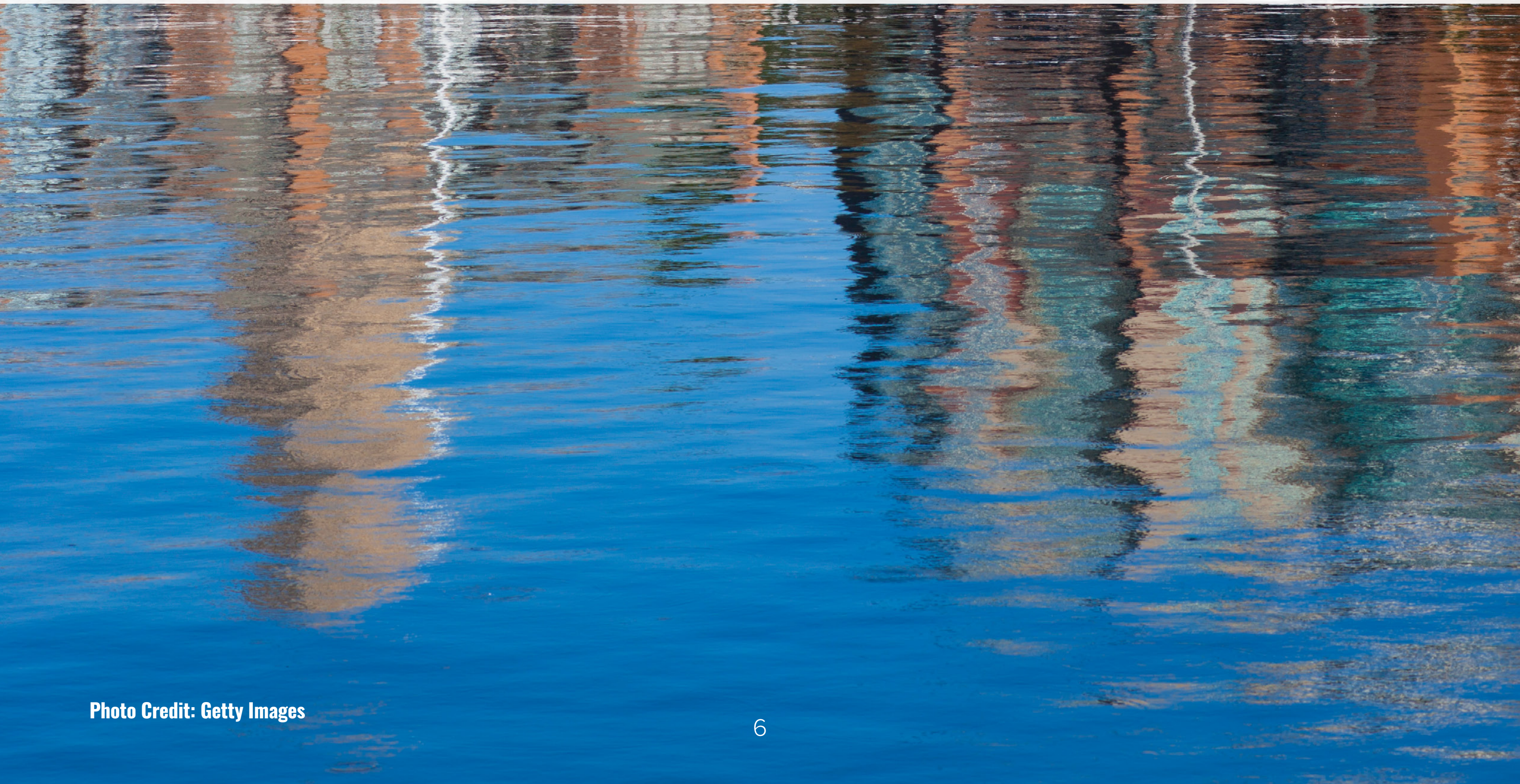


Photo Credit: Getty Images

Physical conditions relevant to wind turbine siting in NYS waters of Lakes Erie and Ontario were assessed. The National Renewable Energy Laboratory (NREL) performed new modeling to update the offshore wind energy resource assessment for the region.

The modeled wind resource data indicate that the annual average wind speeds at a height of 100 m are very consistent across the lakes, with average winds up to 9.0 m/s in the eastern portion of Lake Ontario and part of Lake Erie.

Additional physical site conditions were evaluated including ice climate, waves, currents, and geophysical conditions. The study did not find that any of the physical characteristics examined would present major obstacles to wind energy development; however, many unique factors would need to be considered for design decisions and cost optimization. A key finding was that fixed bottom substructures would be most appropriate for the relatively shallow depths of Lake Erie (less than 60 meters) and floating wind technologies would be more appropriate for the deeper waters of Lake Ontario. Based on detailed physical siting analysis, the technical nameplate generating potential for wind energy was estimated to be up to 2 gigawatts (GW) on Lake Erie and up to 18 GW on Lake Ontario. Daily generation profiles based on 21 years of high-fidelity modeled wind data show that average diurnal wind variations align with New York State electricity loads in the winter.

fixed bottom substructures would be most appropriate for the relatively shallow depths of Lake Erie (less than 60 meters)

An assessment of available infrastructure and wind plant technologies provided possible deployment scenarios and upgrades associated with potential GLW development. The inability of standard wind turbine installation vessels to navigate the locks and canals of the St. Lawrence Seaway is one of the most limiting factors of infrastructure for wind energy development on the Great Lakes. The optimal wind turbine substructure type would likely be some adaptation of an existing substructure that meets the ice, geotechnical, and logistical requirements for the region. In terms of infrastructure, all the ports considered would need upgrades to be able to accommodate GLW, including additional high-capacity (lifting height and weight) cranes, expanded quayside length, expanded laydown area for component staging, and dredging of the channels and cargo ports to be able to accommodate the large vessels required to transport, assemble, and install wind turbines in the Great Lakes. These costs are not included in the cost study herein but should be part of a larger discussion about NYS infrastructure investments and their respective allocations.

floating wind technologies would be more appropriate for the deeper waters of Lake Ontario

To address interconnection feasibility, combined capacity headrooms available to accommodate GLW were determined for Lakes Erie and Ontario. Without significant transmission upgrades, the available Point of Interconnection POIs accessible from Lake Erie have a maximum transmission capacity headroom of 270 megawatts (MW), while the POIs accessible from Lake Ontario have a maximum of 1,140 MW. The total headroom capacity could be increased with tens to several hundreds of millions in transmission infrastructure upgrades. Some land-based transmission upgrades will likely be needed to accommodate significant utility scale electrification of the grid including solar, terrestrial wind, as well as GLW, especially in the context of a full decarbonization of all energy sectors. These grid upgrade costs are not included in the cost study herein but should be part of a larger discussion about NYS energy infrastructure investments and their respective allocations.

The cost analysis in this study provides a high-level estimate of costs that are representative of commercial-scale wind energy projects that could be installed in New York State waters of Lakes Erie and Ontario. A range of scenarios were considered for GLW, including reference years of 2030 and 2035 and plant capacities between 100 MW and 800 MW. Additional costs for GLW relative to Atlantic offshore wind include costs associated with ice protection such as de-icing measures and ice cones on the substructure. For 400-MW wind plants with a Commercial Operations Date (COD) of 2030, levelized cost of energy (LCOE) ranges from \$96/megawatt-hours (MWh) to \$118/MWh, decreasing to between \$89/MWh and \$110/MWh for wind plants with a COD of 2035. The range of LCOEs is similar across both Lakes Erie (fixed bottom) and Ontario (floating); however, there were some differences based on the modeled OpEx and CapEx for fixed bottom versus floating substructures. The assumptions made in the cost analysis were generally conservative and rely mostly on existing technologies. GLW developers and NYS may find more creative and innovative technology solutions that adapt to the local conditions and reap the associated cost reductions. However, there is substantial uncertainty in CapEx and OpEx due to the fact that novel designs may be required for fixed-bottom substructures, and floating wind technologies in general are relatively new. Any actual wind energy development would require detailed, site-specific analysis to assess its technical and economic feasibility.

An assessment of potential economic development and workforce opportunities was performed for a hypothetical wind energy project in Lake Erie and Lake Ontario. Much like other large-scale infrastructure projects, GLW energy projects would be labor and capital intensive to construct and operate. Gross jobs and economic impacts were modeled in association with (1) GLW development, manufacturing, and supply chain, (2) installation (ports, staging, and vessels), and (3) operations and maintenance (O&M). Jobs and economic impacts were estimated for two scenarios representing different percentages of a project's labor and capital expenditures coming from within the State—a base case with some content coming from outside the State, and 100% State content assumption, which determined the maximum possible contribution to the State's gross domestic product (GDP). Both Lakes were assessed using a hypothetical wind project size of 400 MW. For Lake Erie, developing a 400-MW fixed bottom project in NYS could support 4,100–7,900 FTE job years and generate \$590 million to \$1.1 billion in GDP during the construction phase, depending on which State content scenario is assumed. For Lake Ontario, a 400-MW floating wind project could support 6,900–10,500 FTE job years and generate \$960 million to \$1.5 billion in GDP, depending on the scenario. The projects would also create additional jobs from induced impacts during the construction and operations phases. The greatest opportunity for workforce and economic development in NYS stemming from Great lakes Wind (GLW) is through fabrication and assembly of substructures, supporting New York State port infrastructure, developing Great Lake vessel capabilities and long-term O&M jobs.

A permitting and regulatory review and roadmap were prepared to support the assessment of GLW feasibility. The permitting study focused on permitting of construction and operation of wind farms and underwater cables. There are 15 major federal and State permitting or regulatory requirements relevant to GLW. The federal processes are largely driven by or tied to the National Environmental Policy Act (NEPA) review process. At the NYS level, regulatory permitting and reviews can vary depending upon windfarm size. Based on the identified risks that GLW projects could face, opportunities were identified for improving the efficiency of the permitting process. To better understand regulatory dynamics, cross-functional process flow charts were developed for two permitting scenarios—utility-scale and demonstration-scale projects—that demonstrate the interactions of the multiple permitting authorities at the federal and State level.

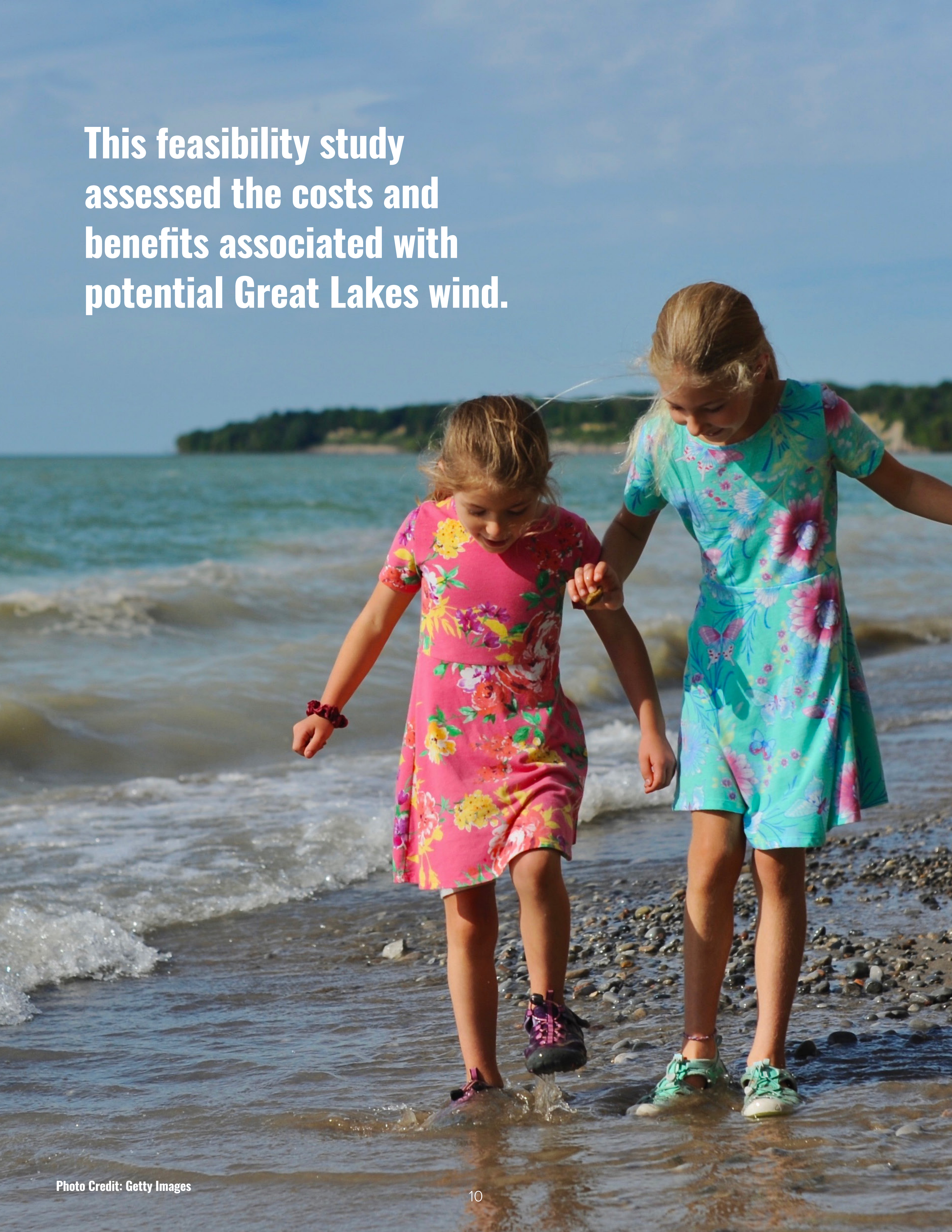
For environmental and multi-use considerations, a relative risk analysis, minimization/mitigation, and benefits assessment was prepared. The findings provide critical information on the key potential environmental and biological impacts, user conflicts, benefits, and knowledge gaps to inform decisions about GLW development. The Environmental Study considered birds, bats, invertebrates, fish, water quality (including contaminated sediments), and a variety of sensitive and specially designated habitats. An analysis of human use conflicts considered fisheries, drinking water, shipping, and viewshed, Department of Defense activities, recreation, tribal uses, and historic/cultural areas. A relative risk analysis assessed potential biological, environmental, regulatory, cultural, and social conflicts associated with GLW. Overall, based on environmental and human use conflict risk assessment, it is feasible to develop wind in either lake, but different constraints apply to each, and filling data gaps and/or developing predictive models could help to reduce risk. In terms of benefits, GLW is much like other renewable energy technologies. If it were to move forward, it could provide job and employment opportunities to address inequalities in local and regional communities, as well as eliminate harmful air pollutants that can disproportionately affect public health in disadvantaged communities.

A visual impact (or viewshed) assessment was prepared to present high-level viewshed analyses for select hypothetical turbine locations and provide a general sense of theoretical visibility in the region. The hypothetical turbine placement sites in each lake (four within Lake Ontario and two within Lake Erie) provide some insight into visibility differences along the lakes within NYS waters. All sites were located at a hypothetical minimum distance from shore (16 km/10 mi in Lake Ontario and 8km/5 mi in Lake Erie) and yield an illustrative "worst case" view for turbine hub-height visibility. The parameters of the modeled turbine defined in the visual impact assessment yield an estimated viewshed radius of 42.6 km (~26.48 mi). If NYS chooses to pursue GLW, a recommended step would be to conduct a detailed and site-specific assessment of the viewshed and visual impacts based on the details of the planned development. Such a study could take into consideration the specific turbine model dimensions, the wind farm layout and turbine placement, and utilize high-resolution elevation and surface model data, as well as land-use data specific for the area near the project where the turbines are likely to be visible.

At this time, no formal sites within Lake Erie or Lake Ontario have been selected for specific consideration of GLW development, and the analysis performed in this study was site agnostic. None of the reference distances used for physical site evaluation or viewshed assessments should be interpreted to have any significance in terms of site identification.

Similarly, no specific turbine design, foundation technology option, or wind farm layout has been officially designated for use in NYS waters of the Great Lakes. This feasibility study assessed the costs and benefits associated with potential GLW through consideration of existing and emerging technologies for fixed and floating turbines, new technology development timelines, physical geospatial conditions, wind resource assessment, State and federal regulatory processes, permitting requirements and risks, potential environmental and human-use conflicts, costs and economic opportunities, electrical infrastructure, and overall cost-reduction pathways. The study did not find any unsurmountable barriers to GLW but illuminated many differences and unique challenges between GLW and offshore wind development in the open ocean.

This feasibility study assessed the costs and benefits associated with potential Great Lakes wind.



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1 Introduction

1.1 Background

New York State's Clean Energy Standard (CES) is designed to fight climate change, reduce harmful air pollution, and ensure a diverse and reliable low-carbon energy supply. By focusing on low-carbon energy sources, the CES is designed to bring investment, economic development, and jobs to New York State.

In July 2019, the State passed the **Climate Leadership and Community Protection Act (Climate Act)**, which represents the most ambitious and comprehensive climate and clean energy legislation in the country. The Climate Act's nation-leading climate and energy goals set the stage for a sweeping set of measures to reduce the carbon footprint and improve the resiliency of communities across the State, including provisions that 70% electricity comes from renewable energy sources such as solar and wind by 2030 and a commitment for 100% zero-emission electricity by 2040.

In response, a significant statewide renewable energy ramp-up is underway with **over 90 solar, wind, and hydroelectric projects totaling 10,800+ megawatts** (MW). This includes five contracted offshore wind projects and **22 large-scale solar, hydroelectric, and energy storage projects** across Upstate New York, totaling **over 4,600 MW of new renewable capacity and 30 MW of energy storage capacity**. As well, the Climate Act commits New York State to a **reduction of at least 85% below 1990-level greenhouse gas emissions by 2050**.

While the State is on a path to fully decarbonize its energy sectors, additional non-carbon energy resources may still be needed to electrify the transporation sector, heat buildings, and eliminate carborn emissions from the industrial and agriculture sectors.

The Great Lakes which make up the State's northern border are a unique and highly valued natural resource providing multiple economic and social benefits that enhance the quality of life for New Yorkers, including sustainable fresh water supplies, recreation, tourism, marine transportation and commerce, and fishing to name a few. The lakes also have a strong and consistent wind energy resource, comparable to Atlantic Ocean sites where significant offshore wind energy development is underway.

The proximity of the Great Lakes' resources to upstate load centers has compelled the commission to investigate the feasibility of expanding the Lakes' purpose to include sustainable wind energy production. While ocean based wind energy is fairly well understood, based on twenty years of European experience, issues that may arise in harvesting wind energy from the Lakes are less known, especially in terms of its economic and technical feasibility, as well as its long-term sustainability.

70%

electricity from renewable energy sources such as solar and wind by 2030

100%

zero-emission electricity by 2040

90+

solar, wind, and hydroelectric projects totalling 10,800+ MW

On October 15, 2020, the New York State Public Service Commission (Commission) issued an Order (in Case 15-E-0302) to adopt modifications to the State's CES. In this Order, the Commission instructed New York State Energy Research and Development Authority (NYSERDA) to conduct a feasibility study of Great Lakes wind (GLW) energy to consider the environmental, maritime, economic, and social issues as well as market barriers and costs of developing wind energy in the Great Lakes as an important step toward assessing the overall value and viability of this potential resource for helping New York achieve Climate Act goals. The Commission directed NYSERDA to commence this study within 180 days of the effective date of the Order to be completed with a total budget of $1 million.

This study herein was conducted by the National Renewable Energy Laboratory and its partners at Advisian and Pterra, and was managed by NYSERDA. The study parameters allowed the investigation of a broad range of topics directed by the Commission but did not direct the researchers to draw conclusions about site identification for potential GLW projects.

Rather, the study results are site agnostic, and the researchers aimed to consider all locations within New York State waters on a geo-spatial grid without bias. As such, the reader should not infer that any decision on site selection has been made. However, there has been significant offshore wind development experienced globally and with the United States federal regulators, the Bureau of Ocean Energy Management (BOEM) and the Bureau of Safety and Environmental Enforcement (BSEE). These entities follow an evolving set of siting "best practices" in the Atlantic that avoid projects close to shore where many major conflicts are anticipated, such as viewshed obstructions and interactions with wildlife.

Taking this industry experience into consideration, the study defined certain distance-from-shore reference criteria in the assessments to establish realistic scenarios and metrics for quantifying Great Lakes potential. For example, the physical siting assessments calulate energy generating potential and summarize the key characteristics of the lakes on a geo-spatial plane. Lake area was quantified at a resolution of 2 statute mile increments based on distance from shore. The research discovered at an early stage that near-shore areas would be significantly more problematic due to greater ice accumulation, potential wildlife impacts (e.g., avian), visual impacts, and greater presence of lakebed contaminants. Consequently, the areas between 0 and 4 statute miles from shore were not assessed to provide a more realistic aggregation of the remaining potential resource area. Since the near-shore areas are ostensibly excluded, one should not assume that all other geo-spatial locations analyzed are considered viable. Similarly, a first order visual impact analysis was done which required the researchers to select specific reference distances; 10 miles for Lake Ontario and 5 miles for Lake Erie.[2] These distances represent possible worst case scenarios but were chosen for reference only, and do not indicate a siting preference linked to these distances.

The conclusions of this report are presented in section 9 and are intended to inform decision makers at NYSERDA, the Commission, and New York State, and help enable them to determine the next appropriate steps.

1.2 Objective and Scope

The GLW Feasibility Study (Study) was directed to consider existing and emerging technologies for fixed and floating turbines (including icing considerations unique to the Great Lakes), new technology development timelines, geospatial conditions, resource assessment, regulatory processes, permitting requirements and risks, potential conflicts, costs and economic opportunities, electrical infrastructure, and overall cost-reduction pathways. The Study was designed to focus on Lake Erie and Lake Ontario and to consist of:

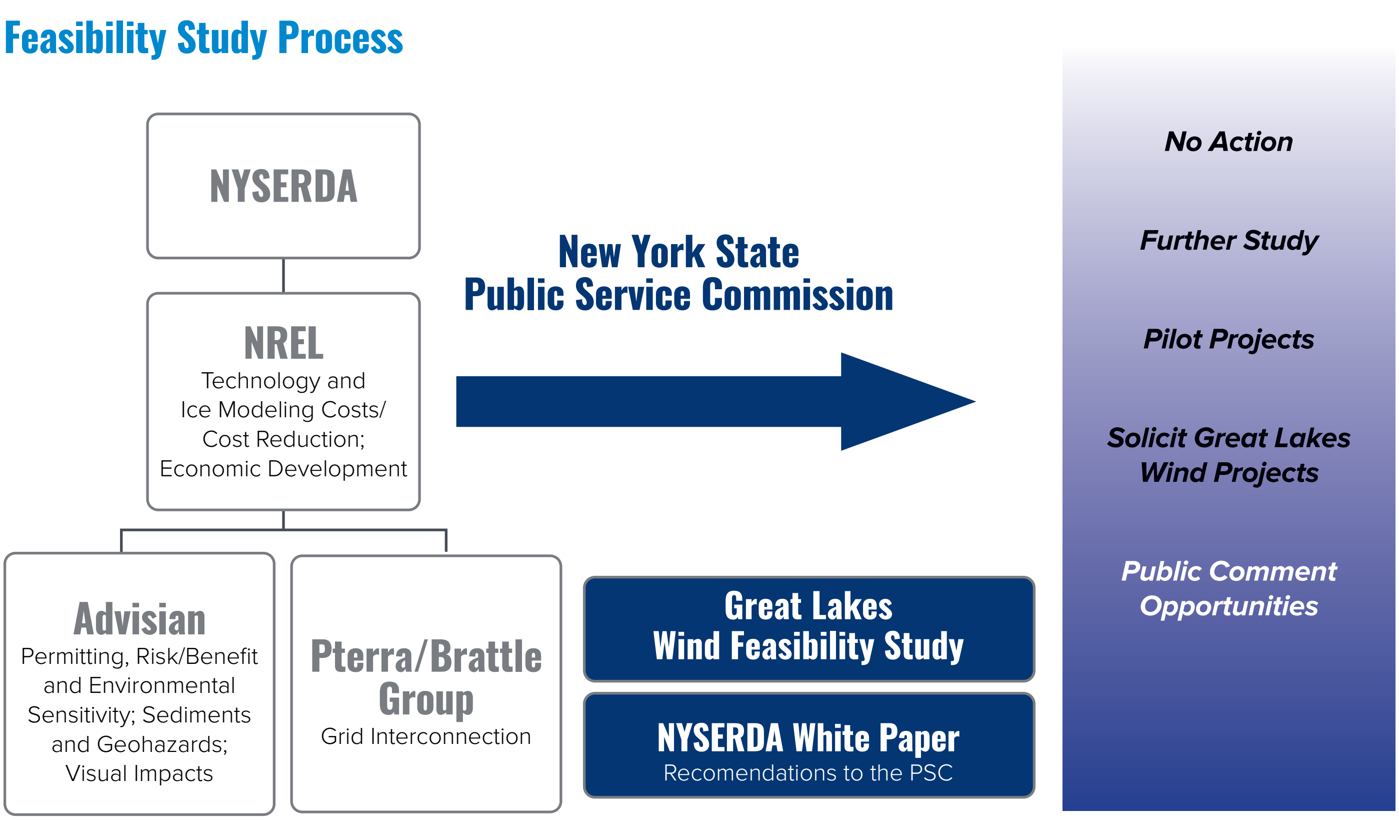
- data and information synthesis,
- technical analysis and, if the technical analysis signals viability,
- an analysis of policy options to explore viable paths forward for GLW to help New York State to achieve its ambitious Clean Energy Standard.

NYSERDA sought to keep the public informed about the study and its progress through public webinars and one public session. Through this process ad hoc public feedback was received; however, the project did not endeavor to poll the public on their perceptions of GLW.

1.3 Approach

The feasibility study spanned analyses by an interdisciplinary team of scientists, engineers, and analysts with the goal of ultimately informing the New York State Public Service Commission on the feasibility, costs, risks, and opportunities associated with GLW (Figure 1).

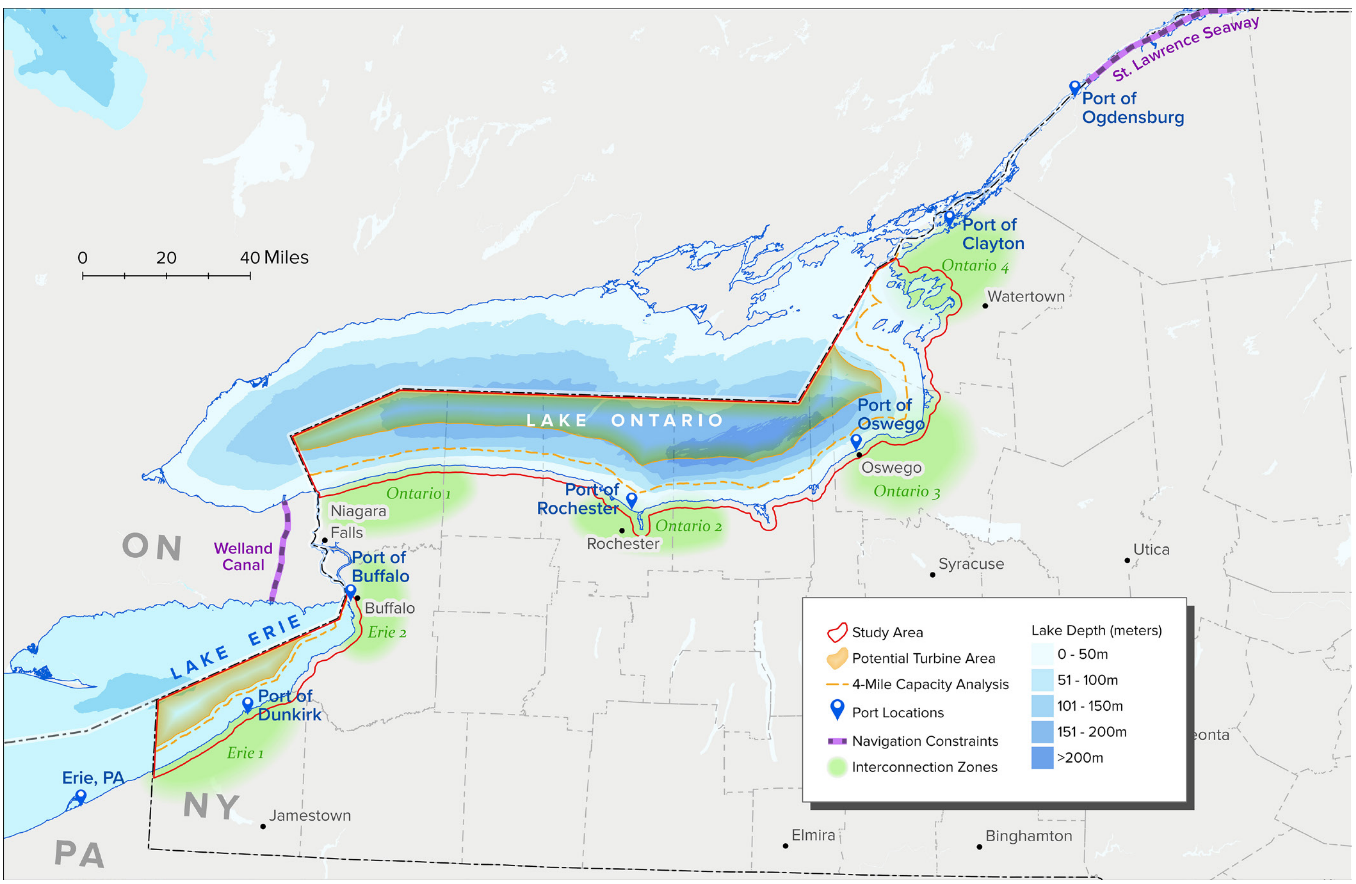
Figure 1. Feasibility Study Flow



NYSERDA engaged three contractors to conduct the various analyses comprising the GLW Feasibility Study, and work began in early February 2021. The National Renewable Energy Laboratory (NREL) served as the overall Study Coordinator and was responsible for evaluation of site conditions, wind plant technology review (fixed bottom and floating foundations), costs and cost reduction pathways, economic development, and workforce opportunities. Advisian Worley Group was responsible for geophysical and geohazards, permitting, environmental, and visual impacts (viewshed) considerations. Pterra LLC and Brattle Group covered aspects of electric grid interconnection, including feasibility of interconnecting GLW resources to the New York Electric Power System and identifying points of interconnection to the land-based power system (i.e., capacity that can be connected, any congestion or curtailment risks, and any needed electric transmission upgrades). NYSERDA facilitated public updates on the study throughout the year and offered informational public webinars and one public comment session in 2021.

The primary region of interest for the Feasibility Study encompassed the New York State regions of Lakes Erie and Ontario (Figure 2). Cost and POI analyses were also informed by land-based infrastructure that could support GLW and other competing renewable energy sources in the State. Some consideration was also given to the larger regional context of the study, including considerations for the neighboring states of Ohio and Pennsylvania and international considerations with Canada (e.g., ports and other proposed GLW projects).

Figure 2. Feasibility Study Region of Interest for Lakes Erie and Ontario



1.4 Stakeholder Mapping and Engagement

Public webinars were held throughout the course of the study to share updates on findings and to gather feedback from interested stakeholders. During each webinar, NYSERDA presented an introduction on the study's purpose, each contractor provided an update on progress made on the feasibility study, and the public had an opportunity to ask questions directly to the scientists.

The first public webinar was held on March 19, 2021 and the topics discussed were NYSERDA and New York State's Clean Energy Standard; the October 15, 2020 Order to conduct a feasibility study for GLW projects; specific technical, environmental, and social components covered by the study; and opportunities to be part of the study process.

The second and third public webinars were held on May 19, 2021 and August 10, 2021 and provided more details on progress made on each component of the feasibility study, as well as methodologies used by the researchers to conduct the study.

The fourth public webinar was held on November 17, 2021 and provided overviews of the draft study, early findings, and stakeholder outreach during the year, as well as the remaining schedule for completion and next steps.

NYSERDA also hosted a Virtual Public Feedback session on June 9, 2021. The public feedback session was intended to ensure that Lake Erie and Lake Ontario residents' concerns were considered within the context of the feasibility study. At registration, participants identified their top areas of interest for the study. Verbal comments were provided during the webinar and written comments were received in the week following the feedback session. This information was synthesized by the Cadmus Group, LLC and provided in a summary report appended to this study and to be submitted to the Public Service Commission with the final feasibility study. Feedback themes included topics related to: the role of wind in energy transition; decision-making; siting considerations, environmental impacts, and socioeconomic impacts. NYSERDA continued to take comments during the Study preparation period via email as well as during the remaining public webinars.

Feasibility Study contractors also engaged external experts on an ad hoc basis as required to inform their respective analyses. Approximately 70 parties were contacted throughout the study from a variety of sectors, including universities, wind developers, technology providers, New York State entities (Department of Environmental Conservation [DEC], Department of State [DOS], Public Utilities Commission [PUC], Department of Public Service [DPS], Office of General Services [OGS], Office of Renewable Energy Siting [ORES]), U.S. federal agencies (National Oceanic and Atmospheric Administration [NOAA], U.S. Army Corps of Engineers [USACE], U.S. Coast Guard [USCG], U.S. Fish and Wildlife Service [USFWS], Federal Aviation Administration [FAA]), port operators, environmental non-governmental organizations, and Canadian agencies. Feedback addressed covered topics of technology, infrastructure, environmental, permitting, and viewshed considerations for Lakes Erie and Ontario.

Public webinars were held throughout the course of the study to share updates on findings and to gather feedback from interested stakeholders.

March 19, 2021

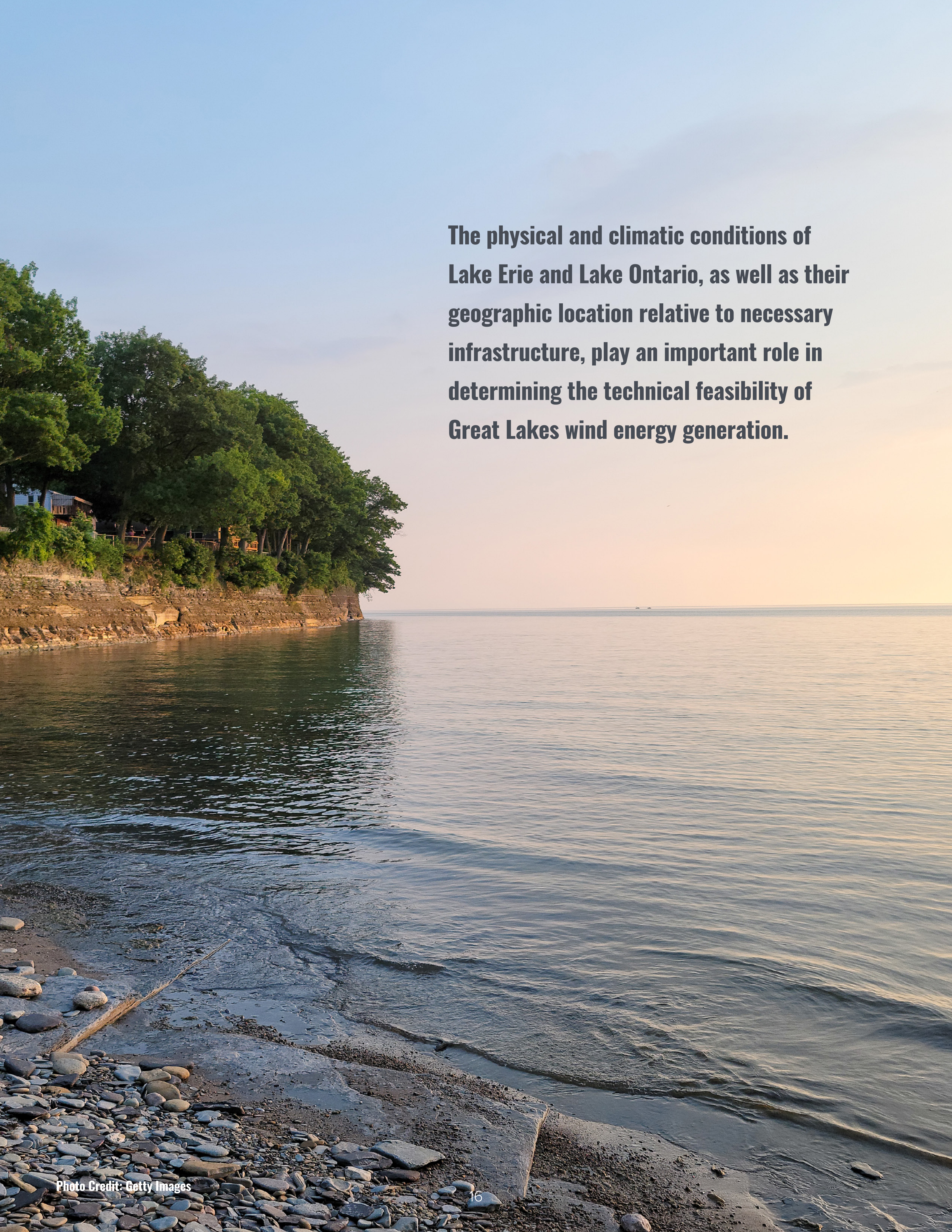
May 19, 2021

August 10, 2021

November 17, 2021

Virtual public feedback session seeking verbal and written comments

June 9, 2021



The physical and climatic conditions of Lake Erie and Lake Ontario, as well as their geographic location relative to necessary infrastructure, play an important role in determining the technical feasibility of Great Lakes wind energy generation.

Photo Credit: Getty Images

2 Physical and Climatic Conditions

Most offshore wind projects to date are located in oceans with minimal surface ice and have full access to large vessels or ports. Physical characteristics were evaluated in Lakes Erie and Ontario and included analysis of wind resource, bathymetry, ice climate, waves and currents. In most cases, existing literature and data sets were compiled and further analyzed to develop a complete picture for this study.

For all characteristics, a more detailed analysis and description can be found in appendices 1–2.

2.1 Wind Energy Resources

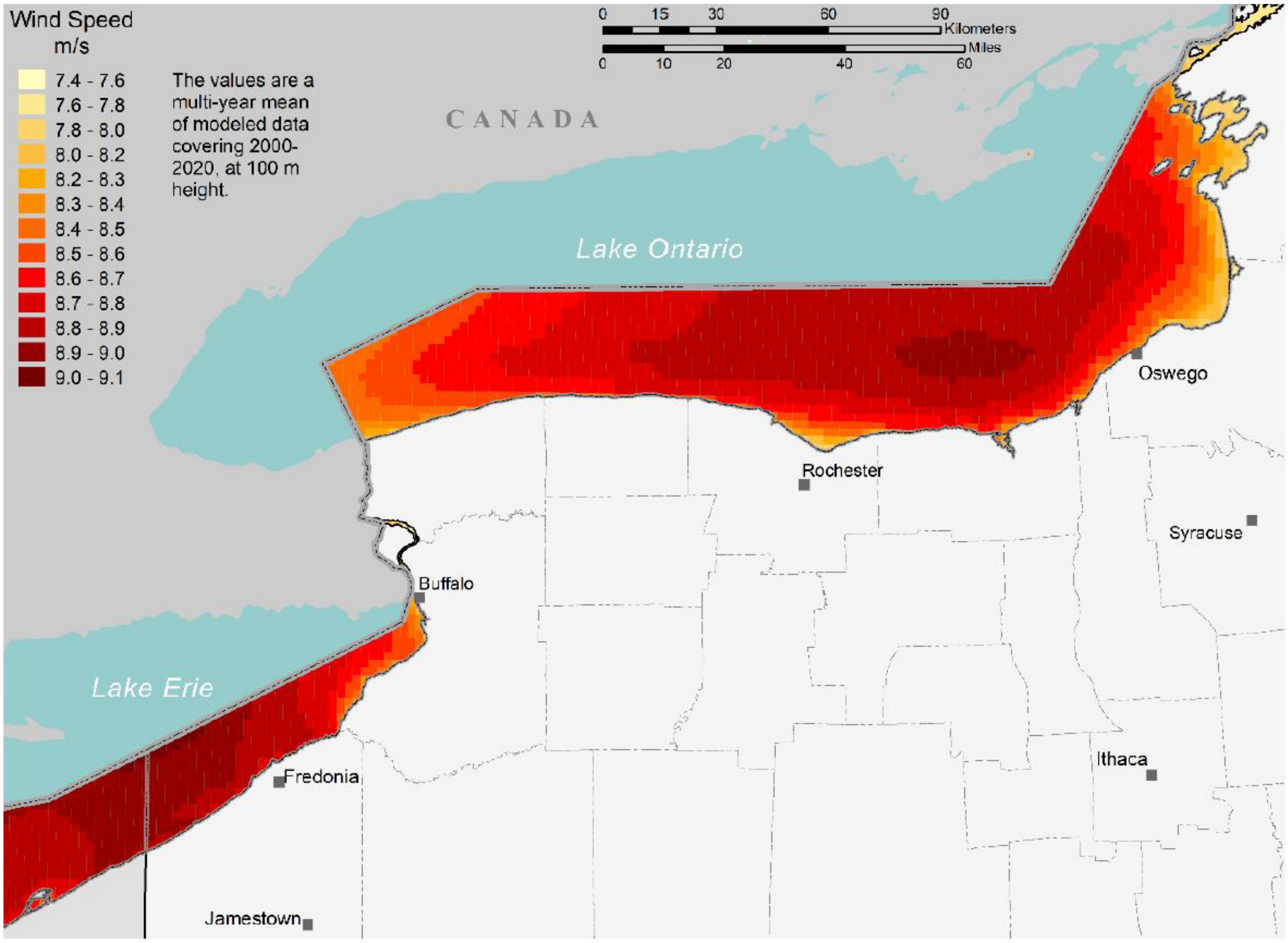
In 2021, NREL performed a new offshore wind energy resource assessment for the New York Great Lakes. The basis for this updated data set leveraged extensive resource and development (R&D) advancements in numerical weather prediction (NWP) modeling as well as higher computational capacity (NREL, 2021).

Wind resource data were produced using the Weather Research and Forecasting (WRF) model (Skamarock et al, 2019)—an open-source, community-based NWP model maintained by the National Center for Atmospheric Research. The wind resource assessment was based on a 21-year time period (2000 to 2020). Data were produced at 2-km spatial resolution at 9 vertical levels below 200 meters, at 5-minute time intervals.

These data are hosted publicly through Amazon Web Services' Open Data Initiative and can be accessed at no cost through various means (NREL, 2021).

The mean 100-meter wind resource for Lakes Erie and Ontario were plotted in Figure 3. For Lake Ontario, the annual average wind speeds range between 8.5 m/s and 9.0 m/s, with the highest average winds in the eastern part of the lake. The eastern part of Lake Erie has a similarly high-wind resource, with wind speeds exceeding 9 m/s on average in some parts of the lake.

Figure 3: Mean 100-m Wind Resource for New York State Portions of Lakes Erie and Ontario



Mean annual wind speeds in the Great Lakes are on par with the mid-Atlantic regions

Lakes Erie and Ontario have a strong seasonal wind resource variation with the highest winds ocurring in winter. The mean wind speed in December is about 2 m/s above the annual mean, while the mean August wind speeds are about 3 m/s below the annual mean. The wind speed also varies over the 24 hours of a day (diurnal variations). The diurnal cycles also have a strong seasonal dependence in both lakes, where the average diurnal range is largest in the summer months and flattens out in the winter months. The diurnal cycles have similar characteristics during all months of the year with the lowest wind speeds tending to be around midday and the peak wind speeds occurring between 10 p.m. and midnight.

Mean annual wind speeds in the Great Lakes are on par with the mid-Atlantic regions where commercial offshore wind is proliferating. As such, these 9 m/s average wind speeds can translate to very productive net capacity factors well over 40%. ***More details of these trends can be found in 22-12a Evaluation of Site Conditions.***

2.2 Bathymetry

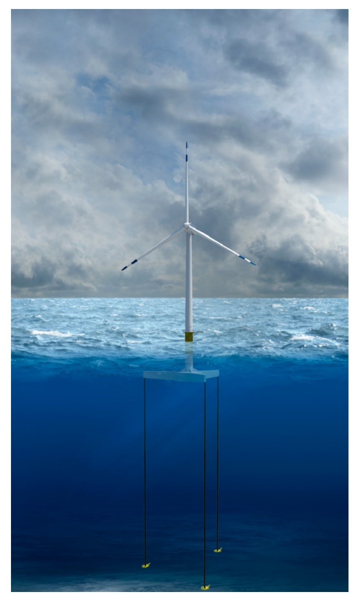
The water depth is a primary characteristic of the environment that would affect the design of GLW systems. It can affect the wave characteristics and the degree to which the lakes freeze. It impacts, in part, the technology that is suitable for a given location and the suitability of vessels and installation strategies used, which can significantly drive the economics of the system.

Depths that are less than 60 m (197 ft) are generally considered to be suitable for fixed-bottom wind turbines, while depths greater than 60 m would likely require floating technology.

Lake Erie is characteristically shallow and almost exclusively less than 60 m deep, and is best suited for fixed-bottom support structures.

Lake Ontario is much deeper, and as a result, major siting conflicts are likely to be offshore in water depth in access of 100 m (328 ft) deep, indicating that floating technology would be the primary option.

Example of fixed-bottom support



Example of floating technology

Detailed bathymetric data for the Great Lakes have been compiled by National Oceanic and Atmospheric Administration NOAA from historic soundings and multibeam sonar surveys (National Geophysical Data Center, 1999a, 1999b). Bathymetric contours are referenced to a standard low-water elevation datum for each lake.

The actual water depth at any given point varies over time as the volume of water in the lake changes. Compared to coastal locations in the Atlantic or Pacific Oceans, the Great Lakes experience much greater variability in the mean water elevation (Gronewold et al., 2013).

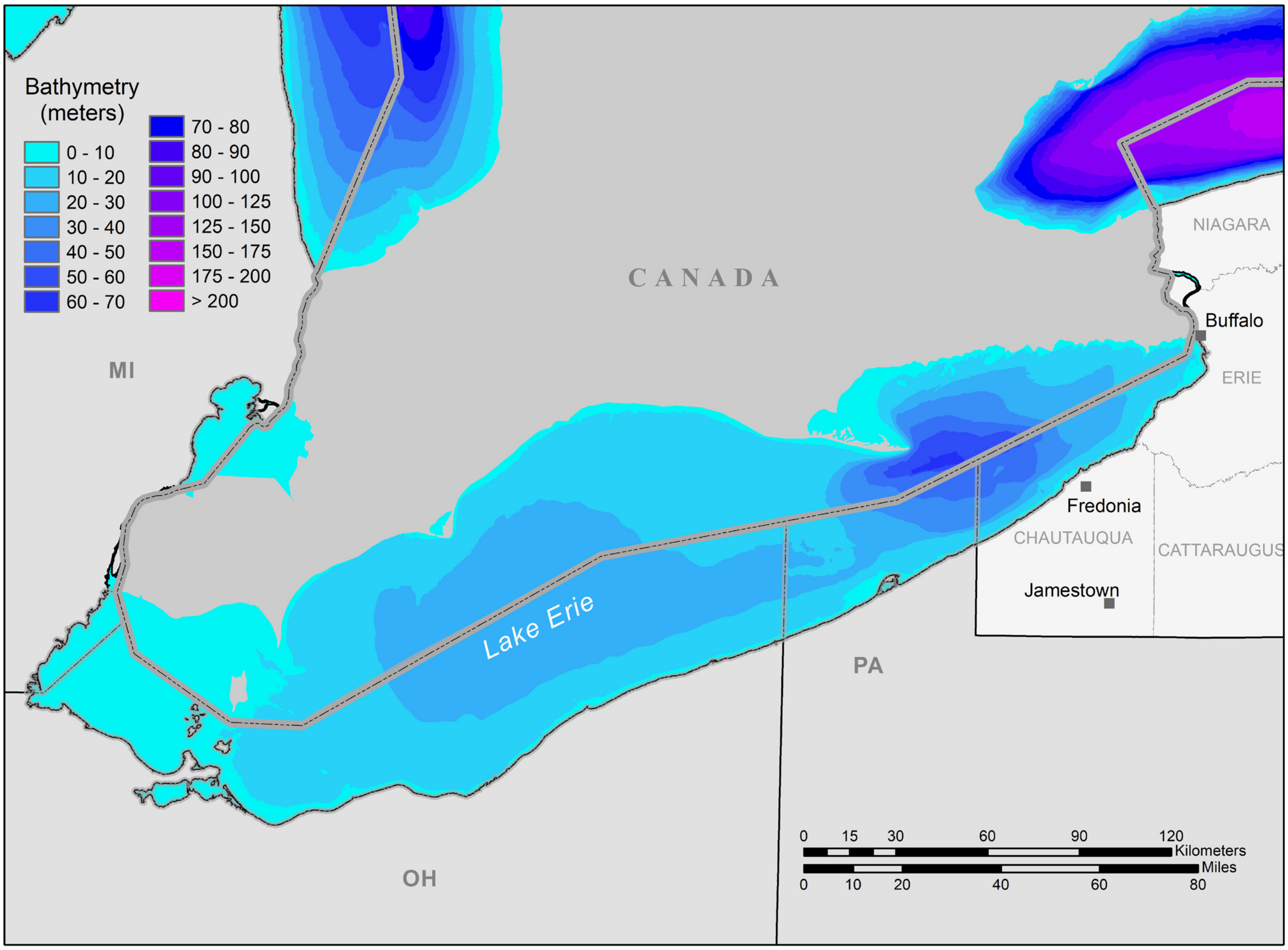
The annual mean water elevations of both Lake Erie and Lake Ontario have historically varied within a range of approximately 2 m (6.6 ft; U.S. Army Corps of Engineers, 2021). The lakes experience cyclical variations in water elevation due to annual precipitation and snowmelt patterns.

Water elevations are typically highest in the summer and lowest in the winter, with a difference of 54 cm (21 in) between the highest and lowest monthly average elevations on Lake Ontario and 35 cm (14 in) on Lake Erie (U.S. Army Corps of Engineers, 2021).

2.2.1 Lake Erie Bathymetry

Lake Erie consists of three basins: the eastern basin, central basin, and western basin, with depths increasing from west to east. The deepest portion of Lake Erie lies just west of New York State waters; the maximum depth within State waters is between 50–60 m (164–197 ft; see Figure 4). Lake bottom slopes in Lake Erie are predominantly gradual inclines without significant steep sections that would hinder GLW development.

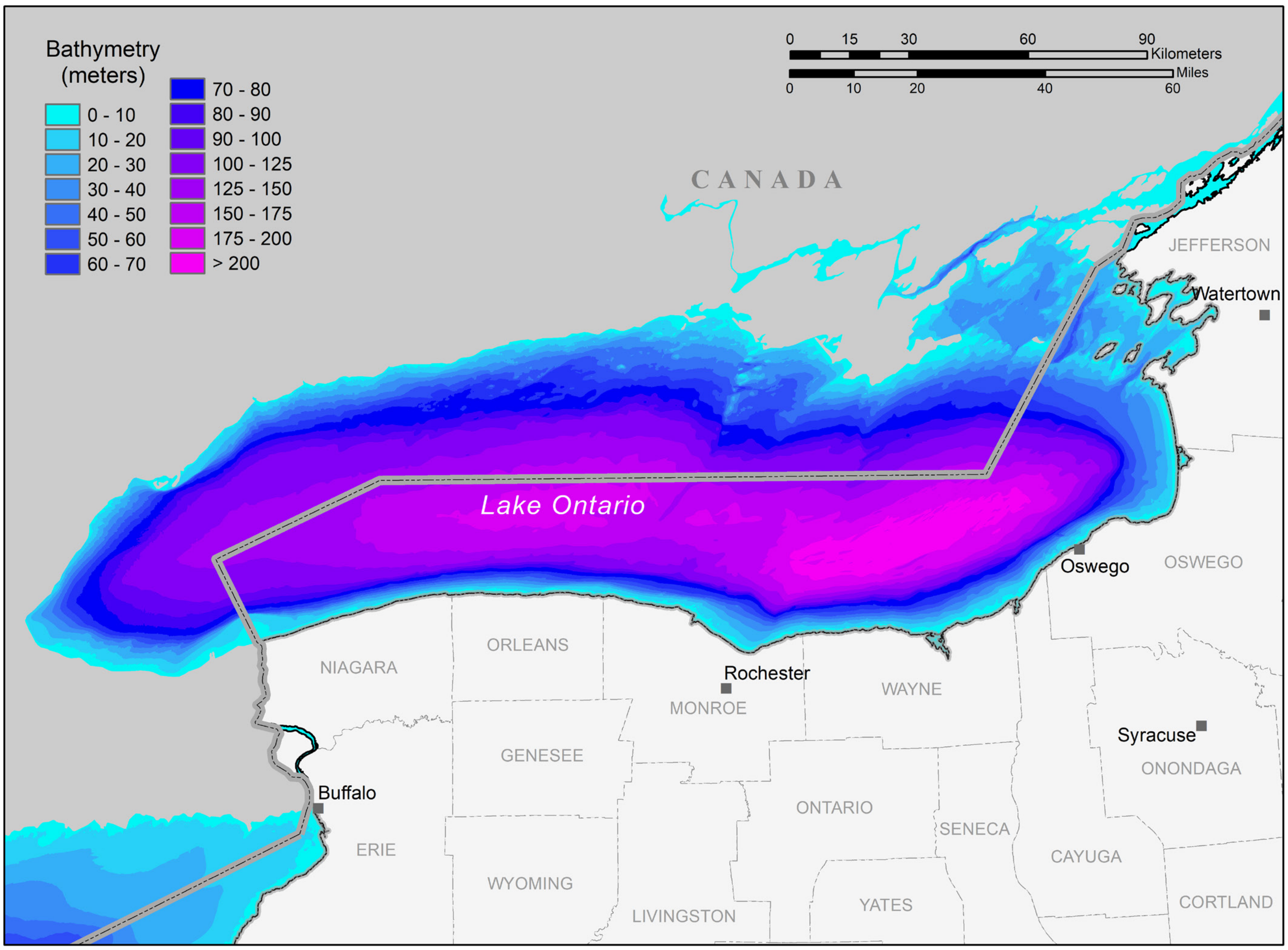
Figure 4. Bathymetry of Lake Erie with Jurisdictional Boundaries by Country and U.S. State (based on data from the National Geophysical Data Center, 1999a)



2.2.2 Lake Ontario Bathymetry

Much of Lake Ontario is significantly deeper than Lake Erie. Only 30% of Lake Ontario waters within New York State boundaries are less than 60 m (197 ft) deep (Figure 5). The lake consists of four basins, from west to east: the Niagara, Mississauga, Rochester, and Kingston basins (Martini & Bowlby, 1991). The shallowest portion of Lake Ontario is the Kingston basin, adjacent to the St. Lawrence River. The lake bottom drops steeply along the southern coast of the lake from Oswego westward.

Figure 5. Bathymetry of Lake Ontario with Jurisdictional Boundaries by Country and U.S. State (based on data from the National Geophysical Data Center, 1999b)



The geology of Lakes Erie and Ontario is primarily defined by the history of glaciation in the region

2.3 Geology and Bottom Types

The geologic setting is another key element for determining appropriate locations and foundation design options for developing GLW. The geology of Lakes Erie and Ontario is primarily defined by the history of glaciation in the region. Important considerations for the siting of GLW include:

- the distribution of lakebed soils and sediments
- the variability of subsurface and exposed bedrock.

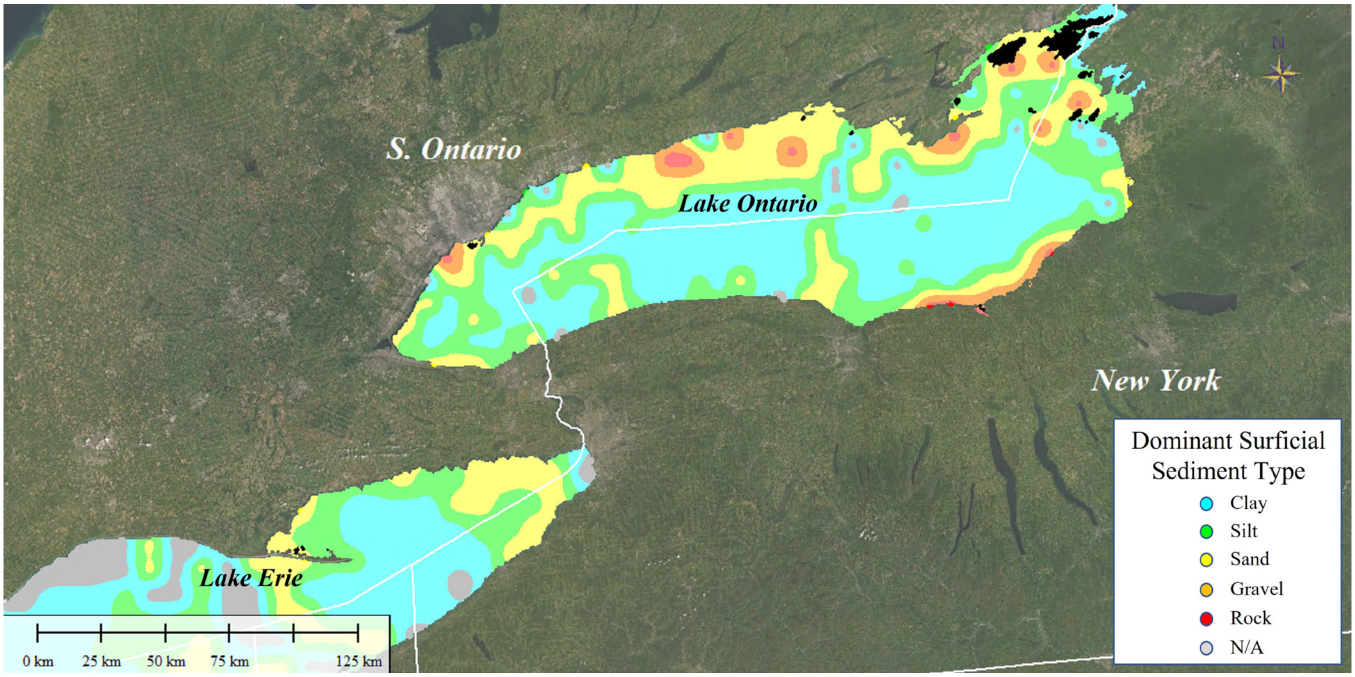
The substructure and foundation type will be constrained by soil stiffness, the depth of bedrock below the surface, and other features and conditions that may exist at the lakebed and in the subsurface.

Using the grain-size statistics from the Great Lakes Sediment Archive Database (GLSAD), a map was created that interpolates between sample sites to characterize the dominant surficial sediment types across the study area (Figure 6).

In Lake Erie, dominant surficial sediment types include clays, silts, and sands. In Lake Ontario, dominant surficial sediment types include the full range of clays, silts, sands, gravels, and rock.

Sand distributions hint at the approximate boundaries of the major basins within the lake: Niagara, Mississauga, Rochester, and Kingston basins separated by ridges.

Figure 6. Dominant Surficial Sediment Type Distribution for Lakes Erie and Ontario (based on data from GLAHF, 2020)



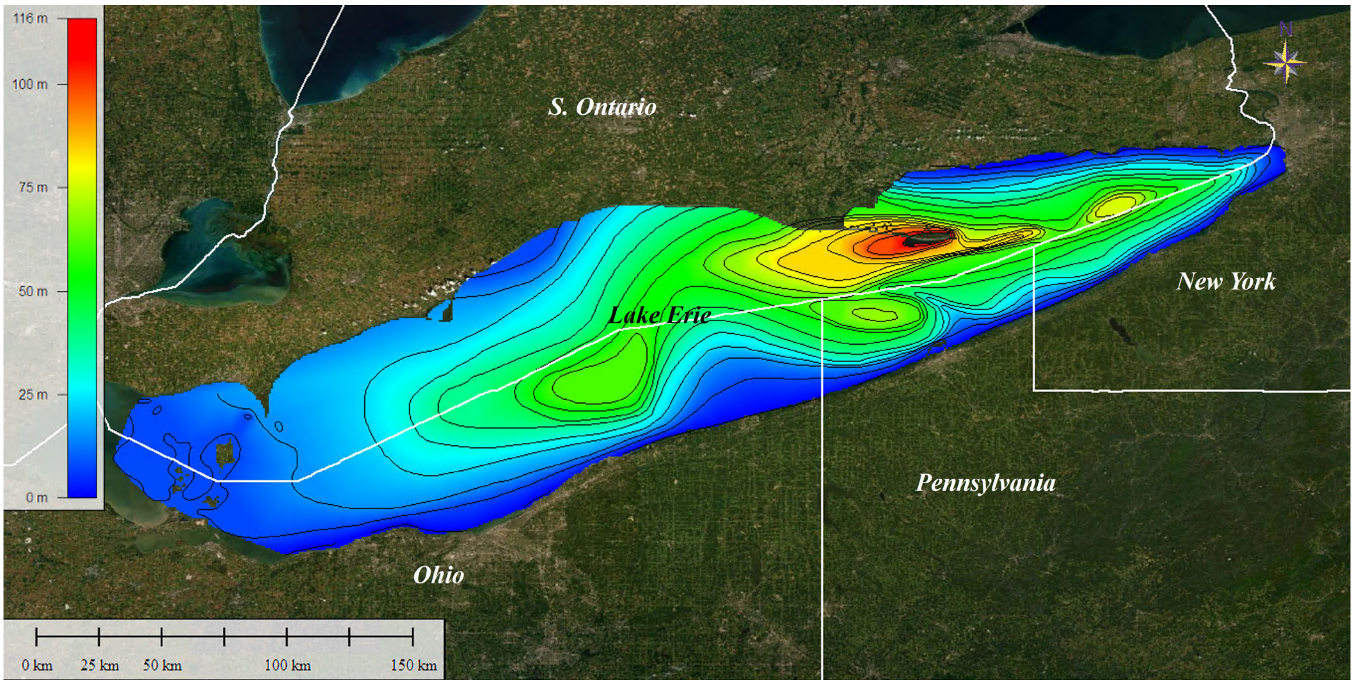
Geology mapping of newer sediments (i.e., quaternary) suggests that the majority of Lakes Erie and Ontario in New York State waters is lacustrine clay and silt. The shoreline areas are dominated by fine or medium-textured glacial till and lacustrine sand and gravel. In Lake Erie, quaternary geology interpretations within the Eastern Basin align with the GLSAD's estimate of dominant surficial soil distribution trends and reinforces the presence of mixed sediments within the lake. In Lake Ontario, quaternary geology interpretations indicate shoreline coarsening and basin fining trends but does not resolve sediment trends associated with the major basins as is observed with the GLSAD data (Great Lakes Aquatic Habitat Framework [GLAHF], 2020).

Bedrock conditions within the lakes are a critical element for consideration of siting GLW infrastructure and the type of technology that might be suitable to install across the area. For example, shallow bedrock may prevent deep piled foundations from reaching a suitable depth to ensure the necessary holding capacities per the design requirements. The depth to bedrock is also a significant consideration for evaluating burial requirements for cables, including identifying appropriate burial methodologies and their feasibility.

2.3.3 Lake Erie Bedrock

Within Lake Erie, the thickest sediment over bedrock is almost 116 m (380 ft) (Figure 7); however, within New York State waters, the thickest sediment thickness is less than 76.2 m (250 ft), with an average thickness of about 30.5 m (100 ft). Bedrock is outcropping along most of the shoreline in the eastern portion of the lake, including the State shoreline.

Figure 7. Lake Erie Sediment Thickness Above Bedrock (Source: Morgan, Todd and Lewis, 2020)



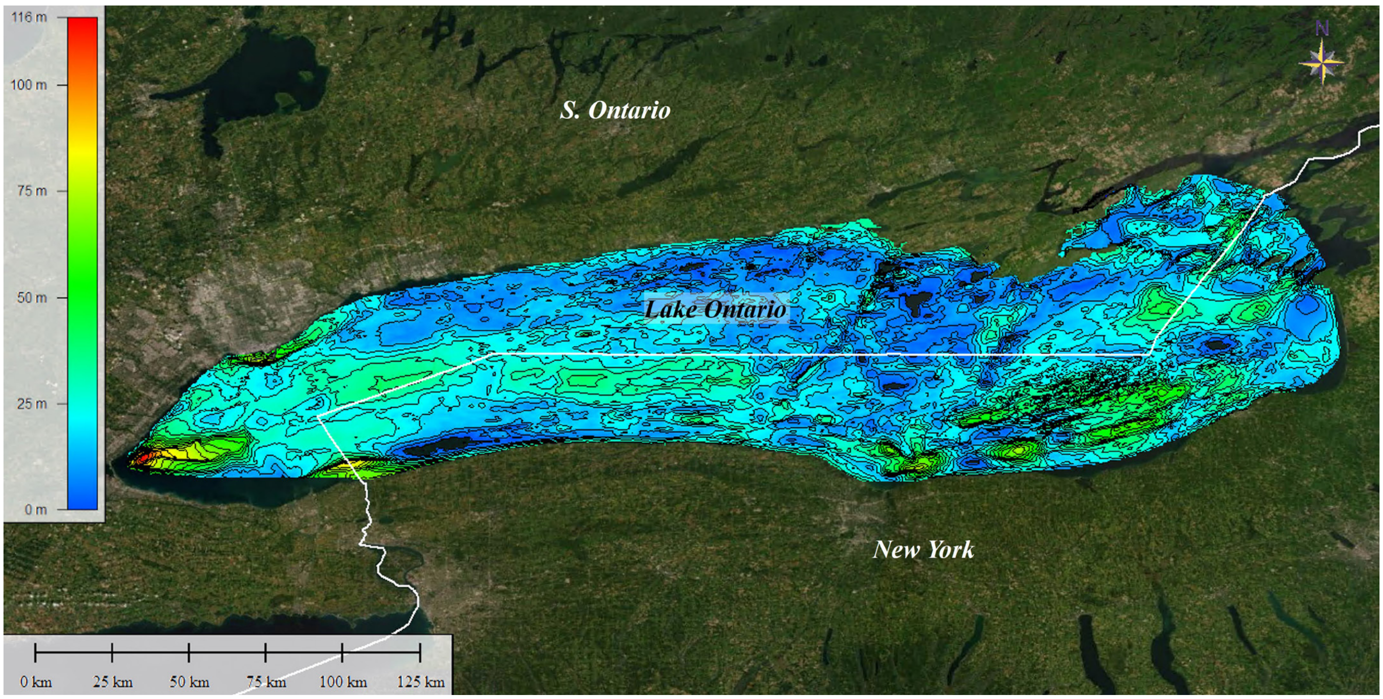
Sediments that overlie the bedrock appear to be interbedded glacial tills, outwash deposits, glacio-lacustrine deposits, and glacial beach sediments. These glacial sediments range from fine-grained clays to coarse sands and gravels. Pebbles, cobbles, and boulders are also possible within these glacial sediments (McNeilan & Associates LLC 2017). Younger sediments are predominantly clays and silts.

Seismic data collected over Lake Erie in the late 1960s “show no evidence of structural deformation of bedrock or overlying unconsolidated materials” (Weston Geophysical n.d.). Faulting is not anticipated to be a significant concern for the siting, installation, or operation of GLW in the New York State waters of Lake Erie.

2.3.4 Lake Ontario Bedrock

In general, the structure map of Lake Ontario bedrock (Figure 8) shows that the NYS shoreline exhibits a steeper bedrock surface, whereas the northern shoreline grades more gently. The sediment thickness over bedrock is thickest, approximately 116 m (380 ft), in a narrow section associated with Dundas Valley in the far western portion of Lake Ontario. More representative of the overall lake, New York State waters have sediment thicknesses that are less than 90 m (295 ft), with an average closer to 22.8 m (74.8 ft).

Figure 8. Lake Ontario Sediment Thickness Above Bedrock (Source: National Geophysical Data Center, 1999; Hutchinson et al., 1993)



Lake Ontario quaternary sediments are described in literature as comprising up to five stratigraphic units (Hutchinson et al. 1993). Buried drumlins, just above bedrock, are identified in the eastern and deepest portion of Lake Ontario (Rochester Basin) (Hutchinson et al., 1993). The drumlins exhibit widths up to 600 m and heights up to 40 m. The drumlins appear as ridge-like features that are oriented northeast-southwest, indicating a glacial flow direction along that same trend. There are no observed direct outcrops of the drumlin deposits exposed at the lakebed, although they do have surface expression (Coflin et al., 2017). These drumlins may present steeper seabed slopes that may influence siting feasibility. They will also exhibit local variability in the subsurface soil column, with a potentially thicker fraction of coarse-grained materials, including sand, gravel, cobbles, etc. where present, which in turn may influence siting and foundation engineering. If NYS moves forward with future siting, it is recommended that these drumlin areas, which make up a small fraction of the total lakebed, be avoided. Seismic studies did not identify any evidence of post-glacial faulting within Lake Ontario. Therefore, faulting is not anticipated to be a significant concern for the siting, installation, or operation of GLW in the New York State waters of Lake Ontario.

In general, within New York State waters, both lakes exhibit the presence of bedrock within 20 m or less from the surface in some places. Under normal site development procedures for specific GLW projects, a detailed site specific geophysical ground model would be developed and geotechnical studies would be conducted at precise turbine or anchor locations to determine the suitability of pile driving or anchoring before selecting a foundation type. ***More details can be found in 22-12c Geophysical and Geohazards Characterization.***


Photo Credit: Getty Images

2.4 Ice Climate

The presence of ice on the surface of the lakes can present a significant design challenge which must be addressed for GLW to be feasible. If wind turbines are installed in the lakes, they will experience additional structural loading from the wind, driving large sheets of surface ice through stationary wind arrays.

The problem of ice loading on wind turbines structures has been addressed in the offshore wind industry with substructures fastened directly to the bottom (fixed bottom) in salt water, cold climate regions of Sweden and Finland in the north Baltic Sea.

In Lake Erie, the Icebreaker project proposed by LEEDCo off the city of Cleveland could potentially be the first GLW project using fixed bottom support structures. However, there have not been any installations of floating wind turbines in ocean or lake ice climates which use buoyant substructures moored with anchors to the bottom. The presence of surface ice will likely limit the type of substructures that are practical in the lakes to ones with slender profiles at the waterline to minimize ice loads and prevent ice jamming.

Two important differences between Great Lakes' freshwater ice and north Baltic Sea ice are the seasonality and salt content.

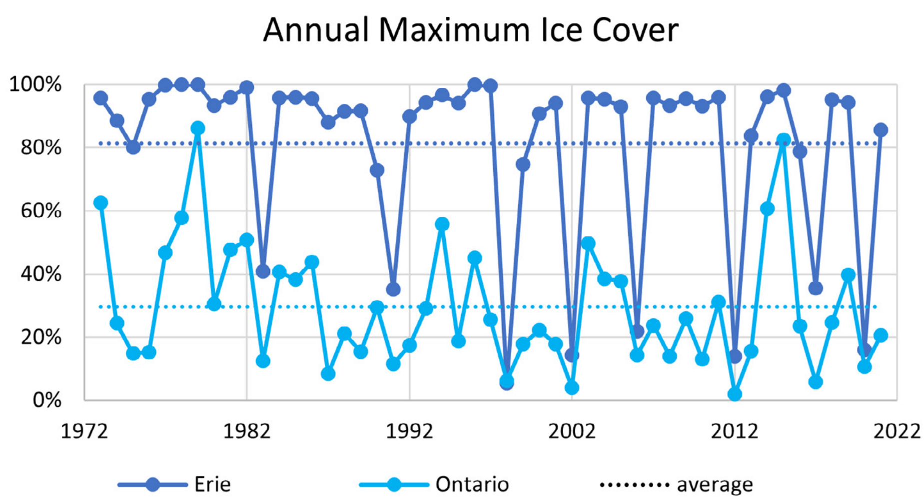
Sea ice in colder climates can result in large floes (large wind driven moving ice sheets) that may persist for years, while ice in the Great Lakes melts completely each summer.

Freshwater ice forms at higher temperatures and is stronger than sea ice (Daly, 2016). **These seasonal differences will favor wind energy technology in the Great Lakes because the buildup of large ice ridges is less likely.** However, designs and operational strategies must account for the additional ice strength that is likely to be encountered and the rare occurrence of possible annual ice ridges during extremely cold years. Warming weather patterns due to climate change may reduce this risk over time but the exact impact on the design conditions is uncertain.

2.4.5 Annual Ice Cover Statistics

Observations of ice cover on the Great Lakes are collected by the U.S. National Ice Center in cooperation with the Canadian Ice Service (U.S. National Ice Center, 2021). Ice coverage has been assessed from satellite imagery, in some cases supplemented by airborne observations, since 1973. Interannual statistics and analysis have been published periodically by NOAA's Great Lakes Environmental Research Laboratory (Wang et al., 2012, 2017). Annual maximum ice cover for Lakes Erie and Ontario was assessed (Figure 9). There is a high degree of variation in the surface ice cover year-to-year, but some important trends can be observed. Ice covers a large percentage of Lake Erie's surface in most years, with an average annual maximum ice cover of 81%, and exceeds that level in three out of four years. In contrast, Lake Ontario's average annual maximum ice cover is only 30% and remains below that level in three out of five years, and moreover, the middle of the lake, where wind turbines might be sited, freezes infrequently. Since 1973, the average maximum ice cover has decreased by 0.53% per year on Lake Erie and 0.25% per year on Lake Ontario (Wang et al., 2017). This trend may be the result of warming weather patterns due to climate change and should be taken into account for future planning. However, it is the extreme ice conditions that dictate the design, cost, and feasibility of the structures.

Figure 9. Annual Maximum Ice Cover on Lakes Erie and Ontario (NOAA-GLERL, 2021)



2.4.6 Ice thickness

Surface ice sheets interact with wind turbines and other structures in the water when they collide. The force transmitted by such collisions depends on the velocity of the ice sheet, the ice thickness, and the failure mode of the ice when it breaks around the turbine substructures. Freshwater ice is approximately three times stronger than sea ice and can deliver a larger impact before buckling (Timco and Frederking, 1982). The velocity of a traveling ice sheet is influenced by currents within the water as well as by the speed of the wind above the ice. To properly design a structure to survive in frozen conditions the maximum ice thickness needs to be determined. This is more difficult than determining ice cover measured by satellites, and has a higher degree of uncertainty.

The thickness of a sheet of level ice grows when the air and water temperatures are at or below freezing. Weather stations around the Great Lakes record freezing degree days (FDD) calculated from the average daily temperature. The accumulated freezing degree days (AFDD) for a given location is the sum of the daily differences between the average temperature and the freezing temperature throughout an ice season, neglecting any days when the average temperature is above freezing.

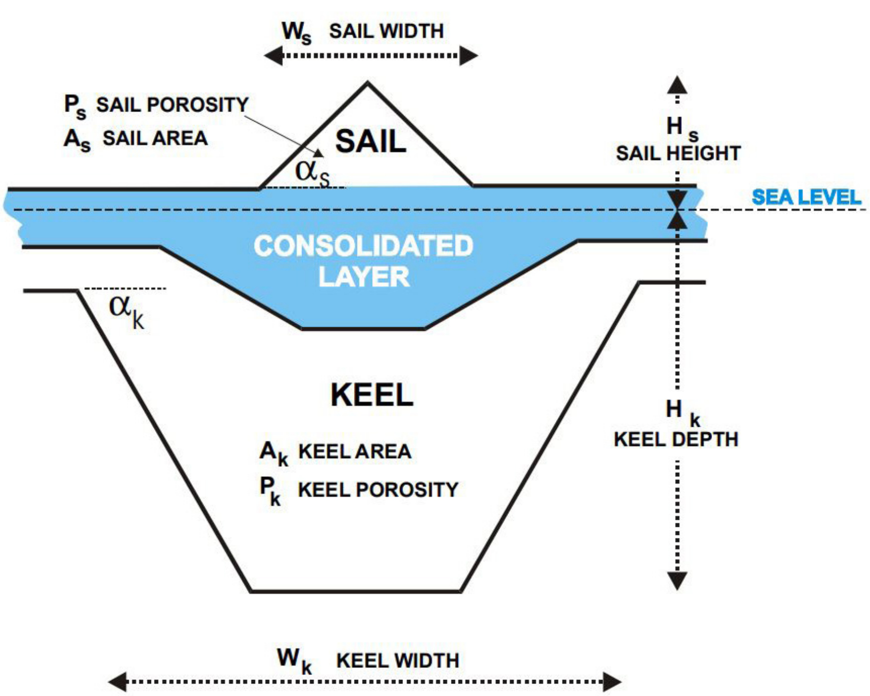
AFDD measurements are used to approximate ice thickness and can explain around 80% of the variability in ice thickness on the Great Lakes, with snow cover and water temperature history contributing additional variability and uncertainty (Hewer & Gough, 2019).

The U.S. National Ice Center publishes estimates of ice thickness based on satellite observations and a freezing degree day model twice weekly during each ice season (U.S. National Ice Center, 2021). These estimates were found to be in good agreement with acoustic measurements of level ice thickness in Lake Erie during the 2010–2011 ice season (Hawley et al., 2018).

Ice thickness on Lake Ontario has been studied less than on Lake Erie but the mechanism for ice formation is the same. However, the relationship between AFDD and ice thickness differs because the deeper water in Lake Ontario requires longer durations of sub-freezing temperatures for ice to form. Based on a synthesis of the available data, the maximum surface-ice thickness with a 50-year return period is estimated at 65–70 centimeters cm (Daly, 2016). Using the same methodology, the maximum ice thickness on Lake Ontario is estimated at 40–50 cm (Sleator, 1995).

For the maximum ice thicknesses noted above, the impact of ice loading on a slender substructure properly outfitted with an ice cone (described later) would be minimal. However, ice ridges which are formed by collisions between surface ice sheets or between surface ice and solid objects, are likely the worst-case ice condition that will drive the structural design of GLW turbine support structures. Repeated collisions of ice sheets can form very long, tall layered ridges that are much thicker than the surrounding surface ice. The upper portion of the ridge is called the sail, while the portion below the water is the keel (Figure 10). The portion of the ridge that exerts the strongest force on offshore structures is the consolidated layer, which forms when layers of ice rubble freeze together in a solid mass (Timco et al., 2000). There has been relatively little collection of data related to ice ridges in the Great Lakes. Direct access to the ice ridges is challenging, and satellite imagery does not provide sail height or keel depth. Limited measurements in Lake Superior and Lake Erie used acoustic sensors mounted on the lake bottom to determine ice thickness (Hawley et al., 2018; Titze and Austin, 2016). For a typical year, Lake Erie's maximum ice ridge thickness was measured to be 10 m. Similar results were obtained for Lake Superior during the heavy ice winter of 2013–2014, with the deepest measured keel depth exceeding 11 m.

Figure 10. Idealized Ice Ridge Geometry (Reproduced from Timco et al., 2000)



Deep ice keels may also cause scouring on the lake bed in shallow water which could affect cable landings (Daly, 2016). The impact of ice ridges on wind turbine structures is difficult to predict accurately due to the lack of site-specific observations. Using best industry design practices, wind turbine substructures should be able to achieve high-structural reliability in Great Lakes ice climates. However, further verification of the frequency, severity, and geographic variability of these extreme conditions may be necessary.

2.4.7 Turbines in Cold Climates

Ice can accumulate on wind turbine blades when temperatures are close to or below freezing and there is moisture in the air from precipitation, fog, or droplets sprayed from the lake surface. The accumulation of ice on blades compromises energy capture and can cause imbalance to the rotor. Ice that falls or is thrown from a blade can pose a potential safety hazard to workers or to people in boats nearby. The Great Lakes region in New York State has been estimated to fall into IEA Ice Class 1 or 2, which suggests that meteorological conditions for ice accumulation may occur up to 3% of the year (Bredesen et al. 2017; Rissanen and Lehtomaki 2016). To put this into perspective, the risk of ice accumulation for GLW due to atmospheric conditions is no more severe than a typical cold weather site on land. However, when there is no lake surface ice cover, turbines in the Great Lakes may also be exposed to freshwater spray from wind and waves, and it is not known if this spray could reach as high as the rotors. In general, blade icing should be considered but probably would not pose a major challenge, given that more than 127 GW of wind capacity has been installed in cold climate regions (Holbein, 2017). Standard wind turbines are designed to operate in temperatures down to -10°C (14°F), but in the Great Lakes wind energy developers would likely use cold climate-adapted models that are commonly offered by the turbine manufacturers. Cold weather turbine packages may be specified to include the following modifications:

- Materials suited for low temperatures.
- Welds performed with low-temperature flux.
- Low temperature lubricants (grease, oils, hydraulic fluids) and/or heating systems for lubricants.
- Robust sensors with an extended range of operational temperatures or heated sensors to prevent ice formation.
- Control systems designed for cold temperature turbine operation.
- Heated and sealed nacelles.
- Ice detection systems that enhance safety and protect turbine components by identifying uneven loading or ice throw risk.
- Anti-icing coatings or active blade de-icing systems.

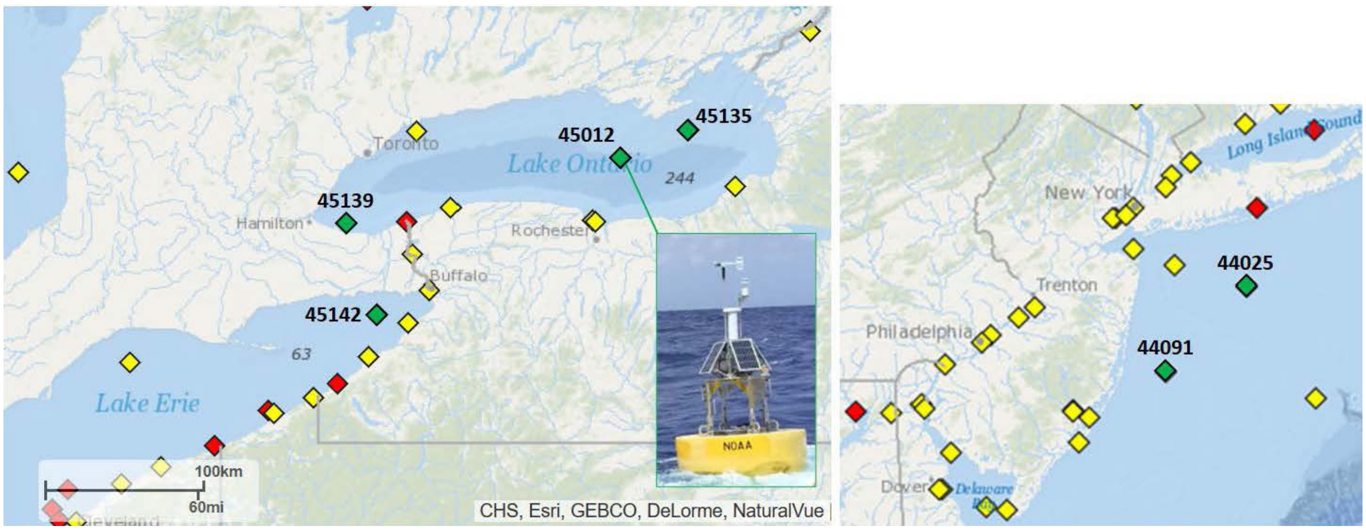
up to 3% of the year

meteorological conditions for ice accumulation on blades may occur in New York's Great Lakes region

2.5 Waves

The waves that are characteristic of the Great Lakes have some significant differences from those found in the Atlantic Ocean. These differences may augment the design basis used to calculate loads and may influence construction and service strategies. The National Oceanic and Atmospheric Administration NOAA National Data Buoy Center in the United States and the Meteorological Service of Canada collect data from buoys deployed in the Great Lakes and weather stations along the shore (Environment Canada, 2019; NOAA, 2021). Data from these buoys and weather stations were compared to buoys moored in the Atlantic in the New York Bight (Figure 11).

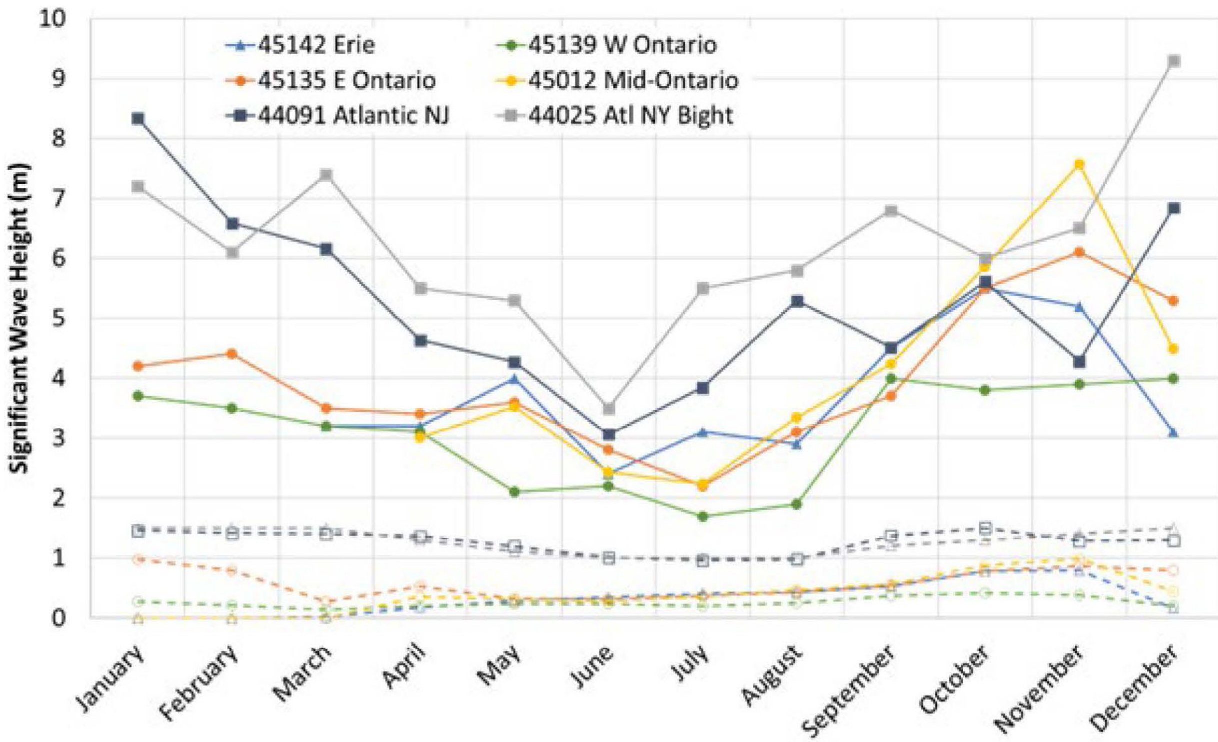
Figure 11. Buoy and Weather Station Locations on Lakes Erie and Ontario (NOAA, 2021) (left panel). Station identifiers (45xxx) are listed for selected buoys, with an inset image of buoy #45012. For comparison, Atlantic buoy data was also analyzed (right panel).



Great Lakes wave heights are relatively low during the summer months and significantly higher in the fall and winter months, although wave data are only available when there is no lake ice. Ice cover may suppress wave formation in the winter months, especially on Lake Erie, but areas of open water, such as the middle of Lake Ontario, will still encounter significant waves. The tradeoff is that wind turbines will not likely encounter extreme ice and wave conditions at the same time. However, the designs will need to accommodate both extreme conditions occurring separately.

With prevailing winds from the west or west-southwest, waves in the eastern portions of the lakes have a longer fetch (distance that wind has traveled over open water) and are larger than waves at the western ends of the lakes. Comparison of the wave heights at buoy #45139 in western Lake Ontario with #45135 in eastern Lake Ontario illustrates this effect (Figure 12).

Figure 12. Significant Wave Heights Recorded by Selected Great Lakes Buoys, with Comparison to New York Bight Buoys (Environment Canada, 2019; NOAA, 2021).



Buoy IDs correspond to the locations in Figure 11. Solid lines/filled symbols indicate monthly maximum wave heights, and dashed lines/open symbols indicate monthly mean wave heights.

Monthly maximum and average significant wave heights were determined based on buoy measurements during the months when data were available (Figure 12). The maximum height of an individual wave can reach twice the significant wave height. The maximum significant wave height measured in the western end of Lake Erie (buoy #45142) was about 5.5 m (18 ft) and at the center of Lake Ontario (buoy #45012) was 7.6 m (25 ft); the latter was the highest recorded wave height in the New York Great Lakes. In comparison to the Atlantic buoy locations near New York State (buoys #44025 and #44091), these maximum significant wave heights in the center of Lake Ontario are on par with the Atlantic.

In most other locations including western Lake Erie, the maximum wave heights were lower than the Atlantic buoys. Since offshore wind turbines are already designed to withstand the extreme conditions of the Atlantic, the Great Lakes extreme waves are significant but would not exceed the present design conditions, and in most cases would likely be lower. Perhaps the more significant characteristic is the nature of the summer winds. In all locations on the Great Lakes, the summer months have lower significant wave heights which would increase accessibility for vessel operations and allow wider construction windows. The lower summer winds would potentially allow customized modular barge vessels to be deployed that could remain moored on the lake during construction, which would not be possible on the open ocean. This could be a significant advantage to GLW and may potentially provide additional cost saving opportunities that are not captured in this study because design and cost analysis of novel vessel solutions was outside the scope.

2.6 Water Currents

The Great Lakes have wind and thermally driven currents, but their average speed is less than 0.03 m/s in both lakes (Table 1). These current speeds are not a significant design challenge although they still should be considered as part of the design basis. During the winter, currents are primarily wind driven. In contrast, in the summer, surface heating produces differences in density that give rise to thermally driven currents in addition to the wind driven currents (Bai et al., 2013).

Table 1. Seasonal and Annual Mean Currents (Bai et al., 2013)

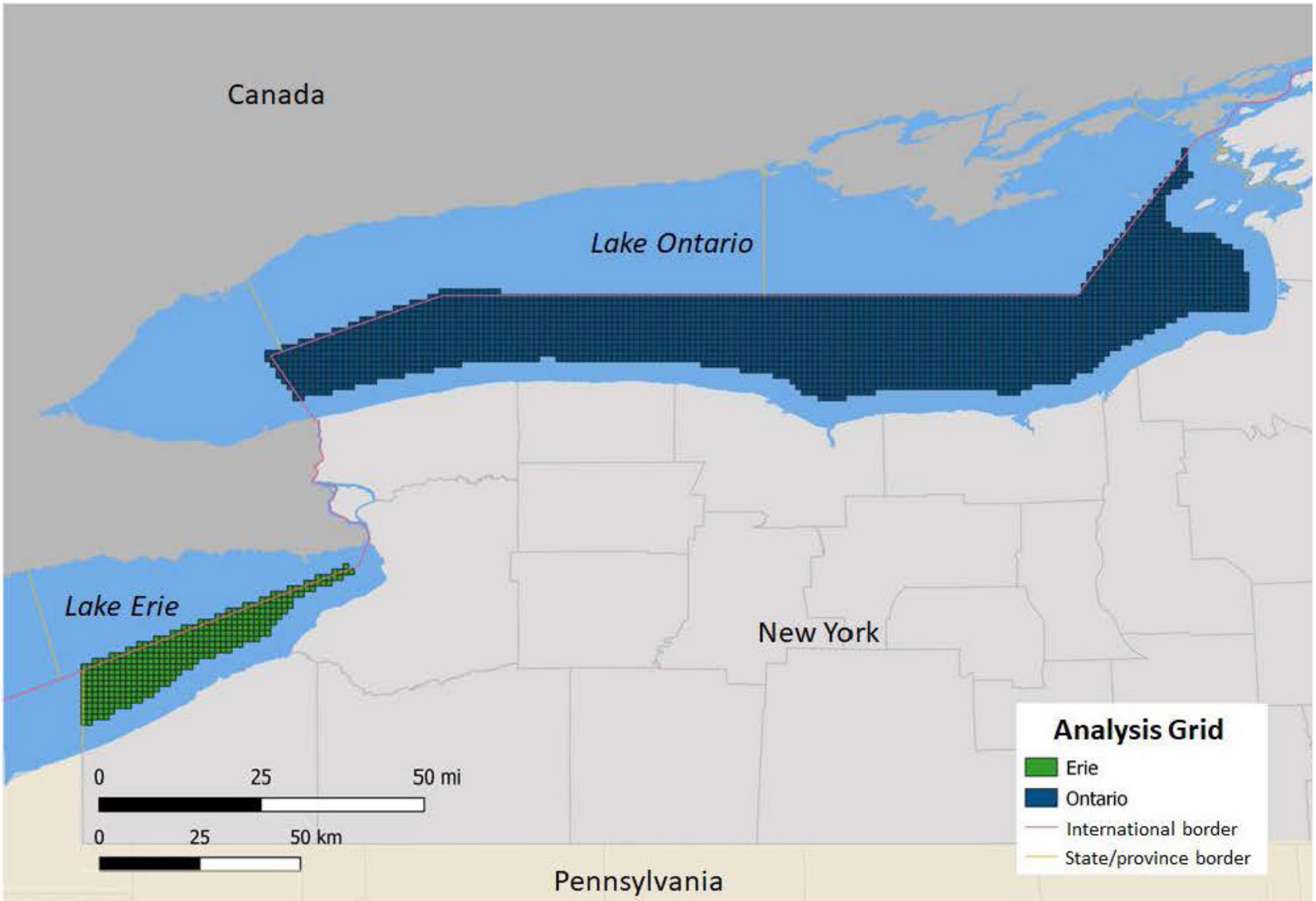
	Lake Erie	Lake Ontario
Winter	0.026 m/s	0.022 m/s
Summer	0.019 m/s	0.016 m/s
Annual	0.023 m/s	0.019 m/s

2.7 Physical Siting Analysis

From the physical characteristics data described in section 2.1 through 2.6 for the New York State portions of Lakes Erie and Ontario, a quantitative geo-spatial assessment of the Lakes was performed. This analysis identified locations that may be less favorably suited to wind energy technology and estimated the amount of generation capacity that could be installed in the remaining areas. ***A more detailed description of these features is provided in 22-12b Physical Siting Analysis.***

A geospatial grid over the New York State portions of Lakes Erie and Ontario was established for analysis of the physical site characteristics, using the methodology established by LEEDCo's Icebreaker project on Lake Erie (U.S. DOE, 2018). The method uses an analysis grid composed of grid elements that are 1 minute in latitude by 1 minute in longitude, or approximately 1 square mile in area (Figure 13). Physical characteristics that are relevant to wind energy feasibility were assessed at each grid element to provide a broad view of development potential in the region.

Figure 13. Analysis Grid for Lakes Erie and Ontario



Analyses consist of 1-minute grid elements located at least 4 miles from shore. Grid elements that overlap the U.S.-Canadian border were not included in the calculated generation potential.

Conservatively, a value of 3 MW/km2 was used to estimate the potential wind generating capacity on an area basis. Historically, many offshore wind developers have installed projects with higher power densities, but until design details are known much later in the process, this estimate allows for the likelihood that some areas which appear suitable for development may face unforeseen technical, environmental, or social challenges that limit the developable area.

These challenges may include:

NECESSARY EASEMENT	UNDERWATER HAZARDS	VISUAL IMPACTS	CONFLICTS WITH OTHER USERS	UNFORESEEN GEOTECHNICAL OBSTACLES


Photo Credit: Getty Images

The physical characteristics in this siting analysis included:

- **Wind speed.** Mean wind speeds at 100 m above the lake surface were obtained from a new analysis of 21 years of data (NREL, 2021). Values in the study region range from 8.3 to 9.0 m/s. The study found no areas where the wind speed was not sufficient to support GLW.
- **Distance from shore.** The minimum distance to shore was calculated for each grid element greater than 4 miles from shore. Grid elements closer than 4 miles were not assessed because generally the enhanced impacts of ice, viewshed, avian flyways, and increased likelihood of dislodging toxins in the sediments may make these areas unsuitable for Great Lake wind development.[3]
- **Water depth.** Average water depths in each grid element were calculated from bathymetric data (National Geophysical Data Center, 1999a, 1999b). Water depth was the primary determinant between fixed-bottom wind technology (less than 60 m depth) and floating wind technology (greater than 60 m depth).
- **Lakebed slope.** The lakebed slope was derived from the bathymetric data. Slopes in Lake Erie are generally below 4% which is considered acceptable for foundation placement. Lake Ontario contains some areas of steeper slopes where development could be challenging but not unfeasible (Tajalli Bakhsh et al., 2020).
- **Ice cover.** Annual ice cover durations during the period 2005–2014 were drawn from the Great Lakes Aquatic Habitat Framework (GLAHF, 2020), which uses remotely sensed imagery to assess the extent of ice coverage. Wind turbines in the Great Lakes are assumed to experience some surface ice cover in winter which will require ice load mitigation.
- **Soil type.** Soils on the lakebed surface were classified into four types, from largest to smallest grain size: gravel, sand, clay, and silt. The soil type affects the choice of foundation or anchor system.
- **Sediment depth.** The depth to bedrock is based on historical data for Lake Erie (Morgan, Todd, and Lewis, 2020) and Lake Ontario (National Geophysical Data Center, 1999b; Hutchinson, Lewis, and Hund, 1993). Sediment depths are reported in increments of 25 ft. (7.6 m) in Lake Erie and 20 ft. (6.1 m) in Lake Ontario.

2.7.8 Analysis of Physical Characteristics

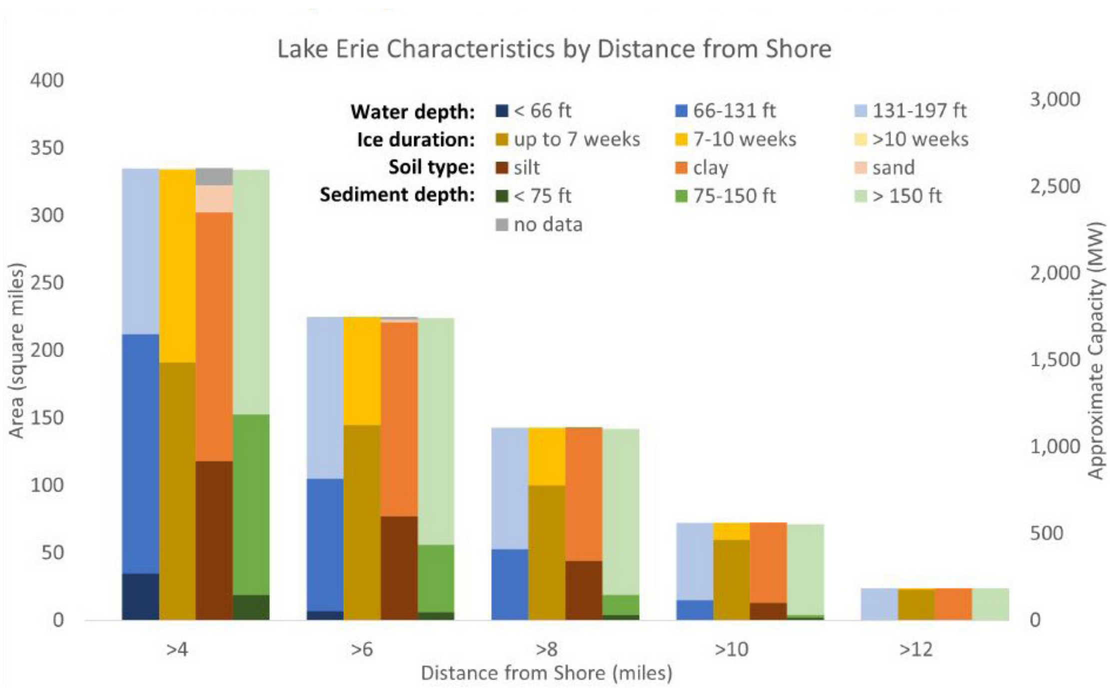
In Lake Erie, the analysis grid encompasses 338 elements (867 km2 or 214,000 acres). The area in Lake Erie was sorted by water depth and distance from shore (Table 2). The distribution of physical characteristics for grid elements in Lake Erie was determined based on distance from shore beyond 4 statute miles (Figure 14). Mean water depths in this region most often fall between 20–40 m (66–131 ft.).

Table 2. Area (sq. mi.) in Lake Erie with Mean Water Depth by Distance to Shore

Distance from Shore	Mean Water Depth		
	< 66 ft	**66-131 ft**	**131-197 ft**
< 4 mi	201	51	0
4-6 mi	28	79	3
6-8 mi	7	46	30
8-10 mi	0	38	33
10-12 mi	0	15	34
> 12 mi	0	0	24
% of Area > 4 mi	**10%**	**53%**	**37%**

Figure 14. Distribution of Physical Characteristics on Lake Erie

(Among 1-minute grid elements located more than 4 statute miles from the shoreline)



The maximum lakebed slope is less than 2% across more than 98% of the grid elements, and the surficial soils are predominantly either clay or silt. Mean wind speeds range from 8.6 m/s to 9.0 m/s (19 to 20 mph). The mean ice cover duration between 2005 and 2014 was 6–10 weeks for most sites within the Lake Erie study area. The duration of ice cover decreases with increasing distance to shore.

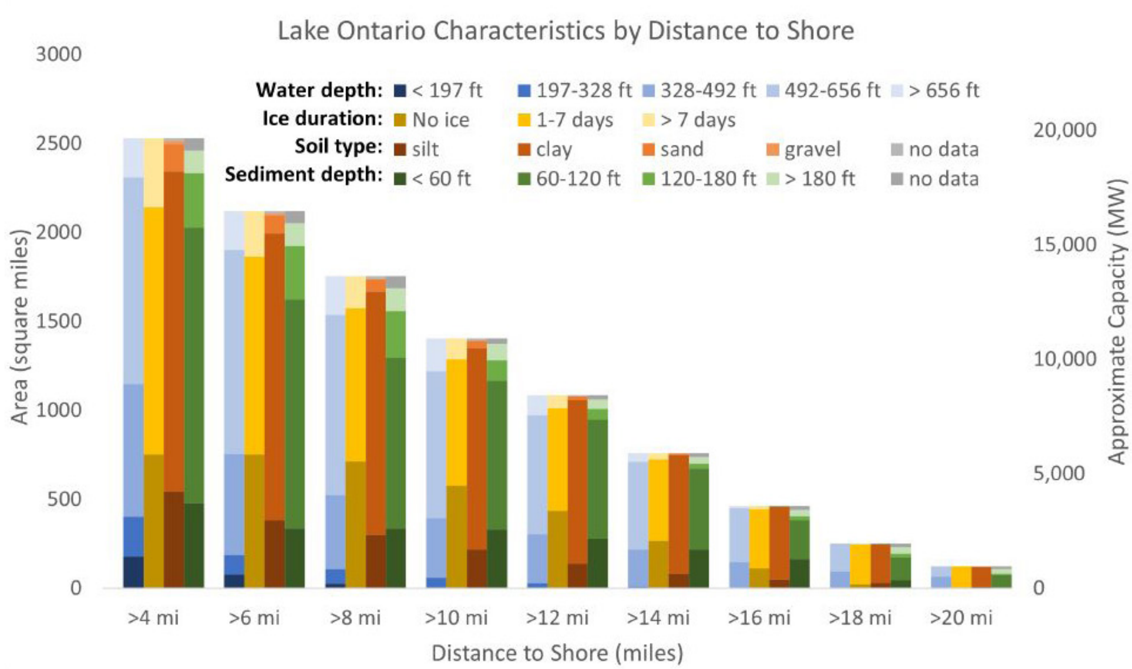
In the New York State portion of Lake Ontario farther than 4 statute miles from shore, there are a total of 2,553 grid elements corresponding to an area of 6,550 km2 (1.6 million acres). The area in Lake Ontario was calculated as a function of water depth and distance from shore (Table 3). Only 7% of grid elements beyond 4 miles from shore have mean water depths less than 60 m (197 ft). Most grid elements at these distances have water depths between 150–200 m (492–656 ft), which requires floating technology. Maximum lakebed slopes are less than 4% in most grid elements. The distribution of physical characteristics for grid elements in Lake Ontario was determined based on distance from shore (Figure 15).

Table 3. Area (sq. mi.) in Lake Ontario with Mean Water Depth by Distance to Shore

	Mean Water Depth				
	< 197 ft	197-328 ft	328-492 ft	492-656 ft	>656 ft
< 4 mi	832	135	10	0	0
4-6 mi	101	114	179	14	0
6-8 mi	52	30	147	137	2
8-10 mi	23	25	83	186	34
10-12 mi	3	28	60	158	70
> 12 mi	0	28	275	669	113
% Area > 4 mi	7%	9%	29%	46%	9%

Figure 15. Distribution of Physical Characteristics on Lake Ontario

(Among 1-minute Grid Elements)



Typical Lake Ontario ice cover durations are one week or less, with an average ice duration of four days across the technical resource area. The maximum ice cover duration of up to 12 weeks occurs in the northeastern portion of the lake. The predominant soil type in the technical resource area is clay, followed by silt and sand, and most sediment thicknesses above the bedrock fall between 18–37 m (60–120 ft). Mean wind speeds on Lake Ontario range from 8.4 m/s to 8.9 m/s (19 to 20 mph), with more sites experiencing wind speeds near the upper end of the range. Typical ice cover durations are significantly shorter on Lake Ontario than on Lake Erie, but in either lake, the shores freeze earlier resulting in a pattern of decreasing ice duration with distance from shore. Less than one day of ice cover in an average year is experienced at a total of 759 grid elements in Lake Ontario, representing nearly 1,950 km2 (480,000 acres) of surface area.

2.7.9 Generation Potential

The power generation potential for GLW is proportional to the area of the technical resource. Although the analysis identified challenging areas that developers and State regulators would likely need to avoid, the analysis found that most of the Lake area did not present any notable challenges. Further, these physical features, which represent about 10% of the total developable lake area include areas with predominately soft silty soils, shallow sediments where pile foundations would be difficult, higher ice cover duration, and steep slopes. These characteristics might limit the technology choices and increase the cost of wind energy development but most would not render the sites completely unsuitable. ***Some of the more challenging characteristics are described in greater detail in 22-12b Physical Siting Analysis.***

Based on a conservative nameplate power capacity density of 3 MW/km,[2] New York State's Lake Erie waters beyond 4 statute miles from shore could support up to 2 GW of wind energy generation, while the State's Lake Ontario waters beyond 4 statute miles from shore could support up to 18 GW. Power generating capacities were calculated based on distance to shore (Table 4).

Table 4. Wind Energy Generation Potential in Gigawatts

	Lake Erie– Whole Area	Lake Erie – Excluding Challenging Areas	Lake Ontario– Whole Area	Lake Ontario– Excluding Challenging Areas
> 4 mi. from shore	2.0	1.6	18	15
> 6 mi. from shore	1.3	1.3	15	12
> 8 mi. from shore	0.75	0.72	12	10
> 10 mi. from shore	0.28	0.28	9.6	8.0
> 12 mi. from shore	0.06	0.06	7.1	6.1

2.7.10 Diurnal and Seasonal Electricity Demand

According to the New York Independent System Operator (NYISO), electricity demand peaks in the evening and is lowest in the early morning. Diurnal changes in projected electricity demand and potential GLW power generation were compared for the summer and winter months (NYISO, 2021; NREL, 2021). Summer peak demand is higher than in the winter months, with the peaks occurring in late July, although wind speeds over the Great Lakes are lower during the summer (Figure 16).

A holistic assessment of the overall value of GLW to the grid system is needed to understand how it could potentially complement other resources such as solar power and hydroelectric generation. Over the next two decades, increasing electrification of space heating and vehicles, and the broader adoption of behind-the-meter solar power, may shift the peak load in New York State from summer to winter (NYISO, 2021). The daily and seasonal trends in wind speeds suggest that GLW could have greater value in a winter peaking system, depending on the overall mix of generation sources.

Figure 16. Projected Electricity Loads in the New York Control Area for Winter 2031–32 and Summer 2031

Compared with daily generation profiles produced from 21-year average hourly wind speeds for selected locations on Lakes Erie and Ontario.

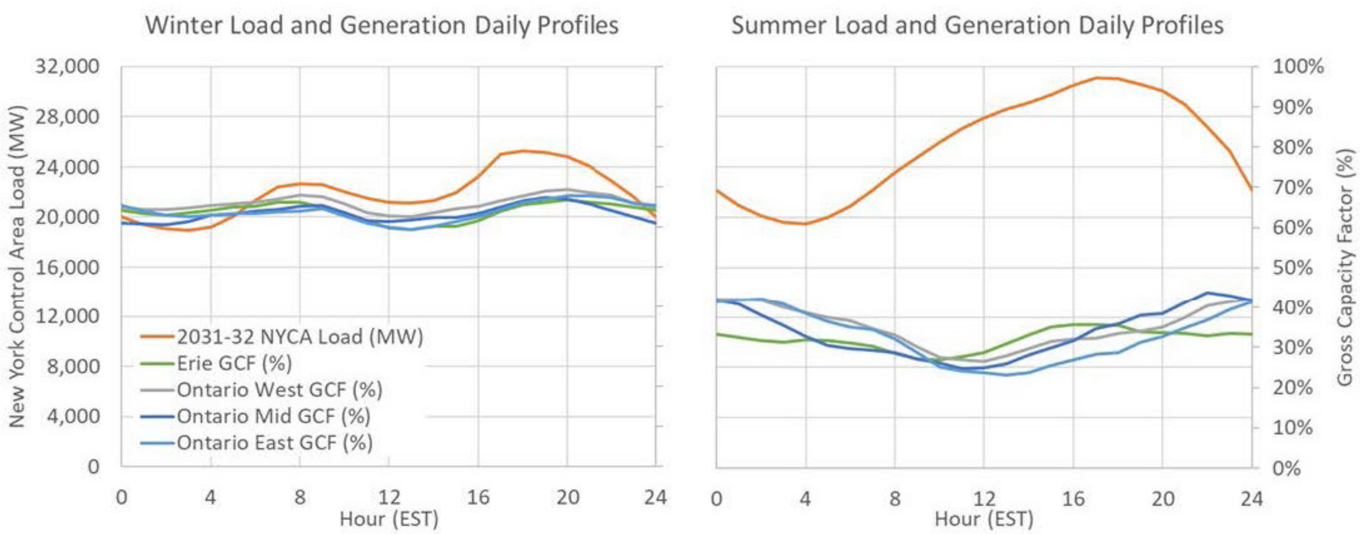


Photo Credit: Getty Images

Photo Credit: Avangrid Renewables

3 Infrastructure and Wind Plant Technologies

This section provides an overview of the available infrastructure and possible upgrades needed for potential GLW development.

Requirements for vessels and ports in the region are considered in the context of both fixed bottom and floating foundations. Additionally, an analysis of their suitability for GLW is provided based on regional conditions, including soils and icing. Finally, a preliminary analysis is provided to assess the feasibility of GLW interconnection to the New York State grid and a discussion of the relevant points of interconnection (POI).

3.1 Vessel Types

The availability of vessels is the primary factor driving the technology options and cost of GLW. Various types of vessels are used for offshore wind development to perform vital tasks such as wind turbine installation, submarine cables laying, and pile driving. Different vessels are needed for fixed-bottom versus floating wind projects and the types and capacities of available vessels in the Great Lakes will significantly determine the requirements for other port and infrastructure systems. These vessels would need to either be able to transit the locks of the St. Lawrence Seaway (already exist in the Great Lakes) or be built specifically for GLW.

The availability of vessels is the primary factor driving the technology options and cost of GLW.

The size of vessels that can enter the Great Lakes from the Atlantic Ocean is limited by the dimensions of the locks on the St. Lawrence Seaway, and for Lake Erie, the dimensions of the Welland Canal (Welland Canal, 2021). The standard lock size allows a maximum vessel size of 225.5 meters long, 23.77 meters wide and 8.08 meters in draft. The maximum height for overhead clearance, or air draft, is 35.5 meters and the maximum weight capacity is 30,000 Metric Ton (MT) (Great Lakes St. Lawrence Seaway Development Corporation, n.d.).

Most conventional vessels used in offshore wind construction are too large to transit the locks and canals and would not be able to access the Great Lakes. The maximum and minimum dimensions are shown for typical vessels required for the installation of offshore wind plants on the open ocean (Table 5; Douglas-Westwood, 2013; Figure 17). Vessels have been characterized based on their ability to fit through the locks (green shading), versus those that exceed the limit (red shading) (Table 5). Note that most vessel types are restricted due to either beam width or draft limitations. The most critical vessel is the heavy-lift wind turbine installation vessel (WTIV) which is needed for the installation of fixed-bottom offshore wind turbines. These vessels, of any capacity, are too big to fit through the locks (Douglas-Westwood, 2013). The Jones Act is another limitation on the available vessels—it requires that any vessel transporting goods from one U.S. port to another be built and registered, owned, and crewed by U.S. citizens. A full assessment of how this might affect Canadian vessels and port capabilities was not done in this study because the primary interest was in the benefits to the New York State economy.

Table 5. Types of Vessels Used to Install Offshore Wind Plants

(With minimum and maximum dimensions of the current fleet)

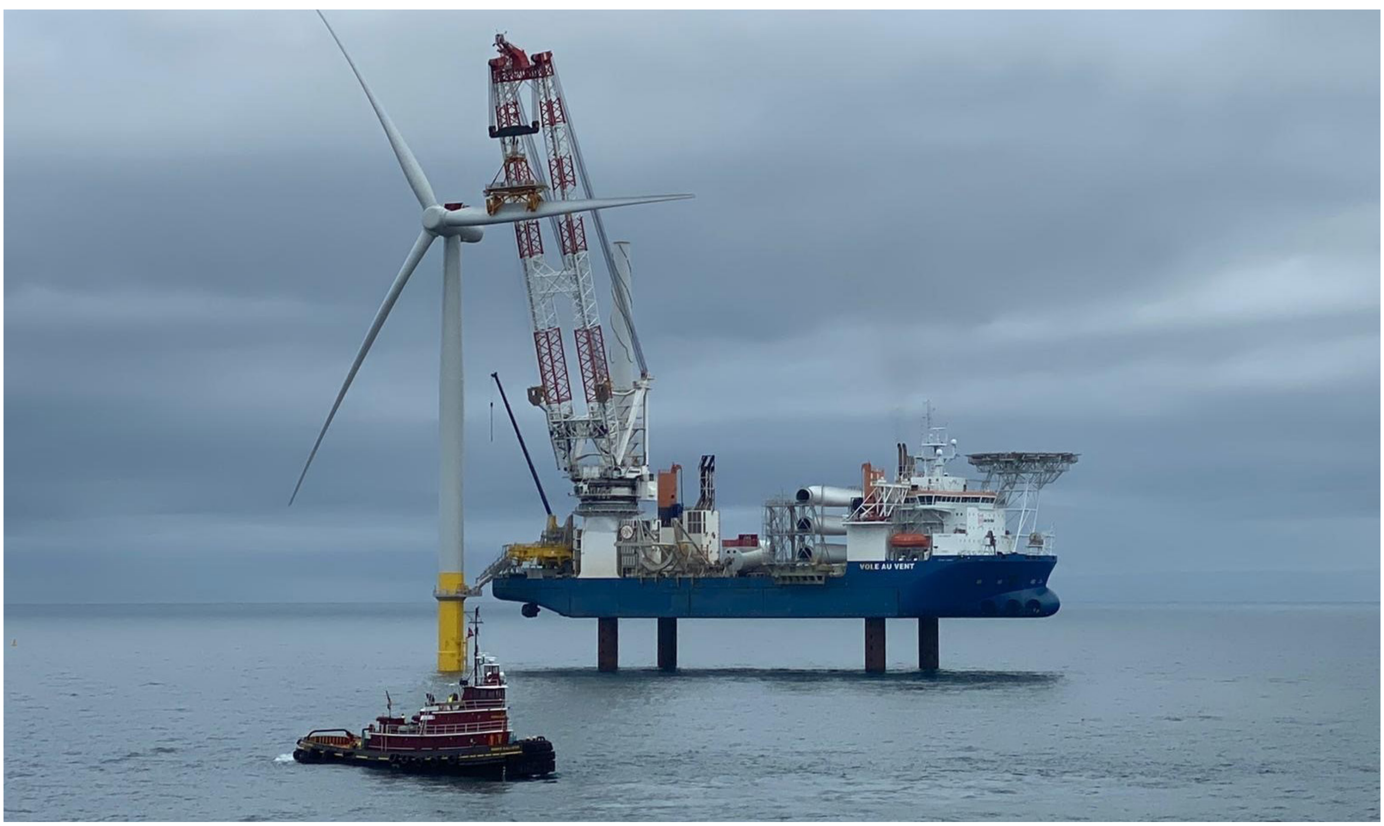
Source: Douglas-Westwood, 2013

Vessels	Min length	Max length	Min width	Max width	Min draft	Max draft
*WTIV	75 m	160 m	30 m	50 m	3.4 m	10.9 m
Jack-ups	40 m	100 m	20 m	40 m	2.4 m	8.3 m
Heavy lift	100 m	180 m	25 m	70 m	3.6 m	13.5 m
Cable lay	25 m	150 m	10 m	30 m	2 m	9.1 m
Offshore supply vessel	45 m	110 m	10 m	25 m	3.8 m	6.7 m
Crew transfer vessel	20 m	70 m	5 m	15 m	0.9 m	3.6 m
Tugs	20 m	50 m	5 m	15 m	3.2 m	6.3 m
Barges	25 m	100 m	10 m	25 m	2.5 m	3.6 m
Survey	15 m	160 m	5 m	30 m	1.2 m	8 m
Max vessel dimensions for lock		225.5 m		23.77 m		8.08 m

*WTIV – Wind Turbine Installation Vessel

Figure 17: Vessels Used for Offshore Wind Development

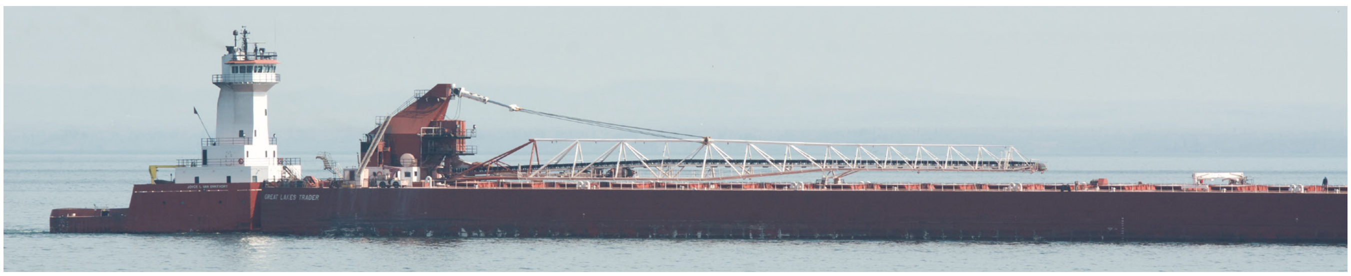
Source: Lyfted Media for Dominion Energy



There are only a few vessels capable of supporting wind farm development already stationed in the Great Lakes (Figure 18). Current ships that navigate the Great Lakes primarily consist of large bulk cargo vessels that transport goods to ports in the Great Lakes via the St. Lawrence Seaway. Most of these freighters are designed for free-flowing bulk cargoes such as coal or grain; however, some vessels can carry large items, including wind turbine blades. Oil or chemical tankers are designed for specific types of liquid cargoes and are unlikely to play a role in the development of wind energy on the Great Lakes. The primary ships that currently exist on the Great Lakes that could be used to install wind turbines are tugboats and barges (Shipwatcher News, 2020).

Figure 18: Existing Fleet of Vessels on the Great Lakes

Source: Peter J Markham



Alternative options to accommodate these vessel limitations would require modification of the conventional installation procedures and possibly lowering the maximum turbine size. Alternatives may include custom barges that use land-based cranes or ring cranes to install fixed-bottom turbines on Lake Erie, or possibly more novel solutions incorporating fully assembled float-out fixed-bottom wind systems. On Lake Ontario where floating foundations are most suitable, the requirements are relaxed for heavy lift vessels because the critical heavy lift activities are focused on the port capabilities. Transitioning the critical lifting and assembly activities to the port could enable higher lifting capacity and possible scaling up to larger, more economical wind turbines, reduce risk to workers, and lower cost (Musial et al., 2021).

3.2 Wind Turbine Options

The size of the wind turbine and its power generating capacity is a key parameter that affects all aspects of a project, including cost, installation logistics, number of turbines, and visual impacts. For ocean-based offshore wind, the economics favor larger scale turbines with most manufacturers now developing offshore wind turbines with capacities of up to 15 MW (Musial et al., 2021). Larger turbines provide significant reductions in wind farm capital costs and, therefore, total energy costs because there are fewer units to install and maintain for a given power output. Reducing the number of turbines and associated cables can also lessen environmental impacts and co-use considerations. However, larger turbines require larger installation vessels and ports that are being developed and upgraded for offshore wind around the world.

Due to vessel transit limitations to the Great Lakes and the capacity limitations of land-based cranes that can operate on the lake or in a port, GLW turbines may need to be smaller than conventional offshore wind turbines. For this study, which assumes conventional installation methods, turbines are limited in size to 4–7 MW. This turbine size is less attractive economically, but land-based turbine manufacturers are beginning to mass produce turbines of this size, enabling GLW to leverage domestic supply chains that will soon exist.

Key turbine specifications were compiled for some of the commercially available and reference wind turbines with rated capacities between 4–7 MW (Table 6). Rotor diameters for 4–7 MW wind turbines are between 120 m and 170 m. Manufacturers typically offer a range of hub heights that can be customized for specific site conditions, but assumed hub height is approximately the rotor radius plus an additional

25 meters minimum to provide sufficient clearance between the rotor and the waterline. The most demanding lift, due to the height and component weights, is the rotor nacelle assembly (RNA). Examples of RNA masses for wind turbines in the 4–7 MW size range include the NREL 5 MW reference turbine with a nacelle mass of 240 t and an RNA mass of 350 t, and the GE Haliade 6 MW turbines with an RNA mass of 400 t (Bocklet 2021). One of the world's largest land-based crawler cranes, the DEMAG CC 8800-1, could theoretically be used on a custom barge for fixed-bottom installation projects. ***The details on its lift capacity are provided in 22-12d Ports and Infrastructure.*** It can lift a weight of 496 t to a height of 120 meters, which is enough capacity for 10-MW turbines or less. However, the associated cost and risk with coupling this large land-based crane with a barge system and bring it onto the lake would be high.

The GE Cypress 6.0-164 was selected from the available large land-based turbines as one example that would be feasible for GLW (Table 6). It was designed to the IEC Class II standards, characteristic of Lakes Erie and Ontario conditions. The turbine has a relatively larger rotor diameter compared to its generator rating compared to most offshore wind turbines, which improves energy production at lower average wind speed sites. This turbine's geometry was used as the baseline for evaluating the viewshed. Our technology analyses for both Lake Erie and Lake Ontario also rely in part on this turbine. The primary driver for selecting this turbine was that it was the largest turbine, with an approximate RNA weight of 350 t, that could be installed with the heavy lift crawler crane identified above, and outfitted on a custom barge for Lake Erie installations. This limitation may be eased as new technology and strategies emerge.

Table 6. Characteristics of Commercially Available and Reference 4–7 MW Wind Turbines

Source: Manufacturers' websites

Manufacturer/ Source	Model	Location	Rated Power (MW)	Specific Power (W/ m^2)	Rotor Diameter (m)	Tip height[4] (m)
GE	Haliade 150-6MW	offshore	6.0	340	150	175
GE	Cypress 6.0-164	land	6.0	284	164	189
Nordex	N149/5.X	land	5.0 – 5.5	315	149	174
SGRE	SWT-6.0-154	offshore	6.0	322	154	179
SGRE	SG 5.0-145	land	4.0 – 5.0	303	145	170
Vestas	EnVentus V150-6.0	land	6.0	340	150	175
Vestas	V136-4.2	land	4.2	289	136	161
NREL	5MW Reference	offshore	5.0	401	126	151

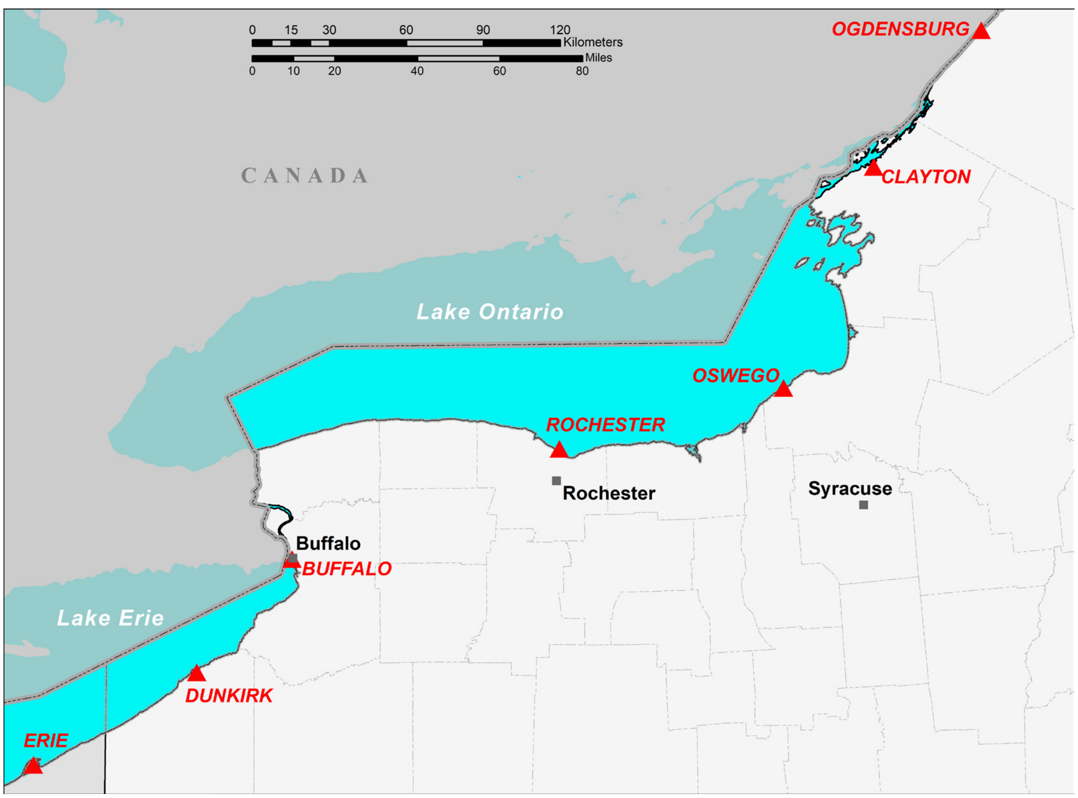
Lake Ontario can potentially support larger turbines, since port upgrades could include multiple heavy-lift cranes at quayside to assemble turbines, or more permanent infrastructure innovations that include large built-for-purpose cranes that enable larger more cost-effective Great Lakes turbines.

3.3 Ports Assessment

The ports considered are all located on the U.S. shore of Lakes Erie and Ontario, with six located in New York State and one in Pennsylvania (Figure 19). They were down-selected from a larger list that contained smaller ports or ports that were too constrained to support potential commercial-scale GLW development. Each port that was assessed has unique benefits, but all ports would require significant upgrades to support GLW development.

From east to west, the ports considered included Ogdensburg, Clayton, Oswego, Rochester, Buffalo, Dunkirk, and Erie. The ports of Ogdensburg and Clayton are located on the St. Lawrence River. The ports of Oswego and Rochester are located on Lake Ontario, while the ports of Buffalo, Dunkirk and Erie are located on Lake Erie. Ogdensburg, Oswego, Buffalo, and Erie all have previous experience handling and distributing wind turbine components for land-based wind projects (Great Lakes Wind Collaborative, 2010; Chamber of Marine Commerce, 2021). Because the floating technology that would likely be used in Lake Ontario is significantly different from the fixed-bottom technology that would likely be used in Lake Erie, the requirements for each lake are described separately.

Figure 19. U.S. Ports Assessed for Supporting Great Lakes Wind Energy Development



The port requirements are determined by the vessels and installation strategies that would be used. For fixed-bottom projects in Lake Erie, likely installation methods include preassembled float-out strategies, or possible jack-up barges or custom modular barges that could accommodate a large land-based crawler crane to assemble the turbine on the water. For example, the latter method could involve lifting the 350-t RNA for the 6-MW reference turbine to the top of an assumed 112-m tower. This potential custom barge strategy was demonstrated using the Sarens Soccer Pitch barge during the construction of Windpark Fryslân on Lake Ijsselmeer in the Netherlands, which had similar vessel constraints (Sarens, 2021). The port would need to have a berth to accommodate the barge assembly and storage during winter months, but would not need the full capabilities of turbine/substructure assembly.

Float-out strategies would be more design-specific and require more space at quayside and a heavy lift capability at the port but could reduce the need for a conventional heavy lift vessel on the lake. Float-out methods have not been commercially demonstrated for fixed-bottom substructures but may be feasible and could potentially be a more optimal solution. There have been many concept designs proposed for ocean-based systems but the availability of convential vessels has reduced the motivation to pursue these ideas. ***A more complete description of the port requirements for Lake Erie, including crane capacities, lifting heights, water depths, wharf lengths, and lay down areas are provided in 22-12d Ports and Infrastructure.***

For floating projects in Lake Ontario, the likely installation methods include assembling the turbine and floating substructure at port and then transporting the fully assembled system to site either by tugboats or by a submergible barge. The complete turbine assembly could be accomplished at port with the proper crane capacities, which saves the need for expensive installation vessels. The port would also need sufficient channel depth, wharf length, and lay-down space to accommodate the size of the floating substructure or any submergible barge, as well as be able to transfer the assembled structures to the water. ***A more complete description of the port requirements for Lake Ontario is provided in 22-12d Ports and Infrastructure.*** More customized approaches tailored for the Great Lakes are potentially more efficient than these conventional assembly and installation methods.

There are several key port requirements for supporting potential GLW development. All ports will require sufficient heavy-lift crane capacity. On Lake Erie, cranes will be needed to lift individual turbine and substructure components onto an installation vessel. On Lake Ontario, assembly of floating turbines and their substructures would most likely be done at port. The most challenging operation is to lift the rotor/nacelle assembly (RNA), with one or more cranes, to the tower top assembly on the floating substructure at port, where it would be commissioned and towed to its site on the lake. In addition, all ports will require enough quayside space to store or assemble the turbines, blades, towers, and substructures. Additional quayside space for assembling the turbines and substructures is more important for floating turbines or for float-out installation strategies where systems are fully assembled at port.

Another critical requirement for both floating turbines and fixed-bottom float-out ports is that there be no air draft limitations such as bridges or powerlines. If the air draft obstruction cannot be removed, then the port is not suited for GLW.

Port readiness was assessed based on the key requirements identified for supporting potential GLW development. A readiness level was assigned for each port based on its ability to meet key requirements (Table 7), which include the port's channel depth, its crane capacity, its quayside space, and its air draft limits. A lower (red) readiness level signifies that the port is not currently equipped to handle the specified criterion, and it is less feasible for the required changes to be made. A medium (yellow) readiness level indicates that with feasible changes the port would be able to handle the specified criterion. Lastly, a higher (green) readiness level indicates that the port is already equipped with the given criterion. Additional port readiness factors, such as permitting or environmental considerations, were not included in this port analysis, but should be included in the greater port evaluation process. The ports with medium and higher levels for each criterion included Oswego, Buffalo, and Erie, and are believed to be the more viable choices for supporting GLW development. The Port of Oswego has sufficient quayside storage that could be used to assemble the turbines (37,100 sq meters), whereas the rest of the ports would likely need expansion of this storage space. The Ports of Clayton and Rochester may be too small to support the transportation, assembly, and installation of turbines for GLW. However, these ports should be considered as opportunities for supporting potential operations and maintenance needs or as interconnection points.

Table 7. Assessment of Port Readiness

Sources: Sea Ports of United States US (n.d.)

Requirement	Lake Ontario				Lake Erie		
	Ogdensburg	Clayton	Oswego	Rochester	Buffalo	Dunkirk	Erie, PA
Channel Depth							
Cranes							
Quayside Space							
Air Draft							

Each of the assessed ports would need to deepen their channels to fully support GLW. Each port assessed received a medium readiness level for channel depth, meaning it is possible for it to support GLW development but require dredging that would involve additional permits and approvals. (Table 7). All ports investigated would require some degree of dredging to increase channel depth to support the required transport and installation vessels or to support a float-out installation method.

The Port of Oswego is the only port that may have access to cranes large enough to support GLW. All of the ports would have to build, buy, or rent cranes. There also needs to be enough quayside space to support the assembly of the wind turbines. The Ports of Ogdensburg, Oswego, Buffalo, and Dunkirk all have enough quayside space currently to support GLW. The Port of Erie has potential to expand its quayside space, but its current lay-down area is not big enough. The Ports of Clayton and Rochester do not currently have enough space to expand.

Air draft is an issue for some ports that have eliminated them as possible options. The Thousand Islands Bridge creates an air draft limit for the port of Ogdensburg and the Port of Buffalo has overhead power cables which present an air draft limit but could potentially be worked around by relocating the cables. The rest of the ports do not have an air draft restriction.

Based on the anticipated vessels required and turbine selection discussed above, any of the ports studied here would require some level of upgrade to support assembly and installation of wind turbines on the Great Lakes. The required upgrades include larger cranes (higher lifts and higher capacity); dredging; expanding quayside storage and assembly area; removing overhead barriers; and systematic permitting and environmental processes. The costs to upgrade each port to support GLW was not calculated since the infrastructure, installation methods, and sizes of turbines and substructures were not specifically defined.

3.4 Substructure Types

The general support structure components for offshore wind turbines will be the same for GLW, including the tower, substructure, and foundation, but the designs may need to be adapted for some of the unique conditions of the Great Lakes. The tower is the most visible component above the waterline and supports the rotor-nacelle assembly. For fixed-bottom structures, the substructure is the structural component that extends upwards from the seafloor and penetrates the waterline to support the tower. The foundation is a structural or geotechnical component on or beneath the seafloor to transfer the support structure loads to the seafloor. For floating wind turbines, buoyant substructures are moored to the lakebed with chains, ropes, cables, and anchors. The following sections evaluate the feasibility of common offshore fixed and floating substructures in the Great Lakes.

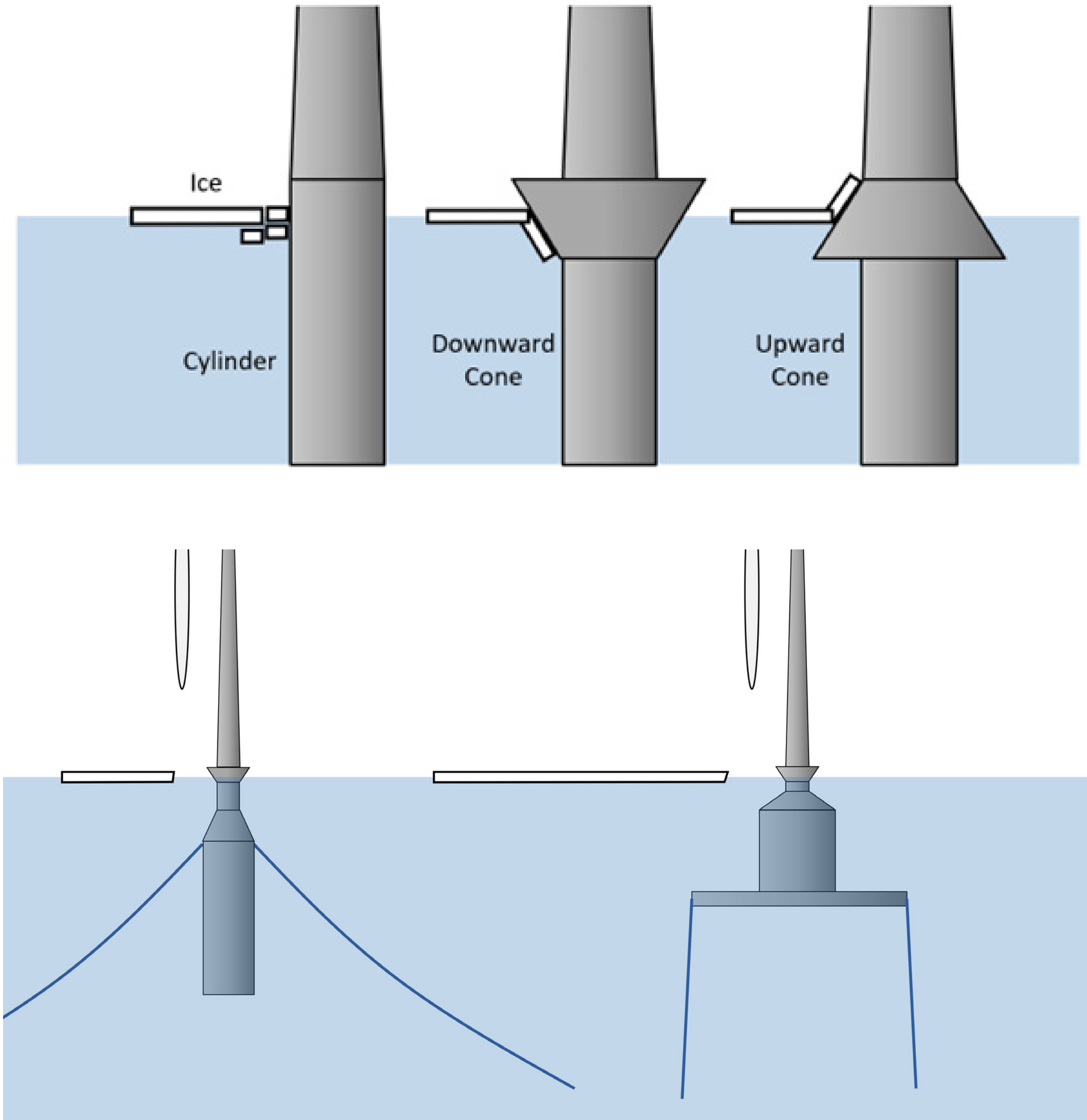
3.4.1 Ice Loading

The presence of freshwater ice floes in the Great Lakes introduce significant loads on an offshore substructure, which has raised some concern about the feasibility of GLW. Although ice loading must be considered, and ice mitigation strategies will be required, this study did not identify any design constraints due to ice that would make GLW unfeasible for either fixed or floating substructures.

The primary ice load mitigation strategies are to limit substructures to only those with slender waterline profiles and to avoid wider profiles with large bearing areas, such as multi-leg substructures (e.g., jackets) that can cause ice jamming between legs. The force that ice exerts on an offshore substructure is related to the force required to break the ice sheet as it contacts, and moves past, the structure. This breaking force can vary significantly depending on the ice failure mode, which depends on the properties and characteristics of the ice sheet and substructure design. When the ice sheet impacts a vertical substructure, the ice is crushed as it moves past. This mode imparts the highest load on the substructure (Figure 20, left side). To avoid crushing the ice, ice cones can be installed on the substructure at the water line which induce a flexural ice failure mode (Figure 20, top-center and top-right side) where the ice sheet is bent up or down, breaking the sheet into pieces. Ice cones can reduce the loads on the wind turbine foundation by an order of magnitude. This is a proven technology that is used in current practice on most offshore wind structures that encounter surface ice floes. Note that the downward cone is the preferred option since it also provides a service platform to facilitate operation and maintenance of the wind turbine.

Figure 20. Potential Ice Interactions with Fixed and Floating Turbines

(Top: Crushing failure induced in vertical profiles (left) and flexural failure induced in downward sloping (middle) and upward sloping (right) profiles. Bottom: Floating substructures (spar left and tension leg platform right) outfitted with similar ice cones to deflect and break ice sheets in flexure mode.)



3.4.2 Ice Load Modeling

The design adaptation of offshore wind for the Great Lakes requires an understanding of the site-specific ice climate, the properties of the ice that will be encountered, and the proper engineering tools to estimate anticipated external ice forces. Over the past decade, multiple ice load calculation methods and models have been developed for use in designing offshore structures, including offshore wind turbines. The two most notable ice-load methods are the Ralston method and the Croasdale method. Both methods are used to calculate the ice loads on a sloped structure, such as an ice cone, and are referenced in the ISO 19906 standards (International Organization for Standardization, 2010). Each one uses various techniques that consider the different forces that arise when an ice sheet breaks, rides-up slope of the ice cone, and creates ice rubble. The preferred method is dependent on the specific ice-structure scenario.

One of the most widely used modeling tools for designing offshore fixed-bottom and floating wind turbines is OpenFAST. NREL developed OpenFAST to simulate the coupled dynamics of offshore wind turbine systems. OpenFAST contains two ice-load modules, IceDyn and IceFloe. IceDyn was developed by Dr. Dale Karr at the University of Michigan (Karr, Yu, and Sirnivas, 2015), and IceFloe was developed by Tim McCoy at DNV (McCoy, 2014). Both modules include a set of ice models that reference various standards and methods to simulate the ice loads in different failure modes on an offshore structure. Because GLW substructures will most likely be outfitted with ice cones, the ice bending models in IceDyn and IceFloe will be of primary interest. Note that the modeling tools discussed herein were developed for fixed-bottom substructures. Ice models for floating wind substructures are in earlier stages of development, but these fixed-bottom ice models may provide a reasonable first order approximation. ***The state of the art in predicting ice loads on offshore structures is described in detail in 22-12e Substructure Options.***

3.4.3 Substructure Feasibility Assessment Criteria

A qualitative feasibility assessment was performed on a range of existing fixed-bottom and floating substructures to determine the suitability of each type for the conditions of the Great Lakes. The following criteria were used to determine support substructure suitability for the Great Lakes:

- **Installability** is assessed based on the support structure's potential to be compatible with local port facilities and feasible with installation methods identified using available lake vessels.
- **Lakebed Compatibility** is assessed based on how suited the substructure's foundation is for the soil conditions of eastern Lake Erie. This criterion was not evaluated for floating substructures in Lake Ontario because anchor compatibilities are not coupled to the substructure type. All soil types in the Great Lakes could accommodate most anchors but their compatibility for certain soils would depend on the coarseness of the soil and the depth to bedrock in the region.
- **Ice-structure Interactio**n is based on the substructure's ability to achieve a slender waterline profile, and if it can be outfitted with an ice cone.
- **Local Manufacturability** is based on the potential to adapt the substructure for manufacturing in the Great Lakes region, including the northeast U.S. and the Midwest.
- **System Cost** is evaluated based on the substructure's ability to minimize the cost of all parts of the design process considering the primary design challenges and constraints for the lakes.
- **Technology Readiness** is an assessment of the risk associated with a support structure's maturity within the global industry and degree to which it can be fully commercialized.

3.4.4 FixedBottom Substructures in Lake Erie

Due to the relatively shallow water depths of Lake Erie, fixed-bottom substructures are assumed to be the only technology that will be used in the Lake as they are likely the most cost-effective solution at these depths; however, they are not recommended for use in the deeper waters of Lake Ontario. Five types of fixed-bottom offshore wind structures were used in this feasibility study; the jacket substructure is included as an example of a typical offshore design not considered suitable for the Great Lakes (Figure 21). An example of a tripod substructure at the approximate scale required for deployment in the Great Lakes was installed at Alpha Ventus near Bremerhaven, Germany (Figure 22).

Figure 21. Common Fixed-Bottom Substructures Considered for Great Lakes Wind

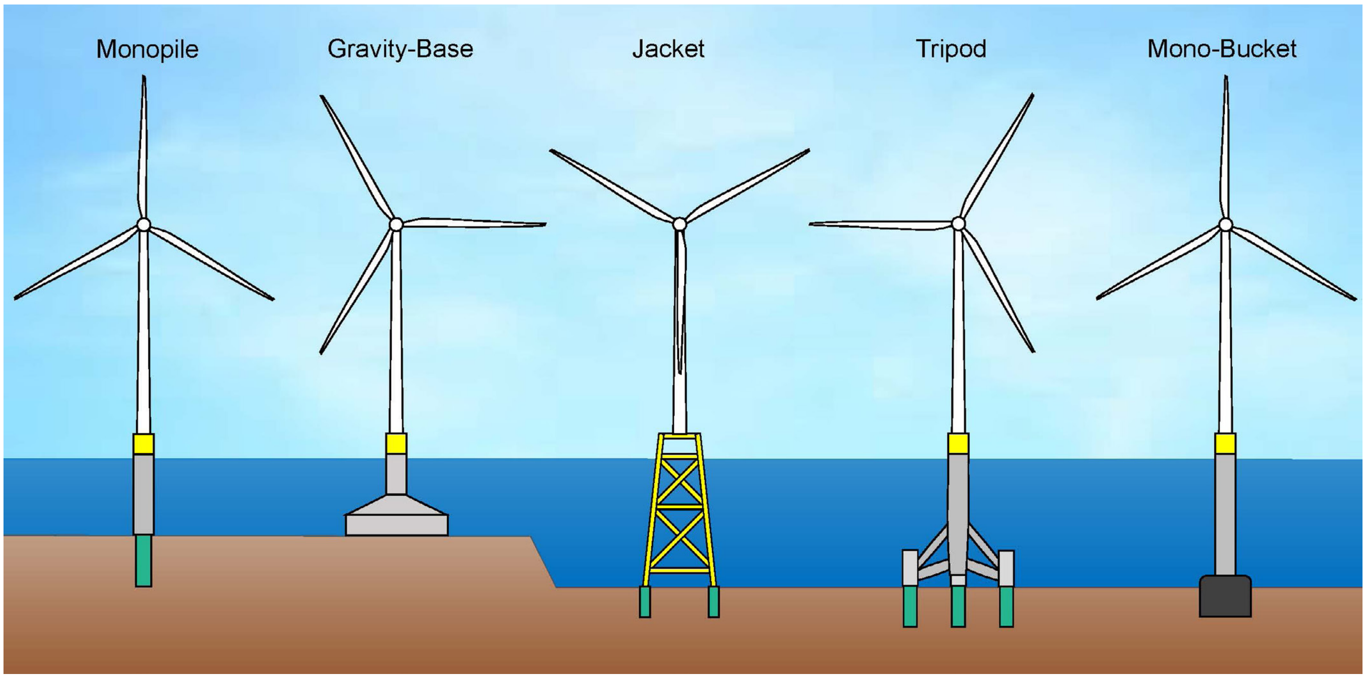


Figure 22. Tripod Substructure Used in 5-MW AREVA Multibrid Turbines Installed at Alpha Ventus near Bremerhaven, Germany

(photo credit: Walt Musial)

Certain features of each substructure type may require design adaptations for the Great Lakes, but in most cases, these adaptations can be implemented with reasonable investments and with minor risk. In other cases, the incompatibility of some substructures with the Great Lakes feasibility criteria may be too large to overcome. As the industry is still young, there are many alternative substructure designs that could be feasibly adapted with incremental design changes. Therefore, it is also recognized that that the optimum substructures for potential GLW development quite possibly has not yet been demonstrated yet.

The existing NREL 5 MW reference turbine model and the estimated extreme ice conditions of Lake Erie were used to model the extreme ice loads on a representative fixed-bottom GLW wind turbine system in OpenFAST. The NREL 5 MW reference turbine was used for this analysis because of its open-source accessibility and close proximity in size to the GE Cypress 6 MW representative turbine used in other sections of this report. The resulting ice loads were then compared to the aerodynamic and hydrodynamic loads on the same structure without the presence of ice. The OpenFAST results for a Lake Erie representative substructure design were compared to an Atlantic Ocean representative design (Table 8).

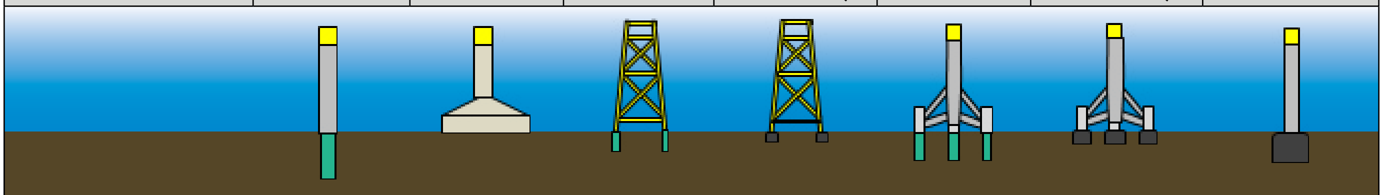
Table 8. Extreme Environmental Load Comparison Chart for NREL 5 MW Reference Turbine

	Lake Erie Representative Design	**Atlantic Ocean Representative Design**
Consolidated Layer Ice Force (MN)	0.7	0
Consolidated Layer Ice Bending Moment (MN-m)	21.0	0
Keel Ice Force (MN)	3.5	0
Keel Ice Bending Moment (MN-m)	105.0	0
Aerodynamic Force (MN)	0.8	0.8
Aerodynamic Bending Moment (MN-m)	96.0	96.0
Hydrodynamic Force (MN)	1.5	1.9
Hydrodynamic Bending Moment (MN-m)	45.0	57.0
Total Horizontal Force without ice (MN)	2.3	2.7
Total Bending Moment without ice (MN-m)	141.0	153.0
Total Horizontal Force with ice (MN)	5.0	N/A
Total Bending Moment with ice (MN-m)	222.0	N/A

Fixed bottom substructure types were assessed for their feasibility in Lake Erie (Table 9), based on the six key criteria identified above—*Installability; Lakebed Compatibility; Ice-structure Interaction; Local Manufacturability; System Cost; Technology Readiness.*

- A lower feasibility level (**red**) indicates a major limitation that renders a substructure unsuitable.
- A medium feasibility level (**yellow**) indicates that a substructure could be feasible for that criterion, but significant challenges exist that must be addressed.
- A higher feasibility level (**green**) indicates that a substructure fits that criterion well.

Table 9. Feasibility Assessment of Fixed-Bottom Substructure Types

Fixed-Bottom Criterion	Monopile	Gravity-Base	Jacket (piles)	Jacket (suction buckets)	Tripod (piles)	Tripod (suction buckets)	Mono-Bucket
							
Installability							
Lakebed Compatibility							
Ice-Structure Interaction							
Local Manufacturability							
System Cost							
Technology Readiness							

From this qualitative assessment, the substructures with major limiting factors are monopiles and jackets. Monopile foundations are likely to not be feasible in eastern Lake Erie due to the lack of soil strength, the shallow soil depth to bedrock, and the lack of large pile driving vessels available in the Great Lakes. The soil depths to bedrock are marginally sufficient for smaller multi-pile substructures such as tripods, (depending on site-specific geotechnical validation), if standard pile driving equipment can be accessed on the Great Lakes. Jackets (lattice substructures) are not considered to be feasible in the Great Lakes due to the high loads that arise from ice jamming between their legs.

Gravity-base foundations, tripods with piles or suction buckets, and mono-buckets did not have any major limiting factors restricting their deployment in eastern Lake Erie but all would need to be adapted to some degree. These substructure types have slender waterline profiles, which can be outfitted with ice cones to reduce ice loads on the structure. Conventional gravity-base foundations would require significant lakebed preparation and dredging depending on the site-specific conditions, but they also have potential for design modifications to minimize issues with the soft lakebed soils. Suction buckets may be suitable for the soils of eastern Lake Erie and may have a less complex installation process because they don't require extensive pile driving vessels, and they avoid major construction noise, but they have not yet been demonstrated on a commercial scale.

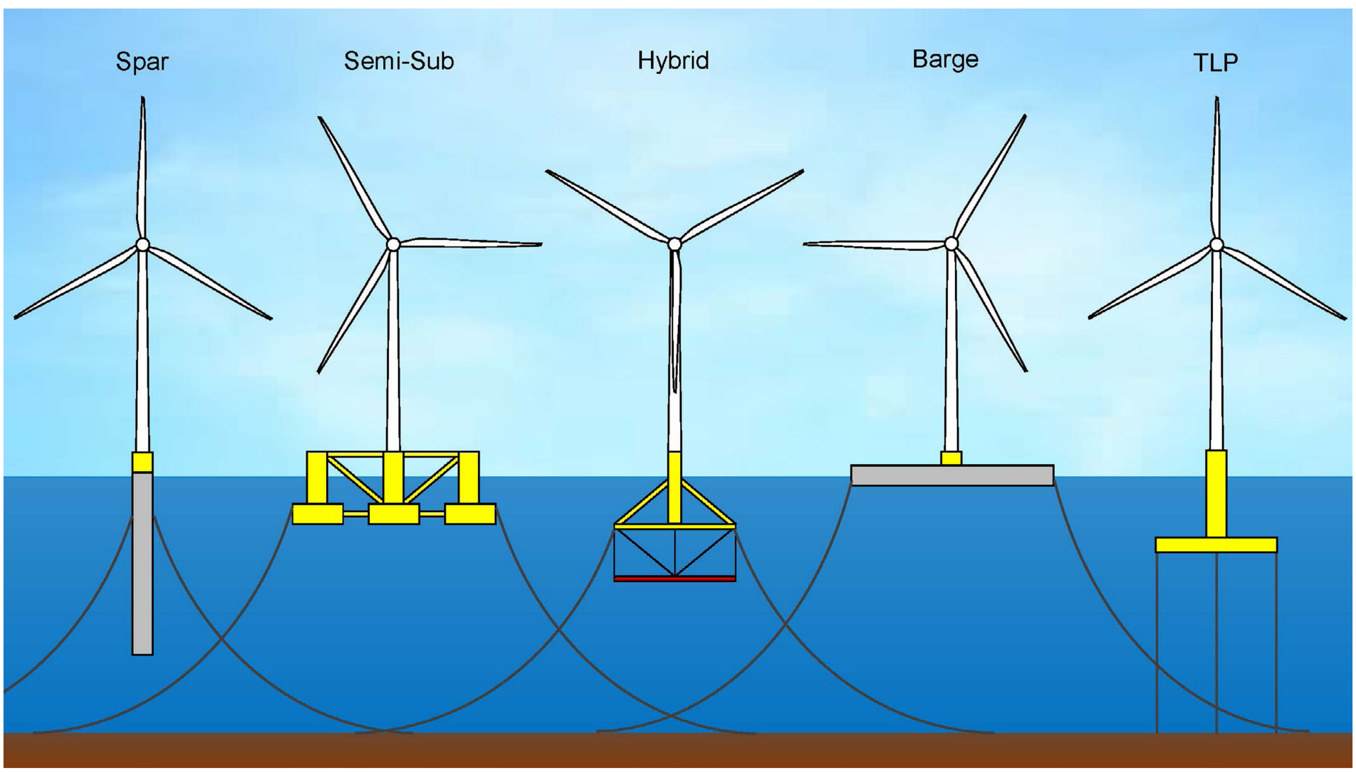
The manufacturability and cost of any substructure deployed on the Great Lakes will be challenged by the nascent supply-chain in the United States. Although there are currently no established production facilities, the mass production of substructures in New York is one of the biggest opportunities for economic growth and jobs that could come from GLW. The optimal fixed-bottom substructure type will likely be a customized adaptation of a gravity-base foundation, a tripod, or a mono-bucket in harmony with the lake's unique physical, environmental and logistical conditions.

3.4.5 Floating Substructures in Lake Ontario

Most types of floating wind substructures considered for offshore wind have been derived from the oil and gas industry. They include ballast-stabilized substructures, like spars, buoyancy-stabilized substructures, like semi-submersibles (semi-subs), and mooring line stabilized substructures, like tension leg platforms (TLPs) (Figure 23).

Floating substructures may eventually become easier to manufacture, install, and decommission relative to fixed-bottom substructures, but more complexities may arise on a floating platform due to the coupled motions of the platform. Because they are decoupled from the lakebed, turbine installation and assembly of the substructure can be conducted in a berth at the port where working conditions are easier to control and labor costs are lower. Generally, we assume that the fully commissioned turbine and substructure can be towed out to the site for connection with the mooring system. Similarly, the platform can be disconnected from the mooring system and towed back to port for maintenance or decommissioning. Hybrid substructures, like the TetraSpar (Stiesdal, n.d.), use the advantages of the deep draft spar to achieve operational stability but can reconfigure its architecture to achieve a shallow draft for port assembly and maintenance. Floating barges were also included in the assessment.

Figure 23. Floating Wind Substructure Types Considered in Feasibility Study



One of the biggest differences between a fixed-bottom substructure and a floating substructure is the method of attachment to the lakebed. Floating systems use buoyant substructures that are moored to the lakebed with chains, ropes, and anchors. There are three general types of mooring system configurations: catenary, semi-taut, and vertical tendons that are typically used for tension leg platforms. Catenary mooring systems are the most common because they are simple to design and install. Their footprints are the largest with typical anchor radii at least twice the water depth. Semi-taut mooring systems use shorter mooring lines and have smaller anchor footprints, but typically have higher anchor loads that are more challenging to design because they are more closely coupled with the substructure. Vertical tendons are attractive because they have the smallest anchor footprints, but they require more complicated deployment strategies and need high-capacity, highly reliable vertically loaded anchors. The moorings and anchors of a floating wind turbine must be designed to resist aerodynamic, hydrodynamic, and ice loading.

Based on ice load estimates, the horizontal ice load from a level ice sheet characteristic of Lake Ontario can range from 0.4–0.7 MN for an ice cone with a 52° slope (Allyn and Croasdale, 2016) and the tower diameter of the NREL 5 MW model of 6 meters. A spar and a TLP substructure were modeled as representative of Lake Ontario floating wind turbine structures in extreme weather conditions. Although the actual substructure may vary slightly in geometry, these loads are representative of the order of magnitude loading needed for this assessment. In this example, a fairlead (i.e., point where mooring lines attach to the substructure) depth of 20 meters was used on the spar and 30 meters on the TLP, resulting in a maximum overturning moment of the ice load in the range of 8–21 MN-m. Comparatively, the wind load on the NREL 5 MW reference turbine is 0.8 MN with an overturning moment on the order of 88 MN-m (Table 10). This expected design ice load represents a potential doubling of the horizontal load on the floating support structure but only a slight increase in the total overturning moment.

Table 10: External Loads and Moments for a Representative Structure in Lake Ontario

Parameter	Spar	TLP
Horizontal Wind Load (MN)	0.8	0.8
Wind Overturning Moment (MN-m)	88	88
Horizontal Ice Load (MN)	0.7	0.7
Ice Overturning Moment (MN-m)	14	21
Total Horizontal Load (MN)	1.5	1.5
Total Overturning Moment (MN-m)	102	109

These changes in the system loads need to be accounted for in the floating substructure design and mooring system. The following spar sizing is based on a maximum steady tower tilt angle of 4°, and the TLP sizing is based on a tension variation of 33% of mean tension between four tension legs. The designs are then resized by changing their ballasting, mooring weights, and substructure diameters to achieve the same maximum offsets when ice loads are included. The values with and without ice and the relative changes in these properties were estimated (Table 11) and represent approximate estimates for the design changes required to withstand ice loads for a floating substructure. For a spar configuration, keeping the same tower tilt angle limits in the presence of ice loads requires an estimated 7% increase in substructure displacement and 9% increase in ballast. For a TLP configuration, keeping the same offsets and tension margins requires a 11% increase in platform displacement. For both designs, the demands on the mooring lines and anchors could almost double in the presence of extreme 50-year ice floe. This will require an increase in anchor capacities to effectively resist the increased loads. Specific requirements for stronger anchors could be completed in a future anchor design study.

Table 11: Estimated Changes in Floating Support Structure Sizing to Support Ice Loads

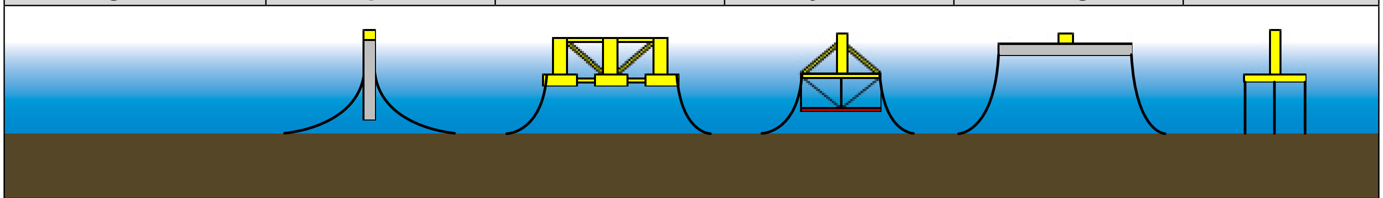
Property	Spar			TLP		
	Without Ice	With Ice	% Change	Without Ice	With Ice	% Change
Horizontal load (MN)	0.8	1.5	88%	0.8	1.5	88%
Overturning moment (MN-m)	88	102	16%	96	117	22%
Substructure displacement (t)	9,550	10,200	7%	4,080	4,550	11%
Ballast weight (t)	6,550	7,150	9%	N/A	N/A	N/A
Mooring line strength (MBL)	Depends on configuration		88%	12.3	15.3	25%
Anchor capacity	Depends on configuration		88%	15.4	19.2	25%

These estimates represent the worst-case values for floating wind systems that are at risk of encountering the maximum-level ice conditions in Lake Ontario. Installations in areas with lower ice thicknesses or ice cover probabilities could conceivably have smaller levels of ice reinforcement. Also, there are several ways to mitigate ice loads since their occurrence will be relatively rare and deterministic. Turbine controls could play a role by shutting the turbine off during ice floes and thereby eliminating the aerodynamic loading. It is also assumed that the wave loading will be eliminated during ice floes.

The ice properties (e.g., thickness, velocity, etc.) measured and collected in Lake Ontario provide reasonable inputs to the ice modeling methods to calculate a maximum level ice load. The uncertainties of the worst-case scenario reside in any ice ridge or extreme ice event that a structure can encounter in Lake Ontario. There is not enough measured ice data to accurately determine the extreme ice properties. GLW ice load estimations would be greatly improved by more data collection and analysis of Great Lakes ice conditions.

The floating substructure types evaluated for this study are not a complete taxonomy of the potential floating support structure solutions for the Great Lakes. Private communications with multiple offshore wind substructure developers indicate there is interest in developing floating substructure designs, customized for Great Lakes conditions. For instance, future innovative floating substructure solutions may be customized for the deeper waters of Lake Erie (at depths of only 50–60m) that would be more suitable than larger fixed-bottom substructures, but this can only be determined once the substructure solutions are more developed. These future designs will incorporate the need for quayside assembly and low waterline profiles to avoid the constraints imposed by ice loading. The designs will also address supply-chain limitations, like the narrow width of the St. Lawrence Seaway. Considering the design challenges and drivers of floating wind technology in the Great Lakes, a feasibility assessment was performed to determine the suitability of each of the floating substructure types for possible deployment in Lake Ontario. The feasibility assessment (Table 12) was performed based on the key criteria identified earlier in section 3.4.3. The feasibility levels for each substructure by criterion were characterized similar to the fixed-bottom substructure evaluation (ranging from lower feasibility red to higher feasibility green). Lakebed compatibility, which was used as a criterion for fixed-bottom substructures, is not used in the floating feasibility assessment, because the compatibility is based on the mooring and anchoring solution, rather than the substructure type. ***The feasibility of specific anchor types is considered in more detail in 22-12e Substructure Options.*** Ice-structure interaction is based on the substructure's waterline profile. Local manufacturability is defined as the potential for manufacturing in the Great Lakes region, which could encompass the U.S. Northeast and Midwest, as well as Canada. The overall cost takes into consideration the relative expected commercial cost potential of all parts of the design process, and technology readiness describes how developed that substructure is in industry.

Table 12. Feasibility Assessment of Floating Substructure Types

Floating Criterion	Spar	Semi-Sub	Hybrids	Barge	TLP
					
Installability					
Ice-Structure Interaction					
Local Manufacturability					
Overall Cost					
Technology Readiness					

From this qualitative assessment, the substructures with a major limiting factor are spars, semi-subs, and barges. Current installation procedures for spars are incapable in Lake Ontario due to their deep drafts, which would prevent port access. The second main limiting factor, which applies to semi-submersibles and barges, is the ice-structure interaction. Semi-submersibles have multiple legs that pierce the waterline and barges have large waterplane areas, which would both contribute to high and undesirable ice loads on the moorings and anchors.

The remaining substructures—hybrids (like the TetraSpar) and TLPs—were determined to have no major limiting factors to be deployed in Lake Ontario. Both can have slender waterline profiles and the ability to be outfitted with an ice cone. Both have relatively easy installation procedures that can work in ports of Lake Ontario. They both have potential to be manufactured in the local Great Lakes region and their costs and technology readiness levels will be dependent on the future supply-chain. TLPs are a well-developed technology used by the oil and gas industry, which should be able to transfer over well to the offshore wind industry. The first TetraSpar substructure was deployed in 2021 off the coast of Stavanger, Norway.

3.5 Electrical Interconnection Feasibility

Great Lakes wind plants would bring large quantities of electric power from wind turbines through a high-voltage export cable buried in the lakebed to a land-based point of interconnection (POI) where the power can be delivered to the New York State electric power grid. The objectives of this study were to develop a preliminary understanding of the feasibility of the interconnection of GLW to the New York State grid and to identify critical information that may inform general feasibility from an interconnection perspective. In addition, the distances from hypothetical projects to possible POIs and the costs of needed transmission upgrades were used in the cost analysis in section 4. The assessment leverages results of the Power Grid Study[5] and other existing power flow and energy deliverability analyses such as the New York State Independent System Operator New York State Independent System Operator (NYISO) Congestion Assessment and Resource Integration Study (CARIS).[6]

Potential impacts and resource constraints associated with proposed transmission facility components, both in offshore and upland areas, are not thoroughly addressed in the study. Although not critical for the purposes of the GLW feasibility study, such impacts and constraints may include cable installation methods, existing utility crossings, EMF, threatened and endangered species impacts, existing land uses, local laws and zoning restrictions, wetlands and water resources, and agricultural uses.

Power flow models developed by the NYISO served as the initial basis for assessment. These models were augmented with projected renewable development out to the year 2030. Potential POIs to the land-based New York Bulk Power System (NYBPS), as reflected in the power flow models, were selected for evaluation based on distance from each lakeshore (Lake Erie or Ontario) and the voltage level. The available capacity headroom was then determined for each of the POIs. The term "headroom,"[7] as used in this report, means the projected capability of the existing grid to support additional electricity generation. Applied to the present analysis, headroom represents the potential capability for GLW to interconnect; however, it also represents the capacity that is available to any other generation resource that may want to interconnect at the same POI. The nature of the NYISO market for new generation is competitive and GLW is expected to compete with other resource development to utilize the available headroom. The selection of POIs was narrowed down by region and the maximum simultaneous headroom was determined for the combined interconnection of all potential GLW. ***Interconnection feasibility for this study is considered in more detail in 22-12f Interconnection Feasibility Study.***

3.5.6 Representing 2030 Grid Conditions

To develop a renewable generation buildout representative of summer peak[8] load conditions in the year 2030, the study team considered two initial sources. The first is the 2019 CARIS Report which included a model that sought to meet the so-called "70 x 30 target"[9] by adding approximately 30 GW of utility-scale renewable generation resources throughout the New York Bulk Power System (NYBPS). The Power Grid Study, on the other hand, noted that the CARIS buildout was much higher than other projections such as those of the Zero Emissions Study.[10] The applied renewable buildout used a third source: NYISO interconnection queue of June 2021, which became the basis for a modified 2030 power flow model. The projected buildout was summarized for each zone, including existing renewables, additional offshore wind, additional land-based wind, and utility-size photovoltaic (Table 13). The modified power flow model also included the Tier 4 awards[11], specifically, the Clean Path NY (CPNY) project which would draw on wind, solar, and hydroelectric generation from Upstate New York, including potential interconnections from GLW, to deliver renewable power to New York City. Furthermore, existing thermal generators with no application or schedule for retirement are assumed to remain in service.

Table 13. Projected Renewable Generation Buildout in MW based on 2021 NYISO Queue and Total Buildout for 2030 in the Zero Emissions Study

Zone	Existing Renewable*	Addl OSW	Addl LBW	Addl UPV	Total Addl
A	2,497		1,620	1,120	2,740
B	620		220	130	350
C	3,421		1,710	700	2,410
D	1,564		1,250	0	1,250
E	831		1420	440	1,860
F	1,265			910	910
G	88			510	510
H	0				0
I	0				0
J	0	3,000			3,000
K	24	3,000			3,000
NYCA	**10,312**	**6,000**	**6,220**	**3,810**	**16,030**

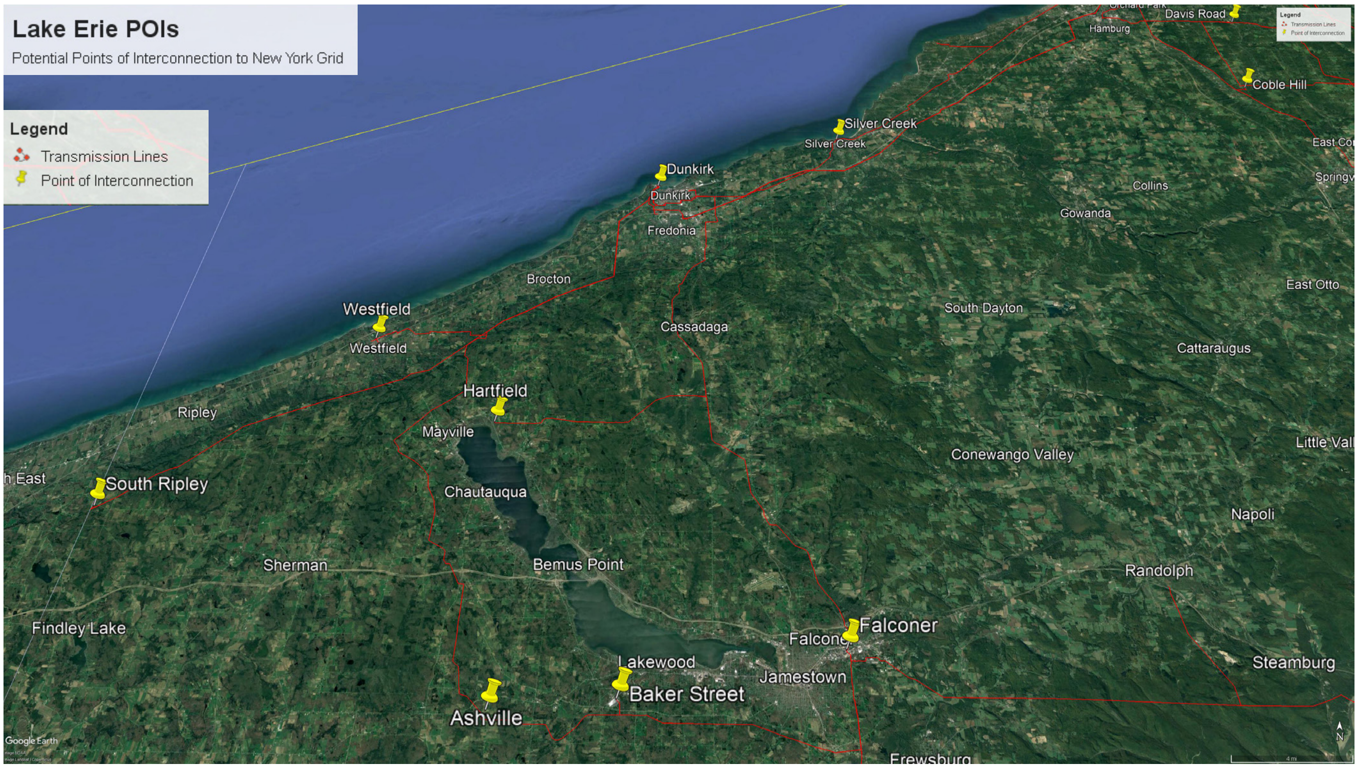
LEGEND: OSW: offshore wind, LBW: land-based wind, UPV: utility-size photovoltaic, NYCA: New York Control Area.

*Includes nuclear, hydroelectric, wind, and solar.

3.5.7 Lake Erie Interconnection

Lake Erie abuts the New York State counties of Erie in the north and Chautauqua in the south. The existing NYBPS has facilities near the shoreline in both counties. Potential POIs for GLW on Lake Erie were mapped (Figure 24).

Figure 24. Geographic Map of Potential Points of Interconnection to the New York Bulk Power System Facilities for Lake Erie Wind Generation



For the analysis of headroom capacity, two POIs were selected for each of the bordering counties. Solo headroom analysis was applied and resulted in estimations of capacity headrooms[12] for each POI (Table 14). The results of the solo headroom analysis indicate that there is headroom capacity for at least a 270-MW GLW farm on Lake Erie.

Table 14: Solo Headroom Capacity for Selected Great Lakes Wind POIs Along Lake Erie Shoreline Based on Modified 2030 Power Flow

POI	County	Capacity Headroom (MW)[13]
Dunkirk 230	Chautauqua	240
Ashville 115	Chautauqua	180
Stolle Rd 230	Erie	140
Elm St 230	Erie	270

To determine the total simultaneous headroom capacity that can be interconnected at multiple POIs from wind generation on Lake Erie, a simultaneous headroom calculation was conducted. The results indicate that without upgrades to the land-based grid the total capacity headroom for Lake Erie wind generation is limited to 270 MW (Table 15). For the purposes of providing a cost basis for increasing headroom capacity, the cost of simple upgrades[14] was considered. The resulting increases in headroom capacity with the associated costs (based on the conceptual cost per mile of a simple upgrade) were summarized. A set of simple transmission upgrades costing $68.8 m can increase the Lake Erie headroom capacity by 60 MW.

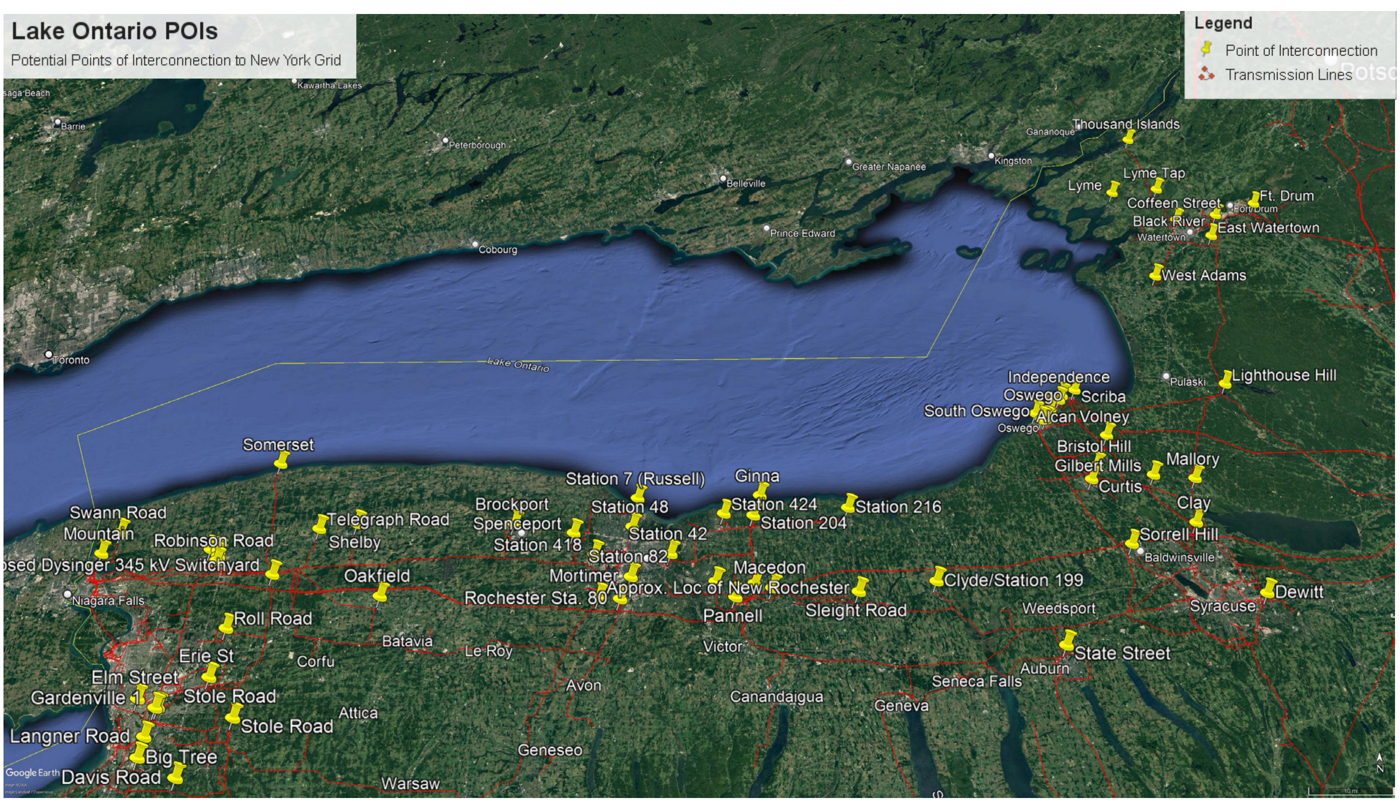
Table 15. Simultaneous Headroom Capacity Gained with Simple Transmission Upgrades for Total Lake Erie Wind Generation

Simple Transmission Upgrade[15]	Simultaneous Headroom Capacity (MW)	Conceptual Cost of Transmission Upgrades ($m)
None	270	0
Wethersfield-Stony Creek 230 kV	280	22.3
South Perry-Wethersfield 230 kV	320	36.0
High Sheldon-Stony Creek 230 kV	330	10.5
Total		**68.8**

3.5.8 Lake Ontario Interconnection

New York has a longer shoreline along Lake Ontario compared to Lake Erie. Several New York State counties border the lake, including Niagara, Orleans, Monroe, Wayne, Cayuga, Oswego and Jefferson. The existing State transmission grid and potential POIs along this shoreline were mapped (Figure 25).

Figure 25: Geographic Map of Potential Points of Interconnection to the New York Bulk Power System Facilities for Lake Ontario Wind Generation



Based on the location of accessible POIs along the shoreline, four counties were selected. For each county, two POIs were identified which had the highest solo headroom capacity in each county. The solo headroom capacities without transmission upgrades for the selected POIs were identified (Table 16).

Table 16: Solo Headroom Capacity without Transmission Upgrades for Selected Great Lakes Wind Point of Interconnetion along Lake Ontario Shoreline

POI	County	Capacity Headroom (MW)[16]
Somerset 345	Niagara	450
Robinson Rd 230	Niagara	40
Pannell 345	Monroe	1000
Rochester 345	Monroe	850
Clay 345	Oswego/Onondaga	1100
Oswego 345	Oswego	1100
Fort Drum 115	Jefferson	0
West Adams 115	Jefferson	0

While there are significant amounts of solo headroom capacity in the Monroe and Oswego County POIs, and about half the capacity available in Niagara County POIs, the POIs in Jefferson County show no capacity without transmission upgrades. The associated conceptual cost estimates for simple transmission upgrades to increase headroom at the Fort Drum POI in Jefferson County are summarized (Table 17).

Table 17: Solo Headroom Capacity Gained with Simple Transmission Upgrades for the Fort Drum Point of Interconnetion in Jefferson County

Simple Transmission Upgrade[17]	Solo Headroom Capacity (MW)	Conceptual Cost of Transmission Upgrades ($m)
None	0	0
Marcy 345/115 kV transformer	10	9.0
Ft. Drum-Taylorville-Boonville-Porter 115 kV	60	155.3
Total		**164.3**

The Ft. Drum solo headroom capacity can be increased from 0 to 60 MW with simple upgrades costing $164.5 million. A similar increase in headroom capacity for the West Adams POI can be achieved for an additional simple upgrade of the West Adams-Coffeen-Black River line at a cost of $39.2 million in addition to the Fort Drum upgrade costs.

The total headroom capacity for Lake Ontario wind generation is 1,140 MW given an allocation of

930 MW interconnected at Clay 345 kilovolts (kV) substation and 210 MW at Oswego 345 kV substation. This capacity may be further increased by transmission upgrades. Applying simple upgrades to address the constrained routes and estimating the cost of each simple upgrade shows that an increase of 140 MW can be achieved for an upgrade cost of $236.6m (Table 18).

Table 18. Simultaneous Headroom Capacity Gained with Simple Transmission Upgrades for Total Lake Ontario Wind Generation

Simple Transmission Upgrade	Simultaneous Headroom Capacity (MW)	Conceptual Cost of Transmission Upgrades ($m)
None	1140	0
Fraser-Oakdale 345 kV	1260	204.8
Coddington-Montour Falls 115 kV	1270	22.9
Coddington-Etna 115 kV	1280	8.9
Total		**236.6**

3.5.9 Interconnection Conclusions

For Lake Erie GLW, the available POIs showed a maximum transmission capacity headroom of 270 MW without transmission upgrades. Applying a set of simple transmission upgrades costing some $68.8 m can increase the Lake Erie total headroom capacity by 60 MW to 330 MW.

For Lake Ontario GLW, several POIs in Monroe and Oswego counties showed solo headroom capacity in the range of 850 to 1,100 MW without the need for transmission upgrades. At most, there is a total transmission headroom capacity of up to 1,140 MW for the Lake Ontario POIs. The total headroom capacity could be increased by140 MW by implementing simple upgrades costing some $236.6 m. The Jefferson County POIs showed no solo headroom capacity. Simple transmission upgrades costing at least $164.5 million may open about 50 MW of headroom capacity.

Applied to the present analysis, headroom represents the potential capability for GLW to interconnect; however, it also represents the capacity that is available to any other generation resource that may want to interconnect at the same POI. The nature of the NYISO market for new generation is competitive and GLW is expected to compete with other resource developments to utilize the available headroom. Other system conditions can impact the capacity headroom, including the continued operation of nuclear units in Upstate New York, variations in the assumed buildout of renewable generation and construction of transmission upgrades by 2030. In an actual interconnection study, the model used may be different based on system conditions deemed to have changed by NYISO at that time. Headroom capacity is only one component that prospective interconnections to the NYBPS need to address. Other reliability issues relating to transient voltage, stability, short circuit, deliverability, transfer capability and higher-level contingencies would also need to be considered.

Capacity headroom values are not necessarily the same as installed capacity or nameplate rating. The total nameplate ratings for wind facilities on Lakes Erie and Ontario may be equal to or greater than the aforementioned headroom capacities and can be as much as twice the headroom capacities. While capacity headroom is measured at a particular hour of the year (in this case, the summer peak load hour for year 2030), the output of resources such as wind will vary hour to hour as some percentage of the nameplate capacity. If the output of the wind farm is, for example, at 50% of nameplate rating during the summer peak hour, then this particular wind farm with a nameplate rating of twice that of the capacity headroom would not be subject to transmission constraints during the peak load hour. Depending on the hourly characteristics of the wind available on the lake, the ratio of the nameplate to headroom capacity at the peak load hour typically ranges from 1.0 to 2.0.

Given the scale of commercial GLW projects ranging from 100 MW to 800 MW that were assessed in this study and larger projects that are under development in the Atlantic ocean, it is likely that the existing headroom would be insufficient for GLW and that some transmission upgrades would be needed. However, since GLW would not be the only renewable energy source competing for interconnection, the allocation of these upgrade costs have not been determined.

Photo Credit: Ørsted

4 Cost-Modeling and Cost-Reduction Pathways

This section provides a projection of costs in 2030 and 2035 for commercial-scale wind energy development in the New York State waters of Lakes Erie and Ontario. The cost analysis used a regional model developed by NREL to assess costs for offshore wind over wide areas throughout the United States. Cost assumptions were modified to reflect the unique specifications of potential wind energy projects in the New York Great Lakes relative to similar projects underway in the Atlantic Ocean. Key differences include constraints on the types of vessels that are available for project construction and service, port infrastructure, smaller 6-MW turbines, smaller project sizes, seasonal wave climate, and presence of lake surface ice during the winter months. The cost model combines information about these site-specific factors with geospatial data across the study area to estimate how costs may vary throughout the region and over time. ***Cost modeling results and cost reduction pathways are considered in more detail in 22-12g Cost Modeling and Cost Reduction Pathways.***

4.1 Analysis Tools

The cost analysis was carried out with NREL's Offshore Regional Cost Analyzer (ORCA), which evaluates the levelized cost of energy (LCOE) within a wind resource area and estimates future costs based on learning curve and innovation trajectories (Beiter et al. 2016). ORCA uses geospatial information to provide site-specific cost estimates that represent the effects of physical parameters such as average wind speed, wave height, water depth, and distances to land-based infrastructure.

The LCOE is derived from a bottom-up assessment of cost inputs in ORCA. The four major cost categories used to calculate LCOE are capital expenditures (CapEx), operational expenditures (OpEx), annual energy production (AEP), and financing terms represented by a fixed charge rate (FCR). CapEx represents the capital costs per kilowatt required to reach commercial operation of the plant, including procuring materials and equipment, installation, project development, and "soft" costs such as site development, permitting, environmental mitigation, insurance, and construction financing. Decommissioning costs are represented within the total CapEx as a percentage of the installation cost. The cost of decommissioning includes a surety bond lease for removing offshore structures. No assumption of residual value is made for the sale or reuse of offshore structures or materials at the end of the project lifetime. OpEx includes the cost of labor, facilities, equipment, and materials for day-to-day operations as well as maintenance and repairs over the lifetime of the plant, expressed in terms of an annual average cost per kilowatt. AEP represents the average annual energy production of the plant over its lifetime. ORCA's assessment of AEP depends primarily on site-specific wind speeds at the turbine hub height, the turbine power curve, and losses including transmission losses, maintenance downtime, wake losses, and other performance loss factors (Beiter et al., 2020). The FCR is defined as the annual revenue required per dollar of investment to pay taxes and carrying charges on the investment. ORCA uses the following equation to calculate LCOE from these inputs (Beiter et al. 2016):

$$LCOE = \frac{(FCR \times CapEx + OpEx)}{AEP}$$

A learning curve for future cost reductions is obtained from NREL's Forecasting Offshore wind Reductions in Cost of Energy (FORCE[18]) model (Shields, Beiter, and Nunemaker forthcoming). The learning rate is expressed as a percent CapEx reduction per doubling of installed capacity worldwide that was derived from a multivariate linear regression of historical global offshore wind CapEx data going back to 2014. This learning rate is then translated into a learning curve (and cost reductions) based on projected global offshore wind deployment in a future year, which is estimated from published forecasts.

4.2 Scenario Development

Scenarios developed for the cost analysis incorporated regional factors that distinguish the Great Lakes from other offshore wind sites. To provide detailed cost estimates, ORCA requires specific wind plant parameters such as turbine capacity and layout. These scenarios are intended to be representative of the general characteristics of potential wind power plants in the Great Lakes. However, the design of any future wind energy projects may differ from the parameters modeled in this study based on local site conditions, differences in technology, and regulatory compliance objectives. The parameters used for modeling on each lake are summarized in Table 19.

Table 19. Summary of Cost Modeling Scenario Parameters

Parameter	Lake Erie Scenarios	Lake Ontario Scenarios
Plant Capacity	100 / 400 MW	400 / 800 MW
Turbine Rated Power	6 MW	6 MW
Commercial Operation Dates	2030, 2035	2030, 2035
Substructure Technology	Fixed bottom	Floating
Plant Locations	Area within NYS waters farther than 4 miles from shore	Area within NYS waters farther than 4 miles from shore
Wind Turbine Array Layout	7D × 7Da spacing on square grid	7D × 7D spacing on square grid
Export System[19]	Includes offshore substation and 220 kV HVAC export cable(s), length set by straight-line distance to the closest point of interconnection identified in Section 3.5.7	Includes offshore substation and 220 kV HVAC export cable(s), length set by straight-line distance to the closest point of interconnection identified in Section 3.5.8

a D = turbine rotor diameter

The nameplate generating capacity of a wind power plant is an important parameter in determining cost. This study focuses on modeling commercial-scale offshore wind costs, rather than pilot-scale projects. Smaller demonstration projects provide opportunities to develop and prove technologies before deploying them at scale; however, the per-kilowatt costs of such projects are much higher relative to commercial projects. Larger plants benefit from economies of scale enabling lower costs per kilowatt. In most offshore lease areas on the Atlantic, project sizes are approaching 1,000 MW for this reason. However, for this cost analysis a plant capacity of 400 MW was modeled. This plant size allows for cost comparisons between both lakes. The 400 MW plant size represents a small commercial-scale project compatible with the estimated currently available headroom for new generation capacity at potential POIs and accounts for the smaller developable area in Lake Erie. Two additional scenarios were also considered to illustrate how cost varies with plant size: a plant capacity of 100 MW in Lake Erie that is representative of a pilot scale project, and a larger capacity 800 MW commercial plant in Lake Ontario.

Costs were evaluated for a turbine rating of 6 MW, which is likely to be commercially available through local supply chains developed for the land-based wind energy industry. Turbines of this size may be more compatible with the infrastructure on the Great Lakes than the 15-MW wind turbine platform in development for the offshore wind market. Although this analysis is based on the 6-MW land-based turbine, it does not preclude the possibility that GLW infrastructure could be adapted for larger turbines, especially on Lake Ontario where heavy lift wind turbine installation vessels are not required.

Commercial operation dates (CODs) of 2030 and 2035 were modeled. Costs were evaluated for fixed-bottom substructures in Lake Erie and floating substructures in Lake Ontario. Substructure costs in the Great Lakes are likely to be incrementally higher than offshore wind substructure costs in the Atlantic because their design must incorporate the impacts of freshwater ice loading and constraints on transportation and installation logistics. Substructure configurations were identified earlier in section 3.4. To estimate costs, a single representative substructure type was modeled in both categories—fixed-bottom and floating. NREL has validated existing cost modeling tools for monopiles and semisubmersible substructures, which incorporate the material costs, labor, design, depth scaling, wind and wave impacts, vessel costs, and turbine scaling effects on substructure cost. The underlying assumptions for these substructure costs are explained in detail in Beiter et al (2016). Although these substructure designs are not recommended for GLW, the cost drivers are the same as for the substructures that are recommended. For example, in Lake Erie, the costs for a monobucket foundation are assumed to scale similarly to costs for a monopile across the relevant range of depths and shore distances. In Lake Ontario, a hybrid substructure design is estimated to have similar material and installation costs as a semisubmersible design, although advances to industrialize the serial production of substructures is likely to lower these costs. For both lakes, the costs of design adaptations for surface ice are included.

4.3 Plant, Port, and Point of Interconnection Locations

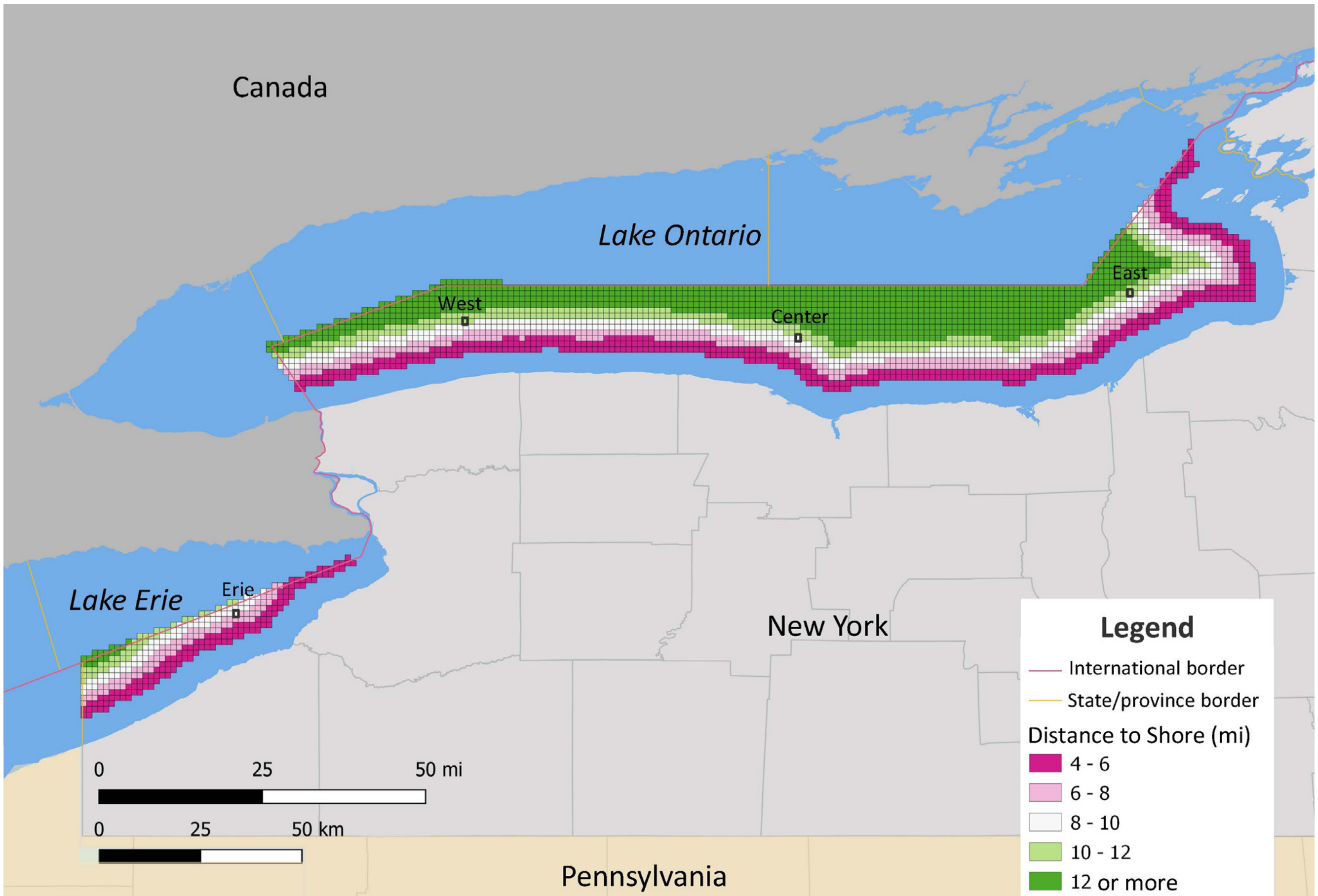
To provide detailed cost breakdowns and illustrate spatial variations in costs, four hypothetical reference locations were chosen: a central site in New York State's Lake Erie waters and three sites between 10 and 11 miles from the shoreline of Lake Ontario, spaced equidistantly east-to-west. Physical parameters of the locations are provided in Table 20 and locations are shown in Figure 26. These sites were chosen for cost reference only and do not represent any indication of site suitabity or site identification.

A wind plant layout with 6-MW turbines on a square grid, spaced 7 rotor diameters apart was assumed, consistent with recent NREL cost analyses (Shields, Duffy, et al. 2021; Musial, Duffy, et al. 2021; Beiter et al. 2020). For a 6-MW GE Cypress turbine with a rotor diameter of about 160 meters, the turbine spacing would be 1,120 meters. Full layout optimization for detailed site conditions is beyond the scope of this study but more optimal layouts would likely be possible.

Table 20. Physical Characteristics of Locations Used for Cost Component Breakdowns

Example Locations	Erie	Ontario West	Ontario Center	Ontario East
Distance from shore	9 miles (14 km)	11 miles (17 km)	10 miles (17 km)	11 miles (18 km)
Mean wind speed at 100 m[s]	20 mph (8.8 m/s)	19 mph (8.7 m/s)	20 mph (8.9 m/s)	20 mph (8.8 m/s)
Water depth	78 ft (24 m)	533 ft (162 m)	513 ft (156 m)	615 ft (187 m)
Distance to nearest port	26 miles (42 km)	57 miles (92 km)	16 miles (26 km)	11 miles (18 km)
Distance to nearest grid connection	11 miles (18 km)	11 miles (18 km)	29 miles (46 km)	12 miles (19 km)

Figure 26. Hypothetical Reference Locations for Cost Component Breakdowns



Grid connection costs include procurement and installation for export cables, cable landfall, and an onshore spur line from the point of cable landfall to the POI using the closest substations from among those identified in section 3.5.

For Lake Erie, installation is assumed to use custom Jones Act compliant vessels employing multiple barges. The day rate for a custom installation vessel is assumed to be higher than the combined day rate of existing barges to cover the cost of its assembly. The assumed day rates for tugs used to tow floating wind turbines or substations on Lake Ontario is the same as conventional ocean-going tugs. The cost analysis assumes that installation vessels are based out of the nearest port among the following options: Oswego, Rochester, and Buffalo, NY, and Erie, PA but the cost of port upgrades is not included in the LCOE. If a port can support multiple projects, the incremental increase in port fees during construction and operation can be reduced.

4.4 Annual Energy Production

Annual energy production (AEP) has one of the largest impacts on LCOE. Using the most recent wind resource data available, NREL estimated AEP for wind farms in Lakes Erie and Ontario with its ORCA and FLOw Redirection and Induction in Steady State (FLORIS) models (Beiter et al. 2016; NREL, 2019). The following loss categories are considered in the AEP calculation process:

- Wake losses for the 7D-by-7D plant and 6-MW turbine capacities modeled with FLORIS.
- Environmental losses including icing, temperature related shutdowns, and lightning.
- Technical losses including power curve hysteresis, onboard equipment power usage, and rotor misalignment.
- Electrical cable conductor losses.
- Availability losses.

As described in section 2.4.7, accumulation of ice on the blades could cause AEP losses for wind turbines without adaptations for cold weather. Therefore, a cold weather package with de-icing capability is included in the modeled costs. In addition, the analysis assumes energy losses stemming from reduced access to turbines in winter conditions, represented by a 1.4% increase in environmental losses and a 1% decrease in availability relative to Atlantic Ocean projects. These added costs are captured in the turbine CapEx.

The cost of operations and maintenance (O&M) is assumed to be impacted by ice conditions. Reduced accessibility during the winter months could increase downtime, although there are also opportunities to increase access using higher-cost O&M solutions (e.g., helicopter access). Therefore, an incremental increase in O&M costs of 15% was assumed relative to a similar ocean-based offshore wind plant.

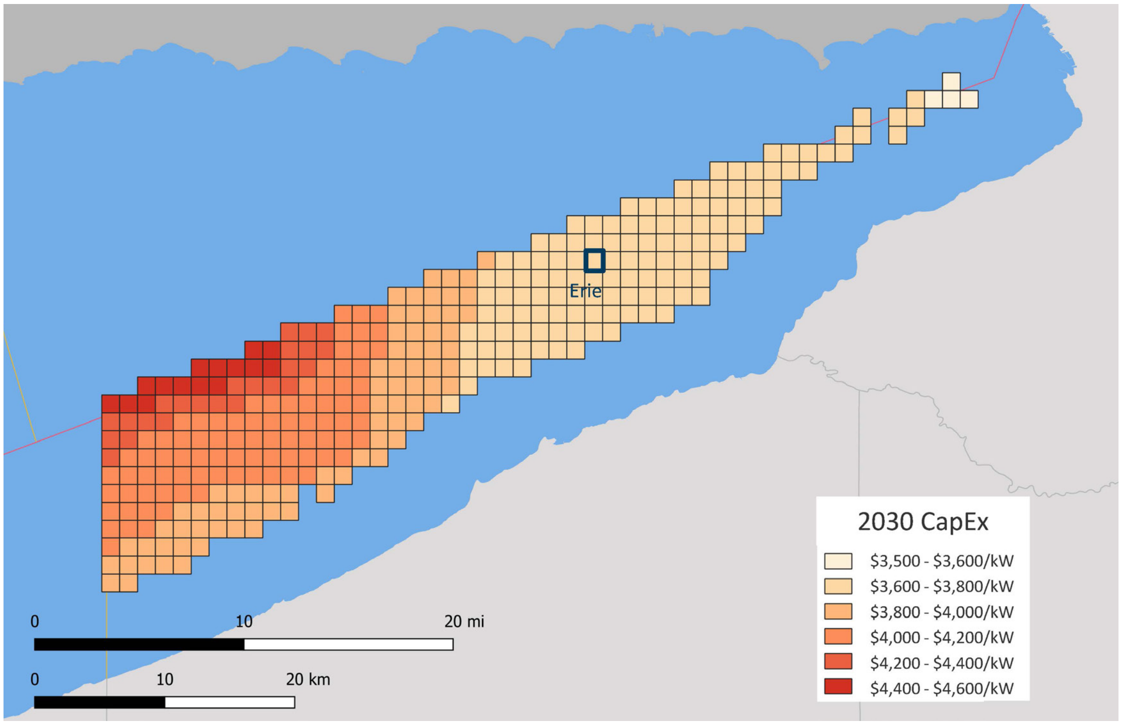
4.5 Results and Discussion

All costs are for GLW power plants with a total capacity of 400 MW and are presented in nominal 2021 dollars. This means effects from inflation are excluded from the COD year throughout the operational lifetime of the project. No assumption is made about the inflation rate between 2021 and the COD year. Cost and wind plant performance results are presented as heat maps depicting the spatial variation throughout the New York State portions of Lakes Erie and Ontario. Heat maps for CapEx, OpEx, and AEP, expressed in terms of net capacity factor (NCF), are presented for wind plants beginning operations in 2030. Modeled costs for wind power plants beginning operations in 2035 are lower but the geographic distribution remains proportional to the 2030 costs.

4.5.1 Capital Expenditures

Spatial variation in costs were calculated for fixed-bottom wind plants in State waters of Lake Erie (Figure 27). For wind plants beginning operations in 2030, CapEx varies from \$3,530/kW to \$4,540/kW with a median value of \$3,890/kW. The large range of cost variation reflects a high degree of correlation between several spatial parameters that affect costs: sites in deeper water also tend to be farther from shore, more distant from POIs to the electric grid, and farther from ports for installation and O&M. The cost model projects a 4% decrease in the average CapEx in Lake Erie between 2030 and 2035.

Figure 27. Modeled CapEx per kW in 2030 for a 400-MW Wind Power Plant in New York State Waters of Lake Erie with Fixed-Bottom Foundations
(A detailed CapEx breakdown is provided in Table 21 for the highlighted location.)



The spatial variation in floating wind plant CapEx was also calculated for the New York State waters of Lake Ontario (Figure 28). The range of CapEx in 2030 is between $3,930/kW and $4,340/kW with a median value of $4,140/kW. The higher capital costs reflect the more nascent stage of the floating industry. The largest contributor to the CapEx for floating wind plants is the substructure cost, which represents nearly a third of the total. Opportunities to reduce the cost of substructures include standardization of components, lowering weight, moving labor-intensive processes to quayside rather than on the lake, and increasing the scale of production and turbine scale. The cost model projects the average CapEx in Lake Ontario to decrease by 4.3% between 2030 and 2035. Details of the line items that contribute to CapEx variations between sites are provided in Table 21. Note all values are rounded to the nearest dollar.

Figure 28. Modeled CapEx per kW in 2030 for a 400-MW wind Power Plant in New York State Waters of Lake Ontario with Floating Substructures
(A detailed CapEx breakdown is provided in Table 21 for the marked locations)

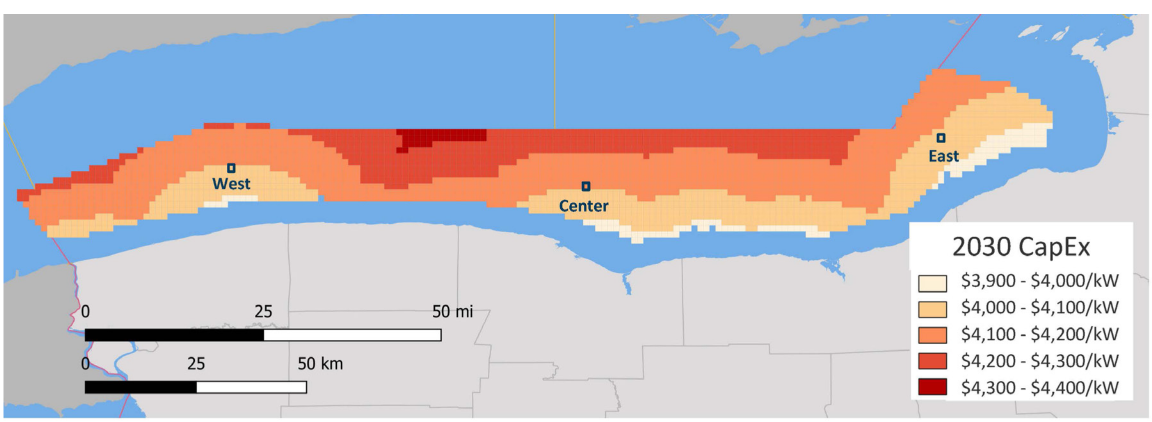


Table 21. Breakdown of CapEx Expressed as % of Total CapEx for 400 MW Plants

Line Item [values in % of Total CapEx]	Erie	Ontario West	Ontario Center	Ontario East
Tower	5%	4%	4%	4%
Rotor nacelle assembly	30%	26%	25%	26%
Turbine supply	**35%**	**30%**	**29%**	**30%**
Substructure	9%	32%	31%	32%
Transition piece	7%	N/A	N/A	N/A
Support structure	**17%**	**32%**	**31%**	**32%**
Port, staging, logistics, and fixed costs	2%	1%	1%	1%
Turbine installation	3%	2%	2%	2%
Substructure installation	4%	1%	1%	1%
Total installation	**9%**	**4%**	**4%**	**4%**
Array cabling	9%	6%	6%	6%
Export cable and offshore substation	7%	5%	9%	5%
Onshore spur line	1%	1%	1%	1%
Total electric system	**17%**	**12%**	**16%**	**12%**
Development	3%	3%	3%	3%
Lease price	4%	4%	4%	4%
Project management	2%	2%	2%	2%
Balance of system	**51%**	**57%**	**59%**	**57%**
Insurance during construction	1%	1%	1%	1%
Project completion	1%	1%	1%	1%
Decommissioning	1%	1%	0%	0%
Procurement contingency	5%	5%	5%	5%
Installation contingency	2%	1%	1%	1%
Construction financing	4%	4%	4%	4%
Total soft CapEx	**14%**	**13%**	**12%**	**12%**
Total CapEx in 2030 [$/kW]	**3,727**	**4,090**	**4,104**	**4,078**
Total CapEx in 2035 [$/kW]	**3,576**	**3,914**	**3,929**	**3,903**

4.5.2 Operational Expenses

Operational expenditures include the ongoing costs of managing operations, carrying out regular maintenance, and repairing or replacing components as needed. A wind plant's proximity to a port that serves as its operations base is the primary geospatial factor affecting OpEx, although factors such as wave height and ice cover that affect accessibility also have an impact. OpEx projections for a 400-MW wind plant were calculated for Lake Erie and Lake Ontario (Figures 29 and 30, respectively; hypothetical locations in Table 22).

Figure 29. Modeled Annual OpEx per kW in 2030 for a 400-MW Wind Power Plant in New York State Waters of Lake Erie with Fixed-Bottom Foundations
(OpEx is provided in Table 22 for the location highlighted in yellow)

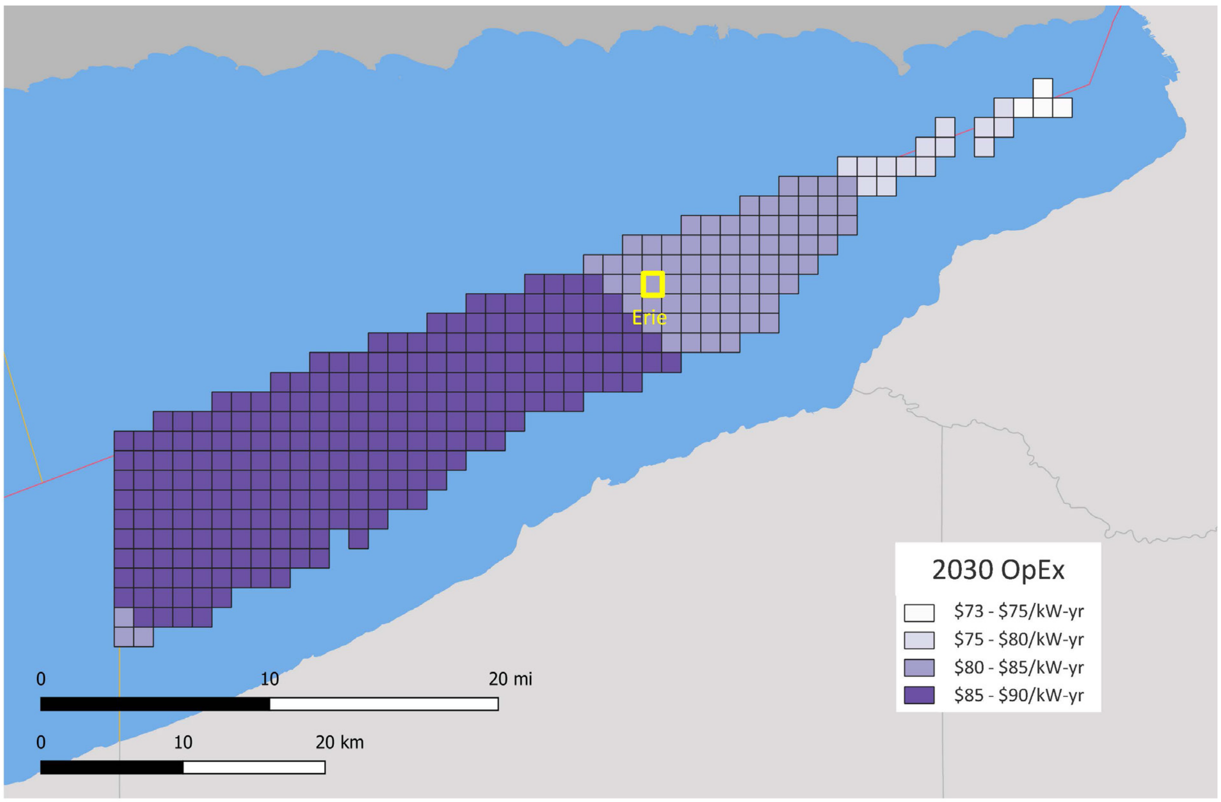


Figure 30. Modeled Annual OpEx per kW in 2030 for a 400-MW Wind Power Plant in New York State Waters of Lake Ontario with Floating Substructures
(OpEx is provided in Table 22 for the locations highlighted in yellow)

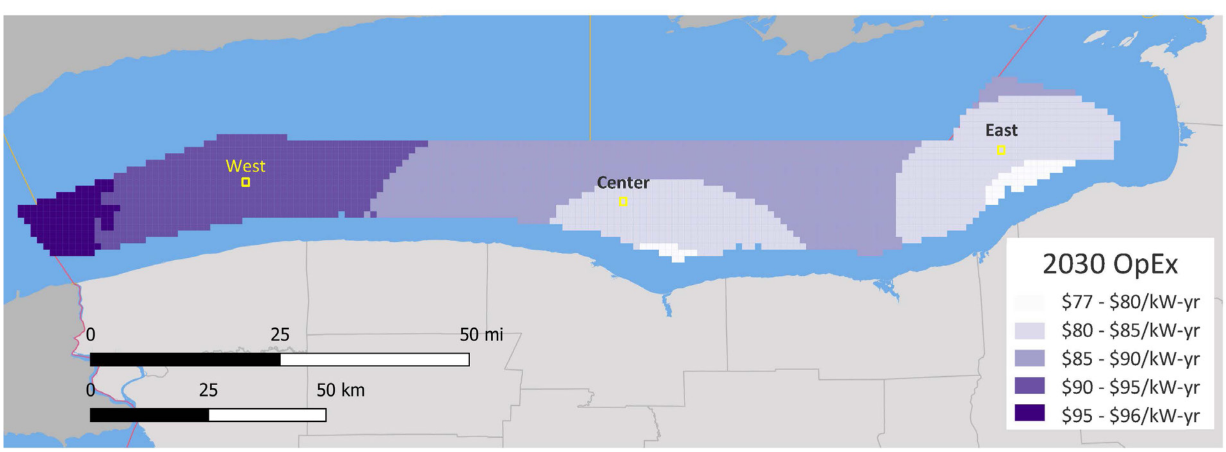


Table 22. Modeled OpEx for 400-MW Wind Power Plants at Example Locations

Values expressed as [$/kW-yr]	Erie	Ontario West	Ontario Center	Ontario East
2030 OpEx	85	93	84	82
2035 OpEx	78	89	80	78

For 400-MW wind plants beginning operations in 2030, annual OpEx varies from $73/kW to $91/kW in Lake Erie with a median value of $86/kW. On Lake Ontario, the range of OpEx is between $77/kW and $96/kW with a median of $87/kW. Annual OpEx is modeled to decrease to median values of $79/kW on Lake Erie and $83/kW on Lake Ontario for wind power plants beginning operations in 2035. This decrease is based on projected global learning curves for offshore wind plant OpEx (Wiser, Rand et al 2021). Differences between fixed-bottom and floating maintenance costs are driven by O&M strategies analyzed by Beiter et al. (2016) for mild wave climates similar to those found in the Great Lakes.

4.5.3 Annual Energy Production

AEP has the largest impact on LCOE, but this varies in space with the wind resource. Modeled net capacity factor (NCF) was calculated from AEP normalized by the theoretical maximum annual generation of the plants in Lakes Erie and Ontario (Figures 31 and 32, respectively; example locations in Table 23). The minimum NCF on either lake is 41%, with maximum values of 44.0% on Lake Erie and 45.6% on Lake Ontario, which is in line with projects in the Atlantic Ocean.

Figure 31. Modeled Net Capacity Factor in 2030 of a 400-MW Wind Power Plant in New York State Waters of Lake Erie (NCF is provided in Table 23 for the location highlighted in red)

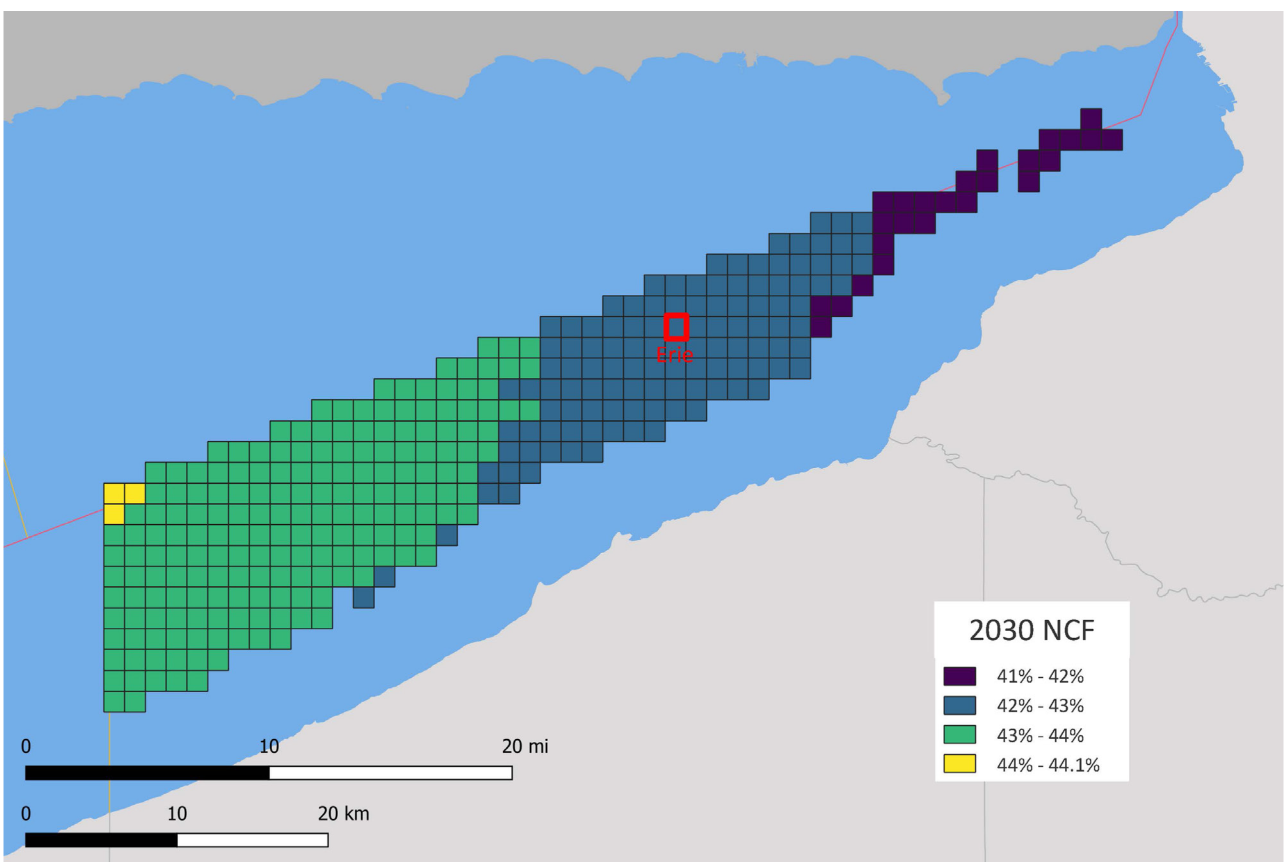


Figure 32. Modeled Net Capacity Factor in 2030 of a 400-MW Wind Power Plant in New York State Waters of Lake Ontario (NCF is provided in Table 23 for the locations highlighted in red)

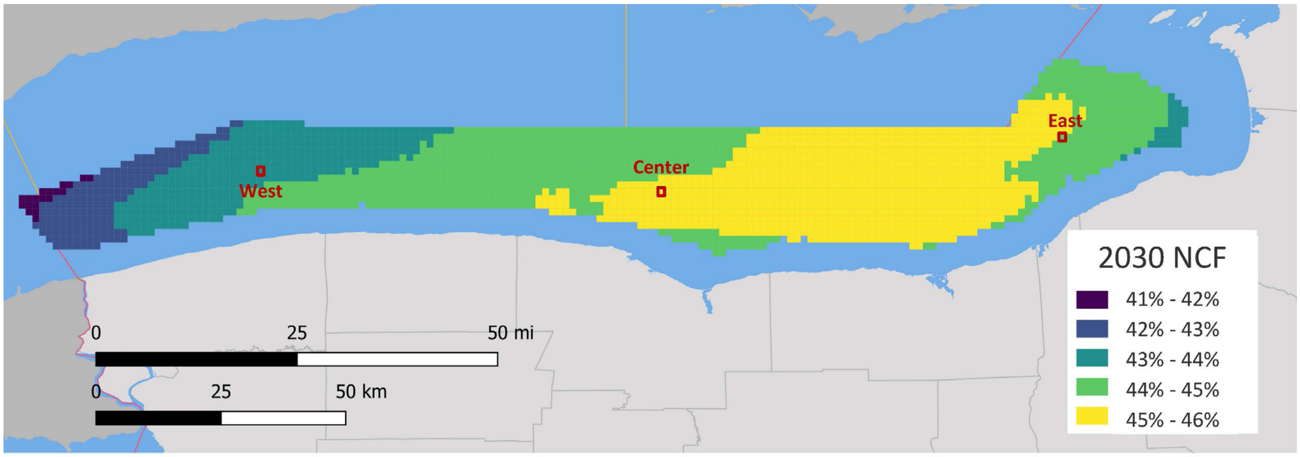


Table 23. Net Capacity Factors at Example Locations

	Erie	Ontario West	Ontario Center	Ontario East
2030 NCF	42.5%	43.6%	45.2%	45.0%
2035 NCF	43.4%	45.0%	46.7%	46.4%

4.5.4 Levelized Cost of Energy

LCOE values for wind power plants on the Great Lakes incorporate the CapEx, OpEx, and NCF presented in the previous sections. Modeled LCOE for Lakes Erie and Ontario are mapped (Figures 33 and 34), with LCOEs at specific locations provided (Table 24). For wind plants beginning operations in 2030, LCOEs range from $96/MWh to $118/MWh with a median value of $105/MWh in Lake Erie and between $97/MWh and $115/MWh with a median value of $103/MWh in Lake Ontario. The lowest LCOEs, below $100/MWh, are toward the eastern end of each lake. These areas are close to ports and grid connection opportunities near Buffalo and Oswego and in Lake Erie are in shallower waters. In both lakes, LCOEs tend to increase as wind power plants are sited toward the western end of the analysis region and farther from shore. By 2035, the median LCOE decreases to $98/MWh in Lake Erie and $96/MWh in Lake Ontario.

Figure 33. Modeled LCOE in 2030 for a 400-MW Wind Power Plant in New York State Waters of Lake Erie with Fixed-Bottom Foundations
(LCOE is provided in Table 24 for the location highlighted in yellow)

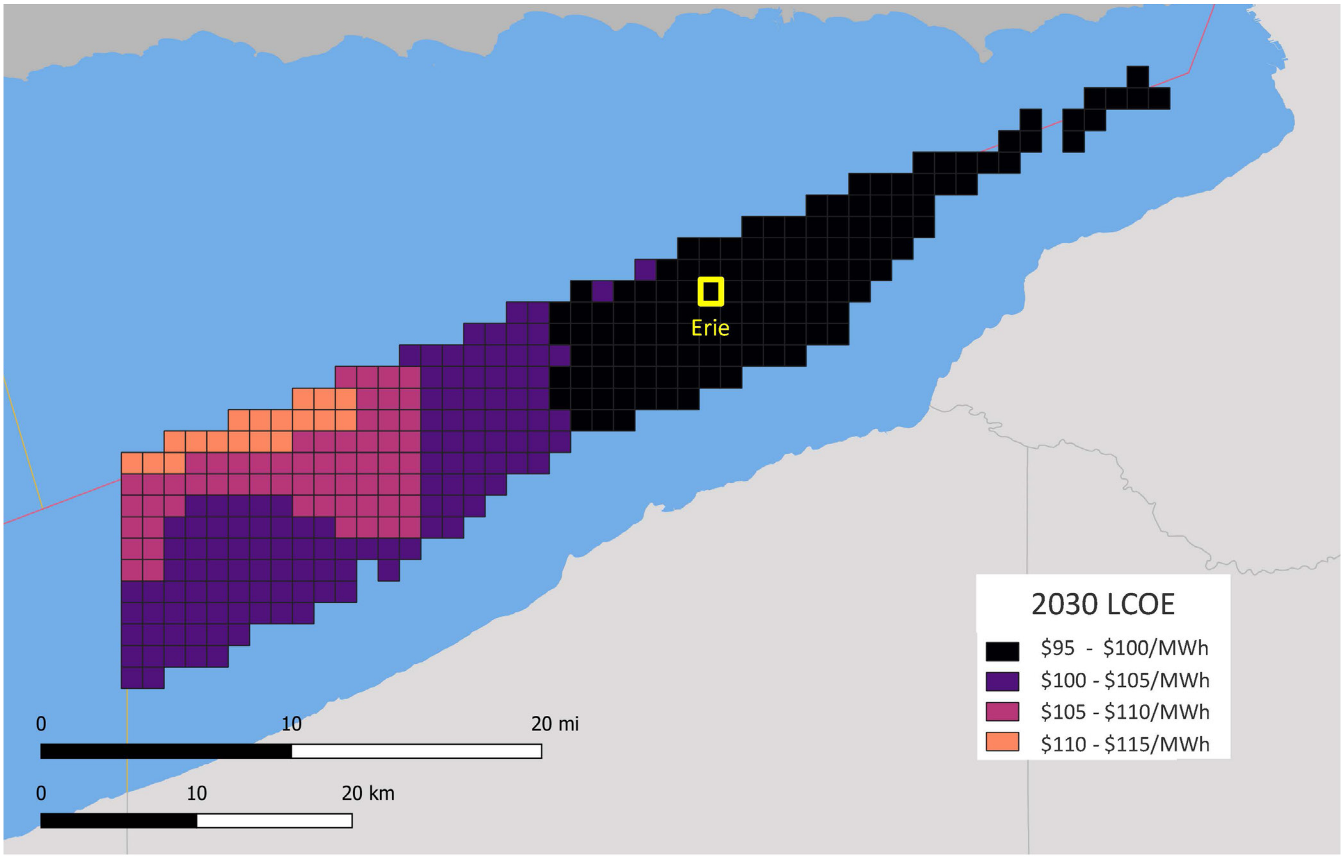


Figure 34. Modeled LCOE in 2030 for a 400-MW Wind Power Plant in New York State Waters of Lake Ontario with Floating Substructures
(LCOE is provided in Table 24 for the locations highlighted in yellow)

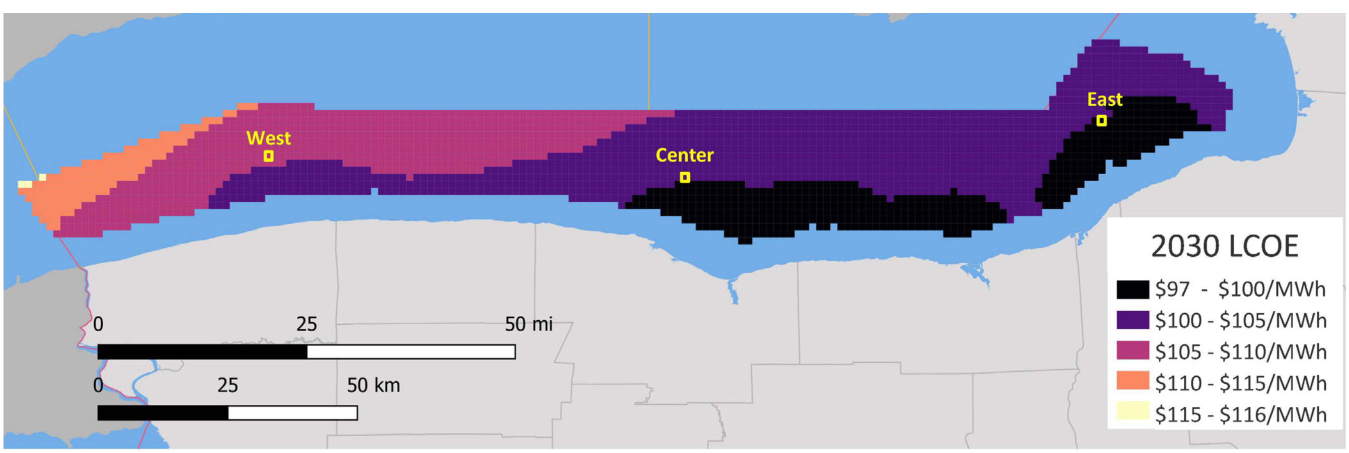


Table 24. Modeled LCOE in 2030 and 2035 for 400-MW Wind Power Plants

	Erie	Ontario West	Ontario Center	Ontario East
2030 LCOE	$99/MWh	$106/MWh	$100/MWh	$100/MWh
2035 LCOE	$92/MWh	$98/MWh	$93/MWh	$93/MWh

4.6 Impacts from Plant Capacity

Alternate scenarios of a 100-MW plant in Lake Erie and an 800-MW plant in Lake Ontario were considered to assess the sensitivity of cost to plant size. The analysis showed a steep increase of between 51% to 55% in LCOE between a 400 MW plant and a 100 MW plant, but the cost decrease going up from 400 MW to 800 MW was only about 2% across the Lake Ontario study area (Table 25).

The study also found that if the regional market size increases, individual project costs can be reduced by sharing infrastructure, ports, specialized vessels, and workforce development. Even though these impacts are not included in the LCOE model, the development of these local supply chains can greatly add to the economies of scale.

Table 25. LCOE for a 100-MW Wind Power Plant on Lake Erie and 800-MW Plants on Lake Ontario

	Erie	Ontario West	Ontario Center	Ontario East
Plant Capacity	100 MW	800 MW	800 MW	800 MW
2030 LCOE	$152/MWh	$104/MWh	$98/MWh	$98/MWh
% Change from 400-MW plant	+53%	-1.8%	-1.9%	-1.8%

4.7 Opportunities to Further Reduce Cost

The cost analysis presented provides a baseline for assessing the cost of wind energy generation in the NY portions of Lakes Erie and Ontario based on current industry conditions. Therefore, the assumptions were generally conservative because they do not account for technology advancements. In the future, developers and the State of New York will likely find innovative technology solutions. Some areas that could result in cost reductions include the following:

- **Larger turbines:** The 6-MW turbine is based on conservative estimates of available crane capacity. This is not a hard limit, and especially for Lake Ontario, larger turbines are feasible and would reduce project costs.
- **Lower specific power rotors:** The 6-MW power curve used in this analysis has a specific power of 320 watts/m^2 which is probably higher than the optimum specific power for this region. A larger rotor would be more optimal given the lower extreme wind and would increase NCF.
- **Larger plant size:** A larger plant size closer to 1 GW (in line with Atlantic offshore wind projects) would lower total project cost per unit of energy.
- **Substructure costs:** Floating substructures make up a large part of the CapEx but no optimization for mass production was assumed. Current designs are seeking greater cost efficiency and future CapEx reductions for substructures is expected.
- **Regional collaboration with other states and Canada:** Leveraging regional infrastructure outside New York State to achieve a larger industrial scale and to access ports, vessels, infrastructure, and facilities could yield substantial savings.
- **Supply chain synergies, industrialization, and economies of scale:** If GLW technology evolves similarly in scale to the booming offshore industry along the Eastern seaboard, additional supply chain and labor force overlaps could enable GLW to leverage the multi-billion-dollar investments being made in the Atlantic region.
- **Innovations to improve accessibility and maintenance in winter months:** If the industry matures in the Great Lakes, the cost to operate and maintain turbines in freshwater ice will decrease further. This study assumes currently available OpEx technology, but further cost savings may be possible with new solutions customized for the lake environment.
- **Proximity to grid:** Proximity to retiring thermal electric plants in the Great Lakes region and the high-population load centers provide a relatively high number of interconnection options that could lower interconnection costs relative to other regions.
- **State Policy and Incentives:** NYS policy has driven the market for offshore wind in the Atlantic and made the State the U.S. leader in offshore wind. Additional targeted State policy could accelerate the maturity of GLW. Incentives such as grant funding for port development could stimulate growth of local economies and provide the infrastructure necessary for GLW.

There are also factors that could result in higher costs. One key assumption is that wind plants are developed at commercial scale and these future costs are derived from strike prices on projects that have not been built yet. These future costs therefore are based on a high degree of uncertainty and speculation.


Photo Credit: Getty Images

5 Economic Development and Workforce Opportunities

5.1 Introduction

This analysis provides an assessment of economic development and workforce opportunities for a 400-MW wind energy project in either Lake Erie or Lake Ontario using NREL's Offshore Jobs and Economic Development Impact (JEDI) model (release 2021–2022). A 400-MW wind energy project was selected as this plant capacity could be installed in Lake Erie and Lake Ontario. Although this size is relatively small, it enables cost and job estimate comparisons between both lakes because Lake Erie may not be able support a project of much larger size. JEDI estimates the gross jobs and economic impacts from constructing and operating power generation at the local and State levels (e.g., Tegen et al., 2015).

This study analyzed two different State content scenarios (e.g., the utilization of labor, components, subcomponents, materials, vessels, and ports from within New York State) customized for this project.[21]

The first scenario, base case, is a more likely State content scenario, assuming some content coming outside the State but with an increase in New York labor, vessel, and component fabrication and installation near both lakes.

The second scenario was more aggressive, assuming 100% NYS content. ***Details about content assumptions for each each industry segment are provided in the 22-12h Economic Development and Workforce Opportunities.*** JEDI estimates the direct, indirect, and induced impacts with 2019 IMPLAN economic data for NYS.[22] Jobs, gross domestic product (GDP), earnings, and gross output are the primary economic metrics for each of the five segments. Jobs are expressed as full-time equivalents (FTE), with one job equal to one person working 40 hours per week for an entire year, or 2,080 hours. GDP is the value of the industry's production. Earnings are defined as any type of income resulting from work. Gross output is the total amount of economic activity that occurs within the State. The precise location of a wind project in Lake Ontario or Lake Erie does not affect the JEDI model results.

Primary inputs for JEDI are the project-based CapEx and OpEx values from section 4.5.1 and 4.5.2 respectively. Results were determined for a fixed-bottom Lake Erie project beginning operations in 2030, and for a floating wind Lake Ontario project beginning operations in 2035.

There are additional induced impacts during the construction and operations phase which are spurred from additional spending in the region by workers who spend their earnings and cause other money to circulate within in the economy. ***A detailed list of caveats, limitations, and sensitivities for the analysis are contained in 22-12h Economic Development and Workforce Opportunities.***

Workers spend earnings and cause other money to circulate within the economy.

Jobs and Economic Development Impact models (JEDI) requires a detailed cost breakdown to attribute costs to different economic industry segments. The jobs and related expenditures were determined for five industry segments. These segments are defined as follows:

- Development activities beginning three years prior to the installation through COD.
- Manufacturing and supply chain including production of GLW equipment and components, spread across two years.[23]
- Installation: ports and staging relate to operation of the port and leasing of the port for assembly or installation activities starting two years before COD.[24]
- Installation: vessels include installation of foundations/substructures, wind turbines (e.g., nacelles, blades, towers), substations, scour protection, array cables and export cables. The fixed-bottom strategy assumes components are transported onto the lake by vessel and installed with a crane. The floating strategy assumes the fully assembled components are towed into the lake from a port, and smaller vessels position the turbine and install mooring lines.
- Operation and maintenance (O&M) for the wind plant, including labor, spare parts, operating facilities, and environmental, health, and safety monitoring. Estimates in this analysis were reported on an annual basis for the life of the project which is typically 25 years.

For the base case impact scenario, the assumptions for the breakdown of local content within the State by industry sector are shown in Table 26.

Photo Credit: Deepwater Wind

Table 26. Base Case State Content Assumptions for New York State

	Local Content (%)	
Local	**Lake Erie (2030 COD)**	**Lake Ontario (2035 COD)**
Development		
Engineering and Management, Legal	75	75
Financial	75	75
Manufacturing and Supply Chain		
Nacelle	15	15
Blades	50	50
Tower	75	75
Fixed Bottom (Substructure)	75	-
Fixed Bottom (Scour Protection)	100	-
Floating (Substructure)	-	75
Floating (Mooring)	-	50
Substation (Topside)	50	50
Substation (Substructure)	100	100
Array Cable	15	15
Export Cable	15	15
Installation (Vessel)		
Turbine	100	100
Fixed Bottom (Substructure)	100	100
Scour Protection	100	100
Substation	100	100
Cable	100	100
All Vessels (Indirect)	50	50
Installation (Ports)		
Ports and Staging	100	100
Operations and Maintenance		
Vessel Crew	100	100
Wind Technicians	100	100
Onshore Operations	100	100
Indirect	75	75

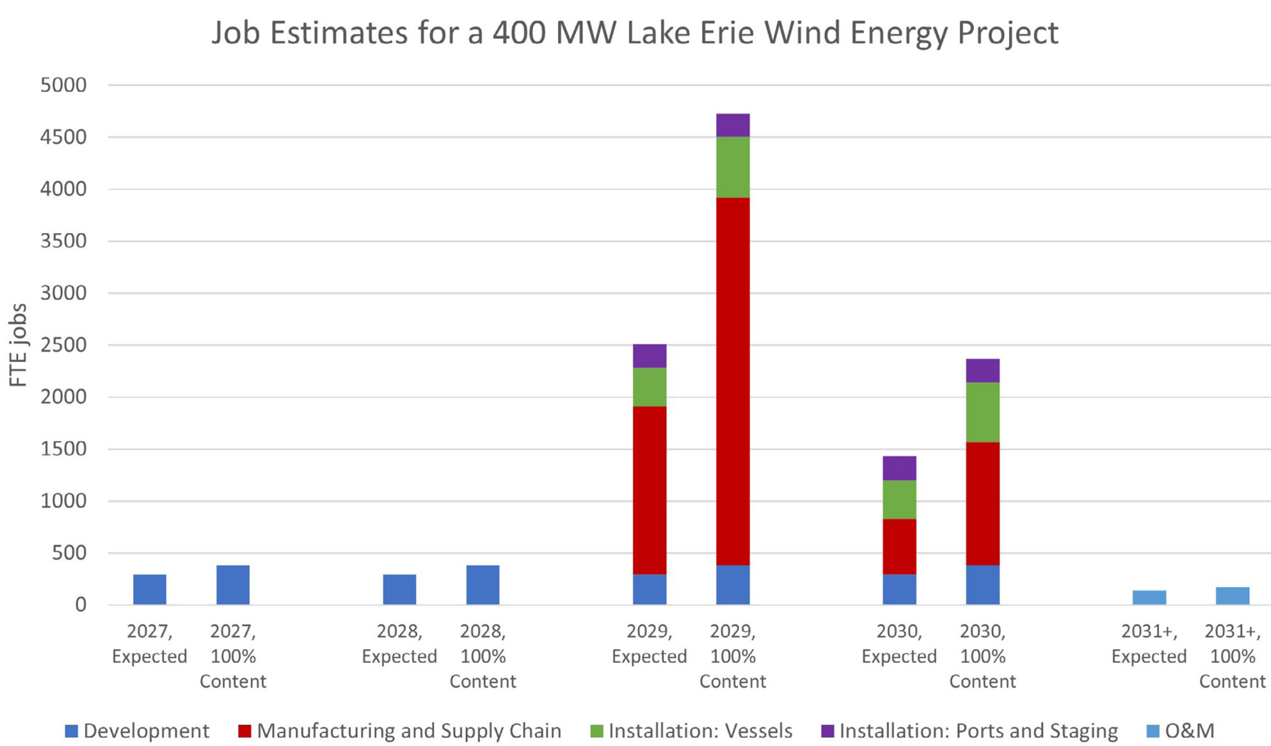
Similarly, for the 100% State content scenario, all labor, components, subcomponents, materials, vessels, and ports shown in Table 26 were assumed to be in-State. The 100% State content scenario represents the maximum possible number of jobs and economic impact that could be supported by a GLW project in New York.

5.2 Lake Erie Results

The JEDI model results indicate that the development of a 400-MW Lake Erie wind energy project in NYS could support 4,100 FTE job years and generate $590 million in GDP across the State during the construction phase when incorporating assumptions for the base case impact State content scenario. The potential exists to support up to 7,900 FTE job years and $1.1 billion in GDP if 100% of the project content come from New York State. The project would also create additional jobs from induced impacts (Table 27). The timing of jobs was determined and spread across years (2027, 2028, 2029, 2030, and 2030+) for the workers completing tasks for each of the industry segments for the base case State content and 100% State content scenarios (Figure 35).

Manufacturing and supply chain represent the largest job and economic contribution, followed by development and installation activities related to vessels and ports.

Figure 35. Total Number of Jobs Each Year during the Construction Phase for a 400-MW Lake Erie Wind Energy Project



For base case State content—projected impact—and 100% State content—maximum potential impact.

For the construction phase, total job and economic impacts were determined for a Lake Erie project for the base case State content and 100% State content scenarios (Table 27). Manufacturing and supply chain represent the largest job and economic contribution, followed by development and installation activities related to vessels and ports.

Table 27. Summary of FTE Job Years and Economic Impacts During Construction Phase for Base Case State Content and (100% State Content) for a 400-MW Lake Erie Wind Energy Project

Category	FTE Job Year	Value Added, $ millions	Earnings, $ millions	Output, $ millions
Development	**1154 (1539)**	**248.8 (331.7)**	**204.0 (272)**	**408.3 (544.4)**
Engineering and Management, Legal	681 (908)	101.1 (134.8)	100.8 (134.4)	204.2 (272.2)
Financial	473 (631)	147.7 (196.9)	103.2 (137.6)	204.2 (272.2)
Manufacturing and Supply Chain	**2162 (4719)**	**250.7 (551.8)**	**155.3 (349.7)**	**591.7 (1340.1)**
Nacelle	258 (1718)	30.6 (204.2)	20.5 (136.4)	77.1 (514.1)
Blades	216 (432)	29.5 (59)	14.7 (29.4)	59.2 (118.3)
Tower	445 (593)	52.4 (69.8)	31.2 (41.6)	114.5 (152.6)
Fixed Bottom (Substructure)	916 (1221)	99.8 (133)	66.8 (89)	257.8 (343.7)
Fixed Bottom (Scour Protection)	32 (32)	5.2 (5.2)	2.3 (2.3)	10.8 (10.8)
Substation (Topside)	142 (284)	16.7 (33.4)	8.4 (6.7)	25.3 (50.6)
Substation (Substructure)	103 (103)	11.2 (11.2)	7.5 (7.5)	29.0 (29)
Array Cable	18 (121)	2.0 (13)	1.5 (9.7)	6.5 (43.6)
Export Cable	32 (215)	3.5 (23)	2.6 (17.1)	11.6 (77.4)
Installation (Vessel)	**748 (1156)**	**101.9 (161.1)**	**71.9 (101.1)**	**186.6 (330.5)**
Turbine	140 (140)	13.6 (13.6)	13.6 (13.6)	13.6 (13.6)
Fixed Bottom (Substructure)	90 (90)	8.9 (8.9)	8.9 (8.9)	8.9 (8.9)
Scour Protection	47 (47)	7.8 (7.8)	7.8 (7.8)	7.8 (7.8)
Substation	3 (3)	0.5 (0.5)	0.5 (0.5)	0.5 (0.5)
Cable	60 (60)	11.9 (11.9)	11.9 (11.9)	11.9 (11.9)
All Vessels (Indirect)	408 (816)	59.2 (118.4)	29.2 (58.4)	143.9 (287.8)
Installation (Ports)	**453 (453)**	**31.3 (31.3)**	**28.6 (28.6)**	**55.0 (55.0)**
Ports and Staging	453 (453)	31.3 (31.3)	28.6 (28.6)	55.0 (55.0)
Direct and Indirect Total	**4137 (7867)**	**592.2 (1075.9)**	**432.3 (751.4)**	**1139.3 (2270)**
Induced	1706 (2544)	209.6 (313.0)	105.1 (157.8)	326.7 (487.3)
All Total	5843 (10411)	801.8 (1388.9)	537.4 (909.2)	1466 (2757.3)

a FTE = full-time equivalent

For the operation phase, total jobs and economic impacts were also determined for a 400-MW Lake Erie project for the base case State content and 100% State content scenarios during the lifetime of the project (Table 28). An estimated 140 to 170 FTE job years could be supported for each year the project is operating. The project could also support $20 to $26 million in GDP for each year of operation. The vessel crew, wind technicians, and onshore operations are jobs directly related to supporting the wind energy project. The indirect impacts estimates are related to replacing parts, supplying materials, and operation logistics. The project would also create additional jobs from induced impacts on an annual basis.

Table 28. Summary of FTE Job Years and Economic Impacts during Operation Phase for Base Case State Content and 100% State Content Scenarios
(For a 400-MW Lake Erie Wind Energy Project)

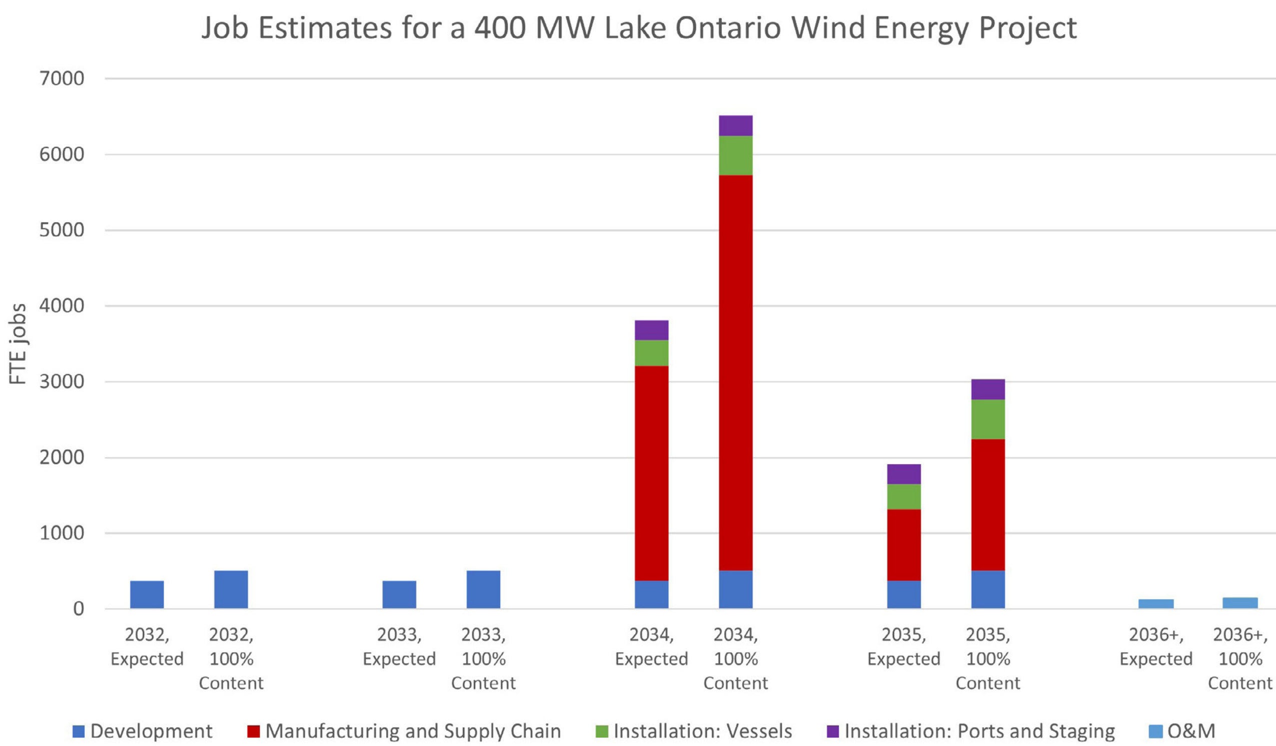
Category	FTE Job Year, annually	Value Added, $ millions, annually	Earnings, $ millions, annually	Output, $ millions, annually
Vessel Crew	4 (4)	0.3 (0.3)	0.3 (0.3)	0.3 (0.3)
Wind Technicians	32 (32)	2.1 (2.1)	2.1 (2.1)	2.1 (2.1)
Onshore Operations	11 (11)	1.1 (1.1)	1.1 (1.1)	1.1 (1.1)
Indirect	94 (125)	16.9 (22.5)	10.4 (13.8)	33.8 (45)
Direct and Indirect Total	**141 (172)**	**20.4 (26.0)**	**13.9 (17.3)**	**37.3 (48.5)**
Induced	46 (61.9)	5.7 (7.6)	3.1 (4.1)	8.9 (11.8)
All Total	**187 (233.9)**	**26.1 (33.6)**	**17.0 (21.4)**	**46.2 (60.3)**

a FTE = full-time equivalent

5.3 Lake Ontario Results

The development of a 400-MW Lake Ontario wind energy project in New York State could support 6,900 FTE job years and generate $960 million in GDP across the State during the construction phase when incorporating assumptions for the base case State content scenario, with the potential to support up to 10,500 FTE job years and $1.5 billion in GDP for the 100% State content scenario. The project would also support additional induced impacts (Table 29). Figure 36 shows the timing of jobs spread across years for the workers completing tasks for each of the industry segments for the projected State content and 100% State content scenarios. Manufacturing and supply chain represent the largest job and economic contribution, followed by development and installation activities related to vessels and ports.

Figure 36. Total Number of Jobs Each Year during the Construction Phase for a 400-MW Lake Ontario Wind Energy Project for Base Case State Content and 100% State Content



During the construction phase, Table 29 breaks down the total job and economic impacts for Lake Ontario (floating technology) for the base case State content and 100% State content scenarios. The estimates are broken out into four industry segments during the construction phase as well as a detailed assessment at the subcomponent level.

Floating substructures likely have a higher labor component due to a more intensive process to manufacture at quayside. Therefore, floating substructures are currently more costly than fixed bottom substructures. For example, if you consider assumptions that some floating designs such as the TetraSpar require more bolting and less welding as well as assembling the turbine onto the substructure, these tasks to assemble may require more labor at quayside but can avoid more expensive labor on the Lake. Production of these substructures may also be the greatest economic opportunity in developing the NYS supply chain for GLW.

Table 29. Summary of FTE Job Years and Economic Impacts During Construction Phase for Base Case State Content and (100% State Content) for a 400-MW Lake Ontario Wind Energy Project

Category	FTE Job Years	Value Added, $ millions	Earnings, $ millions	Output, $ millions
Development	**1502 (2002)**	**341.6 (455.4)**	**303.5**	**531.6**
Engineering and Management, Legal	793 (1057)	100.7 (134.2)	103.9	152.1
Financial	709 (945)	240.9 (321.2)	199.7	379.5
Manufacturing and Supply Chain	**3785 (6971)**	**433.9 (811.3)**	**273.4**	**1062.0**
Nacelle	258 (1718)	30.6 (204.2)	20.5	77.1
Blades	216 (432)	29.5 (59)	14.7	59.2
Tower	445 (593)	52.4 (69.8)	31.2	114.5
Floating (Substructure)	2396 (3194)	260.9 (347.8)	174.5	674.3
Floating (Mooring)	187 (373)	28.2 (56.3)	13.5	67.8
Substation (Topside)	142 (284)	16.7 (33.4)	8.4	25.3
Substation (Substructure)	101 (101)	11.3 (11.3)	7.4	29.1
Array Cable	25 (165)	2.6 (17.6)	2.0	8.9
Export Cable	17 (111)	1.8 (11.9)	1.3	6.0
Installation (Vessel)	**660 (1043)**	**88.5 (144.1)**	**60.4 (87.8)**	**168.1 (303.3)**
Turbine, Floating (Substructure)	92 (92)	12.5 (12.5)	12.5 (12.5)	12.5 (12.5)
Mooring Lines	112 (112)	12.2 (12.2)	12.2 (12.2)	12.2 (12.2)
Substation	3 (3)	0.4 (0.4)	0.4 (0.4)	0.4 (0.4)
Cables	70 (70)	7.8 (7.8)	7.8 (7.8)	7.8 (7.8)
All Vessels (Indirect)	383 (766)	55.6 (111.2)	27.5 (54.9)	135.2 (270.4)
Installation (Ports)	**532 (532)**	**44.7 (44.7)**	**36.8 (36.8)**	**79.3 (79.3)**
Ports and Staging	532 (532)	44.7 (44.7)	36.8 (36.8)	79.3 (79.3)
Direct and Indirect Total	**6861 (10548)**	**964.3 (1455.5)**	**701.5 (1042.4)**	**1976.2 (3089.9)**
Induced	2196 (3218)	269.8 (395.7)	135.2 (198.9)	420.6 (616.3)
All Total	**9057 (13766)**	**1234.1 (1851.2)**	**836.7 (1241.3)**	**2396.8 (3706.2)**

a FTE = full-time equivalent

During the operations phase, Table 31 shows the job and economic impacts of a Lake Ontario (floating technology) project for the base case State content and 100% State content scenarios during the lifetime of the project. An estimated 120 FTE job years could be supported annually with the potential to support up to 150 FTE job years annually. Operating a Lake Ontario wind energy project could support an added value of $17 million in GDP annually, with the potential to support $21 million in GDP annually. The vessel crew, wind technicians, and onshore operations are jobs directly related to supporting the wind energy project. The indirect impacts estimates are related to replacing parts, supplying materials, and operation logistics. The project would also support additional induced impacts on an annual basis.

Table 30. Summary of FTE Job Years and Economic Impacts during Operation Phase for Base Case State Content and (100% State Content) Scenarios for a 400-MW Lake Ontario Wind Energy Project
Results are annually and ongoing over the lifetime of the wind energy plant.

Category	FTE Job Years, annually	Value Added, $ millions, annually	Earnings, $ millions, annually	Output, $ millions, annually
Vessel Crew	4 (4)	0.3 (0.3)	0.3 (0.3)	0.3 (0.3)
Wind Technicians	32 (32)	2.1 (2.1)	2.1 (2.1)	2.1 (2.1)
Onshore Operations	11 (11)	1.1 (1.1)	1.1 (1.1)	1.1 (1.1)
Indirect	74 (98)	13.1 (17.5)	8.0 (10.7)	26.3 (35.1)
Direct and Indirect Total	**121 (145)**	**16.6 (21)**	**11.5 (14.2)**	**29.8 (38.6)**
Induced	36 (48)	4.5 (5.9)	2.4 (3.2)	6.9 (9.2)
All Total	**157 (193)**	**21.1 (26.9)**	**13.9 (17.4)**	**36.7 (47.8)**

a FTE = full-time equivalent

The magnitude and alignment of FTE jobs estimates for GLW are similar to a NYSERDA study which estimated an annual FTE employment of 350 workers for project management and development, 470 workers for installation and commissioning, and 2,250 manufacturing workers during an annual construction phase to meet a market scenario of 2.4 GW of New York State offshore wind capacity by 2030 (NYSERDA, 2017).

Unions have also played a large role in supplying trained labor to support construction, ports, and vessels. Partnerships and collaboration among government, industry, academic institutions, and unions is key to addressing GLW energy workforce needs efficiently and effectively—ensuring a higher rate of local labor, while also ensuring the local labor is qualified with the necessary skills to obtain and retain jobs.[25]


Photo Credit: Getty Images

6 Federal, State, and Utility Permitting Roadmap and Assessment

A Permitting and Regulatory Review and Roadmap study (Permitting Study) was prepared to support assessment of GLW feasibility (22-12k). The Permitting Study focused on permitting of construction and operation of wind farms and underwater cables. Other activities that may require permits (not described here) include port development and pre-development studies and surveys, such as metocean and environmental data collection and geophysical surveys. Pre-construction geophysical and geotechnical surveys may be covered under U.S. Army Corps of Engineers (USACE) Nationwide

Permit 6, which would undergo New York Department of State (NYSDOS) review. Permits may also be required from New York Stated Department of Environmental Conservation (NYSDEC) to conduct geophysical and geotechnical surveys. Below the outcomes of the Permitting Study are summarized, and ***the full study is available in 22-12k Federal, State, and Utility Permitting Roadmap and Study.***

6.1 Federal, State, and Utility Permitting Assessment

6.1.1 Applicable Authorizations and Review Processes

There are 15 major federal and state permitting or regulatory requirements for New York GLW. The federal processes for GLW are largely driven by or tied to the National Environmental Policy Act (NEPA) review process which is likely to be triggered by issuance of a permit by USACE and involve consultations and review by the U.S. Fish and Wildlife Service (USFWS), State and Tribal Historic Preservation Offices (SHPO/THPO), U.S. Coast Guard (USCG), and Federal Aviation Administration (FAA).

At the New York State level, regulatory permitting and reviews can vary depending upon windfarm size. Windfarms with nameplate capacity of 25 megawatts (MW) and above are designated major renewable energy projects under the NYS law (Section 94-c of New York State Executive Law), and therefore, undergo a process under the Accelerated Renewable Energy Growth and Community Benefit Act, administered by the Office of Renewable Energy Siting (ORES). Projects with nameplate capacity of at least 20 MW and less than 25 MW may “opt-in” to undergo 94-c permitting. Projects including major utility transmission facilities, which are defined to include electric transmission lines of length one mile or longer and capacity of 125 kV or more, or lines 10 miles or longer with capacity of 100 kV or more, are subject to Article VII of New York State Public Service Law. Under Article VII, the Public Service Commission (NYSPSC) would control required approvals (e.g., wetlands and coastal erosion permitting if applicable) except for those permits issued under federally delegated or pursuant to federally approved environmental permitting programs or federal consistency review pursuant to the federal Coastal Zone Management Act (CZMA). Although Article VII preempts all State and local permits and approvals that are not federally delegated for transmission infrastructure, the project must meet the requirements of the relevant State and local permits and approvals.

Projects below the thresholds described above for 94-c may be subject to State Environmental Quality Review Act (SEQRA) and several permits from the New York State Department of Environmental Conservation (NYSDEC). An easement must be obtained by the developer for the NYS submerged lands upon which a GLW project would be built from the New York State Office of General Services (NYSOGS). The transmission cables would also require an easement by the developer for the NYS submerged lands upon which the transmission cable crosses from the New York State Office of General Services (NYSOGS § 3(2) PBL). It is also possible that transmission cables may traverse private lands, in which case a private party would be involved with land use. The 15 major regulatory processes are summarized in Table 31.

Table 31. Summary of Major Federal and State Permitting and Regulatory Reviews

Permit or Regulatory Requirement	Covered Activities	Statute	Regulations	Authorizing Agency
NEPA Review	Major federal action such as granting a federal permit	42 United States Code (U.S.C.) §4321 et seq	Council on Environmental Quality (CEQ): 40 Code of Federal Regulations (CFR) Parts 1500-1508 USACE: 33 CFR §230.9	Lead federal agency, such as USACE
Clean Water Act (CWA) Section 404/Rivers and Harbor Act (RHA) Section 10 Permit/RHA Section 408 Review (if project overlaps with USACE project water/lands)	Excavation or placement of dredged or fill in waters of the U.S. Construction of structures or obstructions in navigable waters Alterations of submerged lands or waters occupied or used by a USACE project	33 U.S.C. § 1344 33 U.S.C. § 403 33 U.S.C. § 408	33 CFR Part 323 33 CFR Part 322	USACE Buffalo District
USFWS Consultation and Other Reviews	Federal activities that potentially threaten protected species	16 U.S.C. 1531-1544 Endangered Species Act (ESA) 16 U.S.C. 703–712 Migratory Bird Treaty Act (MBTA) 16 U.S.C. 668-668c Bald and Golden Eagle Protection Act (BGEPA) 16 U.S.C. 661-666c Fish & Wildlife Coordination Act (FWCA)	50 CFR Parts 17 and 400 (ESA) 50 CFR Part 21 (MBTA) and Proposed rulemaking for MBTA permitting process (86 Federal Register [FR] 54667) 50 CFR § 22 (BGEPA)	U.S. Fish and Wildlife Service (USFWS)

Permit or Regulatory Requirement	Covered Activities	Statute	Regulations	Authorizing Agency
CWA Section 401 Certification	Federal action that discharges to navigable waters of the U.S.	33 U.S.C. 1341	40 CFR § 121 (federal) 6 New York Codes, Rules, and Regulations (NYCRR) 608.9 621.4 (b) Article VII New York Public Service Law (State)	NYSDEC, New York State Department of Public Service (NYSDPS), and/or Office of Renewable Energy Siting (ORES) (State)
National Historic Preservation Act (NHPA) Section 106 Consultation	Impacts to historical properties	54 U.S.C. § 306108	36 CFR Part 800	Lead NEPA agency (depends on how Section 106 is completed), SHPO and THPO
Private Aid to Navigation Permit	Obstructions or hazards to navigation	14 U.S.C. 542, 543, 544; 43 U.S.C. 1333	33 CFR §62, 64, 66 et seq	USCG
FAA Obstruction Evaluation	Hazards to air navigation	49 U.S.C. § 106	14 CFR Part 77	FAA
NOAA National Marine Sanctuaries Section 304(d) Consultation*	To be determined upon sanctuary designation	16 U.S.C. § 1431 et seq	15 CFR Part 922	NOAA Office of National Marine Sanctuaries
Accelerated Renewable Energy Growth and Community Benefit Act (94-c)	Major renewable energy project siting and permitting	NYS EXC § 94-c	19 NYCRR Part 900	(/ORES)
SEQRA Review	Discretionary state agency activities not covered by Accelerated Renewable Energy Growth and Community Benefit Act	Environmental Conservation Law (ECL) Article 8	6 NYCRR Part 617	State or Local Agency that approves, funds, or directly undertakes an action

Permit or Regulatory Requirement	Covered Activities	Statute	Regulations	Authorizing Agency
Coastal Zone Management Act (CZMA) Consistency Review	Federal activities affecting New York State's coastal zone	16 U.S.C. Chapter 33	15 CFR Part 930	NYSDOS
New York State Excavation and Fill Permit	Excavation or placement of dredged or fill in New York State waters	ECL § 15-0501 (2015)	6 NYCRR 608	NYSDEC (if not reviewed under Article VII or 94-c)
Easement of Lands Underwater	Structures located on state submerged lands	NYS PBL § 75	9 NYCRR Part 270	NYSOGS
Coastal Erosion Hazard Areas (CEHA) Permit	Activities in designated CEHA areas	ECL § 34-0102	6 NYCRR Part 505	NYSDEC or delegated certified municipality (if not reviewed under Article VII or 94-c)
New York State Incidental Take Permit	Take of New York State listed species	ECL § 9-1503 (plants) ECL § 11-0535 (animals)	6 NYCRR Part 193.3 (protected native plants) 6 NYCRR Part 182	NYSDEC (if not reviewed under Article VII or 94-c)
Article VII	Certificate of Environmental Compatibility and Public Need	PSL Article VII	16 NYCRR Subpart 85-2	NYSPSC

*Currently there is no National Marine Sanctuary in New York State waters in Lakes Erie and Ontario, but because a sanctuary is proposed for Lake Ontario, the consultation process for sanctuaries is discussed in this review. Notice of Intent to Conduct Scoping and Prepare a Draft Environmental Impact Statement for a sanctuary in Lake Ontario was published April 17, 2019 (84 FR 16004), and a Draft Environmental Impact Statement and Draft Management Plan were made available for public comment July 7, 2021 (86 FR 35757). Although this feasibility study focused on permitting for the in-water infrastructure, additional permits will be applicable for terrestrial activities, such as port and utility development, for example, coordination and review by NYS Department of Transportation for terrestrial utility line installation and other terrestrial activities.

6.1.2 Regulatory Risks and Opportunities

In this context, “risk” refers to the hurdles or difficulties that GLW projects could face which could impede project activities. “Opportunities” refers to increases in the efficiency of the processes, the likelihood of successful permitting, and synergies among the permitting processes. ***See 22-12k Federal, State, and Utility Permitting Roadmap and Study for more detail on risks and opportunities.***

6.1.2.1 Risks

- **Policy Uncertainty and Compliance with Migratory Bird Treaty Act (MBTA):** The lack of regulations and the changing of Department of Justice opinions and potential to address prosecution differently across presidential administrations is a significant risk for wind projects in general, and Great Lakes is no exception.
- **Citizen Suits over NEPA and other Federal Statutes:** Citizens can initiate litigation against a federal agency if they are adversely affected by that agency’s actions. This can include individuals or advocacy groups suing federal agencies over improper implementation of NEPA and other statutes.
- **New York State Article 78:** Under Article 78, individuals or advocacy groups can challenge State agencies over improper implementation of SEQRA or Article VII.
- **New York State Submerged Lands Easements and Adjacent Upland Landowners:** According to officials at NYSOGS, the State currently lacks the ability to legally issue a submerged lands lease for a parcel of submerged land that is not adjacent to the shoreline.
- **New York State Accelerated Renewable Energy Growth and Community Benefit Act (94-c):** The new regulations under this Act offer an opportunity; however, the regulations are relatively untested, posing the risk that state agencies still need to develop standard operating procedures to execute the regulations and that undiscovered challenges with the process may exist.
- **Proposed Lake Ontario National Marine Sanctuary:** If the proposed area is designated as a National Marine Sanctuary, NOAA Office of National Marine Sanctuaries, in principle, could limit or prohibit GLW energy activities.
- **NYS Agency Discretion over GLW Authorization:** New York State agencies have significant discretion over GLW projects through the Clean Water Act (CWA) Section 401 and Coastal Management Program consistency. If regulatory requirements are not met, agency officials cannot approve certifications and permits will not be issued.
- **Grass Roots Community Opposition:** Controversial projects are often subject to organized opposition that seeks to impact decisionmakers, and this often does not require citizen suit or other litigation.

Photo Credit: Getty Images

6.1.2.2 Opportunities

- **Contributions to New York State Climate Goals:** Great Lakes Wind could contribute to New York State's Clean Energy Standard goal and goals associated with the Climate Leadership and Community Protection Act and the Accelerated Renewable Energy Growth and Community Benefit Act.
- **FAST-41:** The Fixing America's Surface Transportation Act codifies into law a permitting approach to improve interagency coordination and expedite timelines to complete NEPA review and issue authorizations.
- **New York State Accelerated Renewable Energy Growth and Community Benefit Act:** The Accelerated Renewable Energy Growth and Community Benefit Act regulations involve the submission of a consolidated application package, a consolidated process for public review and input, and a single organization, ORES, to oversee the process. If implemented successfully, this could save time and reduce effort.
- **Eliminating Redundancies among Federal and State Reviews:** Existing law provides for several areas where federal review can eliminate or truncate redundant state level review.
- **Optimizing Mitigation Plans across Multiple Permitting Processes:** An opportunity in the environmental review and authorization process is for project applicants to integrate and optimize mitigation and any adjustments to the project to maximize environmental protection and compliance.
- **Optimize the Project Relative to the Permitting Risks:** Addressing environmental compliance and major risks at the outset of proposed projects can allow the project itself to be optimized relative to permitting risks.
- **Leveraging Studies for Multiple Permits:** Identifying common studies and materials across regulatory reviews can help project applicants reduce duplication of effort.

6.1.3 Recommendations

The following actions are recommendations to improve processes for development of GLW if New York State were to pursue such development:

- Pursue larger utility-scale projects to capture the full benefits of clean energy, local economic synergies and lower power prices.
- Consider New York State legislation to allow NYSOGS to allow easements for submerged lands that lack adjacent upland landowners.
- Reduce development risks associated with GLW for developers to ensure a competitive process with optimal outcomes for ratepayers.
- Consult and coordinate closely with the NOAA Office of Marine Sanctuaries.
- Leverage public engagement and incorporate GLW into climate action goals.
- Key steps for efficient regulatory management include:
  - Early engagement with regulators, relevant agencies, and key stakeholders.
  - Openly sharing information, regularly communicating project goals and objectives, avoiding premature commitments, and fulfilling commitments.
  - Early establishment of project environmental goals.
  - Early identification of key issues and strategies, regulatory issues, and risks.
  - Regulator engagement and reviews of permitting, engineering, construction, and logistics schedules.
  - Close communication and coordination between engineering and regulatory teams.
  - Avoid scope changes that would require agencies to reassess the project and repeat steps.
  - Optimized and integrated mitigation plans.
  - Establishment of a clear timeline and plan for permit acquisition (milestones).
  - Effective management of change.
- Conduct studies on the following topics to reduce uncertainty around major permitting and stakeholder concerns including:
  - Birds and bats.
  - Sediment composition and potential to disturb and release contaminants.
  - Additional visual impact studies.
  - Fishery resources and use conflicts.
  - Threatened and endangered species.
  - Design studies to answer specific questions and directly address environmental and stakeholder risks with realistic timeframes and costs.
  - Regional and international impacts on Indigenous Nations.
  - Cultural resources studies in consultation with Indigenous Nations, SHPO, and NOAA.

6.2 Federal, State, and Utility Permitting Roadmap

To better understand regulatory dynamics, cross-functional process flow charts that demonstrate the interactions of the multiple permitting authorities at the federal and State level were developed. Two permitting scenarios were considered:

- **Scenario 1 — Utility-scale project:** In this scenario the wind project has a total capacity of 25 MW or greater and transmission lines less than 10 miles in length (but greater than 1 mile) with a design capacity greater than 125 kV that are connected to the generation facility, making the New York State Accelerated Renewable Energy Growth and Community Benefit Act and Article VII applicable. It is funded by a commercial developer, therefore USACE is the NEPA lead agency because it has what is likely to be considered the most significant federal authorization process.
- **Scenario 2 — Demonstration-scale project:** In this scenario the wind project has a total capacity less than 20 MW, putting it below the threshold for the New York State Accelerated Renewable Energy Growth and Community Benefit Act, and transmission lines greater than 10 miles in length with a design capacity over 100 kV, making it subject to review under Article VII. As a result, NYS SEQRA review is potentially applicable (but if a federal NEPA EIS is prepared it may serve to satisfy SEQRA) along with several other NYS permits that are not necessary for Accelerated Renewable Energy Growth and Community Benefit Act projects. The project is also funded by a commercial developer, making USACE the NEPA lead agency. While the transmission line may require an Article VII Certificate, other project components such as the turbines, port infrastructure, etc., would be subject to other NYS permits and approvals.

Within scenario 1, the utility-scale project permitting process, there are 11 (possibly 12 if a sanctuary is designated) major permitting and regulatory approval processes (Figure 37).

Within scenario 2, the permitting process for small demonstration-scale projects, there are 13 (possibly 14 if a sanctuary is designated) major permitting and regulatory approval processes (Figure 38).

The main difference in process between scenario 1 and 2 is that in scenario 1, the ORES jurisdiction ensures compliance with State environmental regulations with support from NYSDEC and in scenario 2, the NYSDEC jurisdiction provides this assurance.

Figures Key: State Environmental Quality Review Act (SEQRA); Environmental Assessment Form (EAF); Private Aid to Navigation (PATON); New York State (NYS); United Sates Army Corps of Engineers (USACE); Federal Consistency Assessment Form (FCAF); Water Quality Certificate (WQC); Endangered Species Act (ESA); Bald and Golden Eagle Protection Act (BGEPA); Migratory Bird Treaty Act (MBTA); Environmental Assessment (EA); Finding of No Significant Impact (FONSI); Environmental Impact Statement (EIS); Categorical Exclusion (CE); Notice of Intent (NOI); Record of Decision (ROD); State Historic Preservation Office (SHPO); Tribal Historic Preservation Office (THPO); Memorandum of Agreement (MOA); Advisory Council on Historic Preservation (ACHP); New York State Public Service Commission (NYSPSC); New York State Department of Public Service (NYSDPS); Certificate of Environmental Compatibility and Public Need (CECPN); Environmental Management and Construction Plan (EM&CP); Memorandum of Agreement (MOA); Office of National Marine Sanctuaries (ONMS); Federal Aviation Administration (FAA); US Coast Guard (USCG); New York State Office of General Services (NYSOGS); National Oceanic and Atmospheric Administration (NOAA); New York State Department of Environmental Conservation (NYSDEC); New York State Departement of State (NYSDOS); Office of Planning, Development, and Community Infrastructure (OPDCI)

Figure 37: Scenario 1 Utility-Scale Project Permitting Process (abridged)

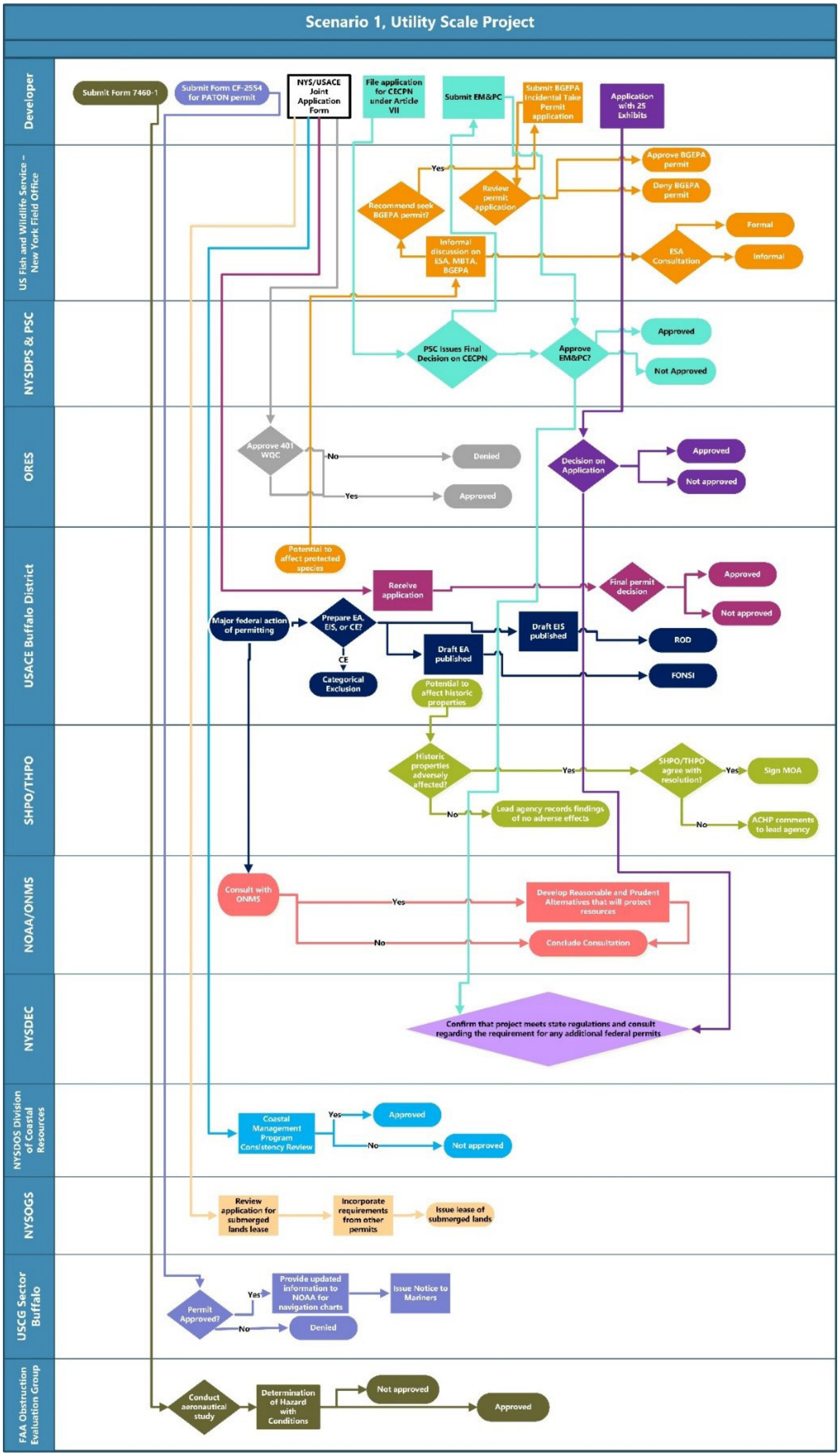


Figure 38: Scenario 2 Demonstration-Scale Project Permitting Process (abridged)

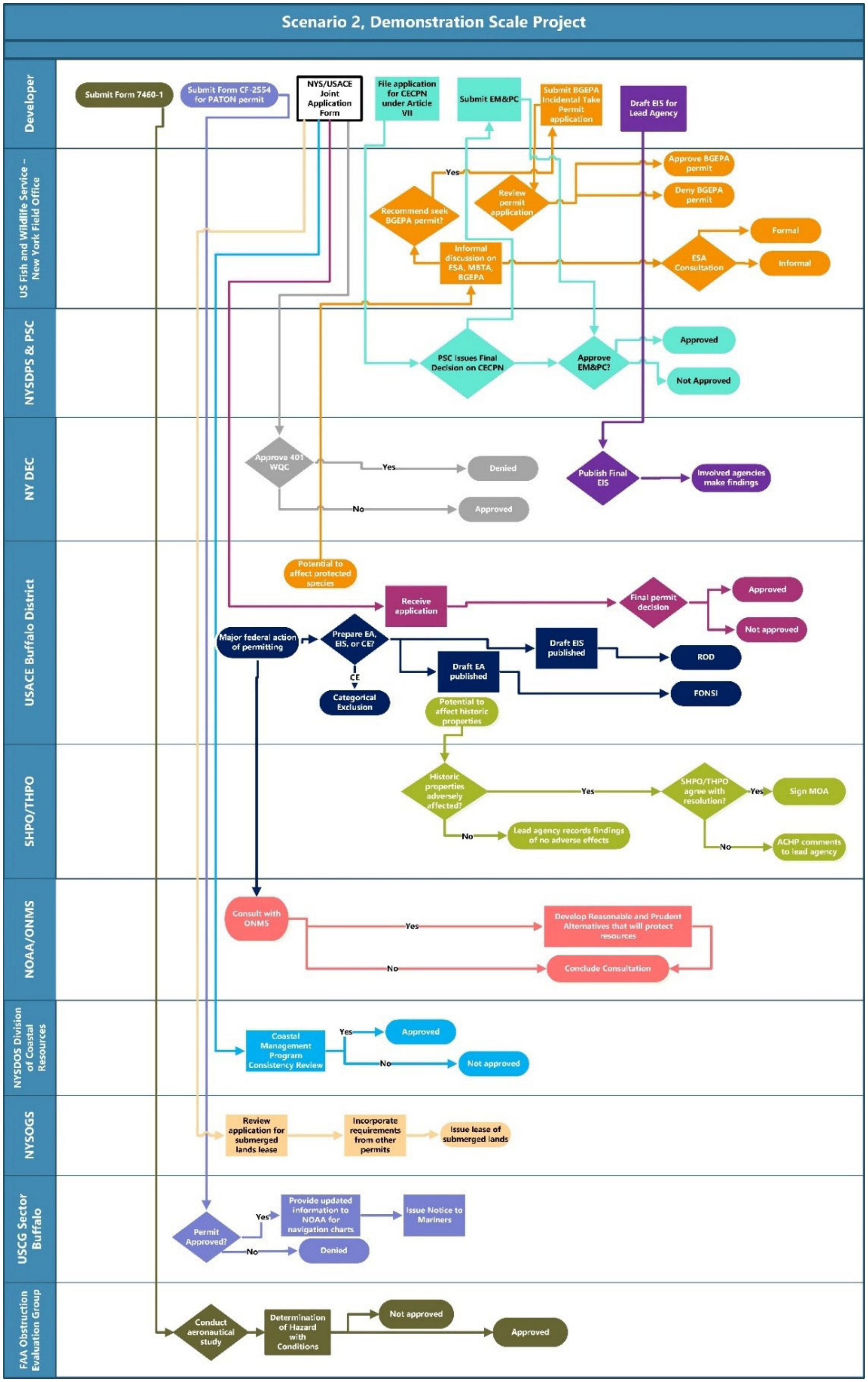



Photo Credit: Getty Images

7 Relative Risks, Minimization/ Mitigation, and Benefits: Environmental and Multi-User Considerations

An Environmental, Multi-User, and Risk Benefit assessment (Environmental Study) was prepared to support assessment of GLW feasibility (22-12i Environmental, Multi-User, and Risk Benefit). The Environmental Study describes:

- the distribution and habitat use of wildlife, human use conflicts, and potential risks of environmental and resource impacts;
- mitigation measures that are currently available in offshore wind that could be applied to minimize potential adverse impacts and
- the potential benefits of GLW. The Environmental Study Area encompasses New York State waters of Lakes Ontario and Erie and coastal areas up to 2 km (1.3 miles) inland.

Because no GLW project has been developed to date, the environmental interactions and potential impacts described herein draw on interpretation of current species and lake-user distribution information, experience with comparable wind energy projects, and relevant local information. The Environmental Study captures the main risks associated with GLW development and assesses these risks at a high level with the best available science in NYS waters of Lakes Ontario and Erie. A risk may be greater in one area than another, so a relative risk assessment has been developed that captures spatial differential risk in cases in which there were sufficient differential data to allow for such comparisons. These findings provide critical information on the key potential environmental and biological impacts, user conflicts, benefits, and knowledge gaps to inform decisions about GLW development.

The Environmental Study was developed with a desktop literature review, synthesis of available data, webinars soliciting public input, and phone interviews with experts and State and federal agency representatives. For the purposes of the Environmental Study, "receptors" are resources (e.g., wildlife, habitats, and human activities, such as fishing and recreation) that may be affected by GLW; "stressors" are aspects of GLW (e.g., pile driving, long-term structures) that can affect receptors; "impacts" are adverse or beneficial effects of influencing factors on receptors; and "mitigation" is choices or actions (e.g., application of sound dampening technology, seasonal limits for installation) that can avoid, minimize, offset, restore, or compensate for adverse impacts on receptors. The outcomes of the Environmental Study are summarized on teh following pages, and ***the full study is available in 22-12i Environmental, Multi-User, and Risk Benefit.***

These findings provide critical information on the key potential environmental and biological impacts, user conflicts, benefits, and knowledge gaps to inform decisions about GLW development.

7.1 Wildlife and Habitats

The Environmental Study considered birds, bats, invertebrates, and fish as major types of wildlife with the potential to be affected by GLW. A variety of sensitive and specially designated habitats were also considered.

7.1.1 Birds and Bats

The Great Lakes are within the Mississippi and Atlantic flyways, major bird migration routes with millions of birds (of over 395 species according to BirdLife International) passing through the Atlantic flyway each year. Of these migratory birds, 34 species are federal or NYS listed as endangered, threatened or species of concern. Bird distribution and habitat use is described in the Environmental Study in the context of bird clades: waterbirds, shorebirds, landbirds, raptors, and gulls and terns. These are generalizations for purposes of assessing risk of likely spatial and temporal overlap with GLW stressors, but actual bird movements and use patterns are variable by species and conditions.

Generally, waterbirds spend most of their time on water, and some forage in areas up to 16 kilometers (km; 10 miles [mi]) from shore. Shorebirds rarely travel more than 100 meters (m) from the water's edge. Landbirds include upland game birds, songbirds, and others that may migrate in the region but do not forage on or spend significant time on or over the lakes or shorelines. Raptors are large, predatory species with wide home ranges that may forage over nearshore areas. Gulls and terns typically forage nearshore but can forage over open water. Within these groups, there are also birds that nest along the Great Lakes shoreline areas, some in colonial nesting habitats where large numbers of birds could be disturbed concurrently during activities like cabling to shore, port development, or substation and terrestrial infrastructure construction. Migratory birds tend to migrate mainly around the lakes rather than over open water, but it is uncertain how many birds travel over open water, under what conditions, at what heights and flight behaviors, and how weather and day/night cycles affect movements over the water. Migrating birds tend to use islands and peninsulas to move across lake areas, so areas close to western Lakes Erie and Ontario and eastern Lake Ontario in the Environmental Study Area have potentially more migratory activity than other locations. There are specially recognized habitats, mainly in nearshore areas, that have been identified as nesting, stopover, and roosting areas, which were considered in evaluating relative risk to birds from GLW development in different parts of the Environmental Study Area.

Less is known about bat than bird distribution and habitat use, but it is thought that bats also use islands and peninsulas to move across lake areas and roost in areas also used for nesting and roosting by birds (though threatened and endangered bats are not known to make long migrations), so important habitats for birds likely also constitute important habitats for bats. Similar to birds, landscape features such as forest cover, wetlands, and river margins are likely also important habitat areas for bats.

7.1.2 Invertebrates

Invertebrates in the Environmental Study Area are distributed in zones associated with depth and bottom substrates, for which different species have preferences, but there is not enough information to differentiate densities or species of invertebrates in the Environmental Study Area beyond those preferences. Invasive zebra mussels prefer hard substrates, so turbine structures may create connectivity for spread of this species, though benthic surveys of both lakes in 2018 and 2019 showed no presence of zebra mussels. Quagga mussels are the dominant benthic organism in the lakes.

7.1.3 Fish

Fish are also generally distributed according to habitat preferences for nearshore, offshore benthic, and offshore pelagic habitats and move widely within these zones, but little is known about more refined distribution and use patterns in the Environmental Study Area. Data associated with movement and habitat use are available for some species, particularly those with commercial and recreational importance. Temperature preferences are used in fishing to locate some species, suggesting temperature may be predictive of dynamic fish distribution in certain cases. Most fish spawn in nearshore areas, making those areas potentially more vulnerable to disturbance of fish. There are some migratory species that have different distributions by season, such as walleye. As with benthic organisms, invasive fish species cause problems for native fish and habitats, and potential to affect those species with GLW is important to consider in project development.

7.1.4 Habitats

Specially designated habitats, such as critical habitat under the Endangered Species Act, NYS Areas of Concern, NYS Critical Environment Areas, Significant Coastal Fish and Wildlife Habitats, and Coastal Erosion Hazard Areas were all considered in the relative risk analysis. Potential to impact terrestrial species is mainly related to the potential to affect terrestrial habitats with activities like cable landing and port development. Wetlands and dunes were identified as terrestrial habitats that would have potential to be affected by GLW. Further, habitats identified by stakeholders, such as critically Important Bird Areas and Important Bird Sites were also considered and are shown in maps included in the relative risk analysis.

7.2 Human-Use Conflicts

The Environmental Study's human-use conflicts analysis considered fisheries, water use, shipping, Department of Defense activities, recreation, tribal uses, and historic/cultural areas. A visual impact analysis was conducted separately ***(see 22-12j Visual Impacts)***. There are a variety of terrestrial areas within the Environmental Study Area that have historical or cultural sites, and the Cattaraugus Reservation is within part of the Environmental Study Area on the shoreline of Lake Erie. There are major shipping lanes that traverse the northwestern part of the Environmental Study Area in Lake Ontario, and the Department of Defense and the Federal Aviation Administration have specially designated sites on Lake Ontario as well. A National Marine Sanctuary has been proposed to protect ship wrecks in Lake Ontario, and there are larger concentrations of known and possible ship wrecks in the eastern half of Lake Ontario than the rest of the Environmental Study Area. There are few data available on refined patterns of use by fisheries, recreational users, or communities and tribes within the Environmental Study Area, so relative risk associated with these factors is difficult to assess. Fishing activity also can vary with markets, conditions, fuel costs, and environmental factors that make future fishing effort distribution difficult to predict.

7.3 Relative Risk Analysis

The relative risk analysis provided information related to relative risk associated with potential biological, environmental, regulatory, cultural, and social conflicts associated with GLW across the Environmental Study Area. A phased approach to relative risk analysis was used to select GLW stressors, identify receptor groups, assess the quality and quantity of data regarding receptor groups' distribution, and prepare relative risk maps. Although there are a variety of data that inform species distributions in the Great Lakes, there are limited data at the level of detail and resolution needed to show differential risk of species and/or user groups across the Environmental Study Area. The relative risk maps include potential points of interconnection (POIs) for cables to shore, and are ***assessed in 22-12f Interconnection Feasibility Study***. The Interconnection Study focuses analysis on POIs that are within the Environmental Study Area as the cable-to-shore locations are more readily assessed as they are likely to be proximal to the POI; however, all POIs in the general assessment are also considered in evaluating potential cable-to-shore risks along the shoreline for inland POIs where there may be multiple options for bringing the cable to shore. Receptor groups were identified based upon their vulnerability and likelihood of interaction with GLW and available data regarding locations, distribution, and seasonal use within the Environmental Study Area. The maps developed to inform relative risk were synthesized to describe relative risk across the Environmental Study Area.

7.3.5 Environmental Study Area

For purposes of this analysis, the area where turbines would most likely be installed was considered to be at least 10 statute miles (16 km) from shore in Lake Ontario and at least 5 statute miles (8 km) from shore in Lake Erie. The 16 km minimum distance from shore was chosen in Lake Ontario as a means to assess potential turbine stressors in Lake Ontario, where substantial lake area for possible development exists at that distance and beyond. In the narrow, east end of Lake Erie, the same 16 km minimum distance would eliminate most of the lake's developable wind area in New York State waters. Therefore, a closer minimum distance for turbine placement was necessary for feasible construction in New York State. For the purposes of this analysis, a distance of 5 mi from shore in Lake Erie was used. These distances

(10 mi and 5 mi, respectively) were used as references to illustrate possible impacts but do not represent any decision by New York State regarding placement of wind turbines should GLW development move forward in the future. These reference distances are shown in Figure 39 and ***detailed further in 22-12i Environmental, Multi-User, and Risk Benefit.*** This approach was used to identify a "turbine zone" offshore and a "cabling zone" (turbine zone to shore) to consider most likely potential impacts in those areas. The Environmental Study does not consider physical factors, like ice presence or geology, and is focused on relative risk to wildlife and human uses based on the best available information about how these receptors use the Environmental Study Area. ***22-12b Physical Siting Analysis provides information on physical factors***.

Figure 39: Environmental Study Area with 10 mi (16 km) Distance Line in Lake Ontario and 5 mi (8 km) Distance Line in Lake Erie Indicating the Offshore Turbine Zones and Inshore Cabling Zones for Each Lake

7.3.6 Data Gaps

In reviewing the data, data gaps were identified, and ongoing and potential future research was described. Spatial data for birds and bats flying over the lakes in the Environmental Study Area are not readily available, including data on flight paths, flight height, magnitude of birds/bats flying over the lakes, and changes in flight patterns over the lakes relative to weather and light conditions. Likewise, habitat use patterns and movements of most fish are not well studied within the Environmental Study Area. Distribution and use patterns of fisheries, including subsistence and cultural fisheries, are at lower resolution than ideal for assessing relative risk. Marine fish with swim bladders have more potential to be injured by sound and particle motion than fish without swim bladders, but little is known about the potential for freshwater fish with swim bladders to be impacted by sound or the potential behavioral reactions of Great Lakes fish to sound, electromagnetic fields, and other disturbance. Some data are available on distances from shore where benthic organisms are most likely to be found, but high resolution species distribution data are not available. There is also a lack of resolution in data regarding human use patterns, such as recreational activities, tourism, and cultural uses.

7.3.7 Stressors

The stressors associated with potential GLW development were identified in the relative risk analysis, including for pre-construction, construction, and post-construction phases. Each potential stressor, including both short-term and long-term, were linked to potential impacts (Table 32).

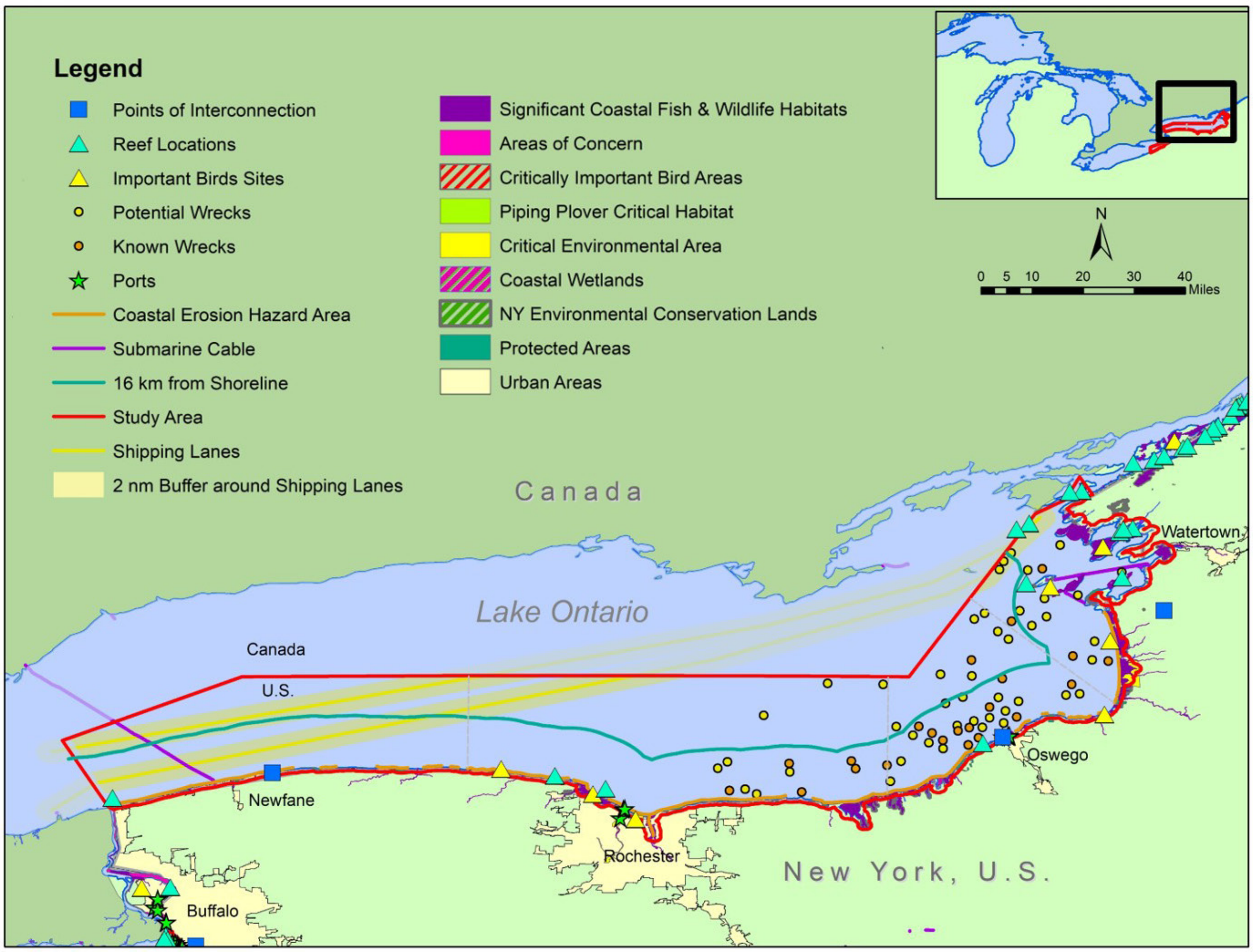
Table 32: Great Lakes Wind Potential Stressors and Impacts

Pre-Construction	
Potential Stressors (Short-Term)	**Potential Impacts**
Sound/particle motion	Behavioral disturbance, interference with human uses.
Bottom Disturbance	Behavioral disturbance, turbidity, contaminant release, injury/mortality of some benthic organisms.
Increased Vessel Traffic	Behavioral disturbance, emissions
Short-Term Structures	Short-term habitat changes, attraction, displacement, connectivity for invasive species, navigational/fisheries hazard.
Construction	
Potential Stressors (Short-Term)	**Potential Impacts**
Sound/Particle Motion	Behavioral disturbance, injury/mortality, interference with human uses.
Sound/Particle Motion with Pile-Driving	Behavioral disturbance, injury/mortality, interference with human uses.
Increased Vessel Traffic	Behavioral disturbance, emissions
Bottom Disturbance	Behavioral disturbance, turbidity, contaminant release, injury/mortality of some benthic organisms.
Habitat Alteration	Behavioral disturbance, displacement, navigational/fisheries hazard, injury/mortality for benthic organisms.
Post-Construction	
Potential Stressors (Long-Term)	**Potential Impacts**
Sound/Particle Motion	Behavioral disturbance, displacement.
Scour	Behavioral disturbance, displacement.
Electromagnetic Fields, Vibration, Heat	Behavioral disturbance, displacement, barrier.
Long-Term Structures	Lighting attraction, other attraction, displacement, collision, barrier, navigational/fisheries hazard, connectivity for invasive or native species, reef effects, habitat creation/modification/fragmentation, radar interference, aircraft hazard.
Increased Vessel Traffic	Behavioral disturbance, emissions, interference with other human uses.

7.3.8 Lake Ontario Relative Risk

Assuming a project site at least 10 miles from shore, turbines placed in the area of Lake Ontario south of the southernmost shipping lane and to the east of the ship wrecks, with cables to shore at the westernmost POI in the Environmental Study Area, would likely have the least impact to the receptors considered, based on the available data (Figure 40). POI choice is driven mainly by ability to receive power, so if that POI were infeasible for projects, additional mitigation for sensitive habitats and Coastal Erosion Hazard Area (CEHA) permitting could be applied to bring power to shore in other identified POI locations, with risk increasing for cabling moving eastward. Alternatively, POIs outside the Environmental Study Area, further inland, may be used with cables extending larger distances on land to reach those POIs.

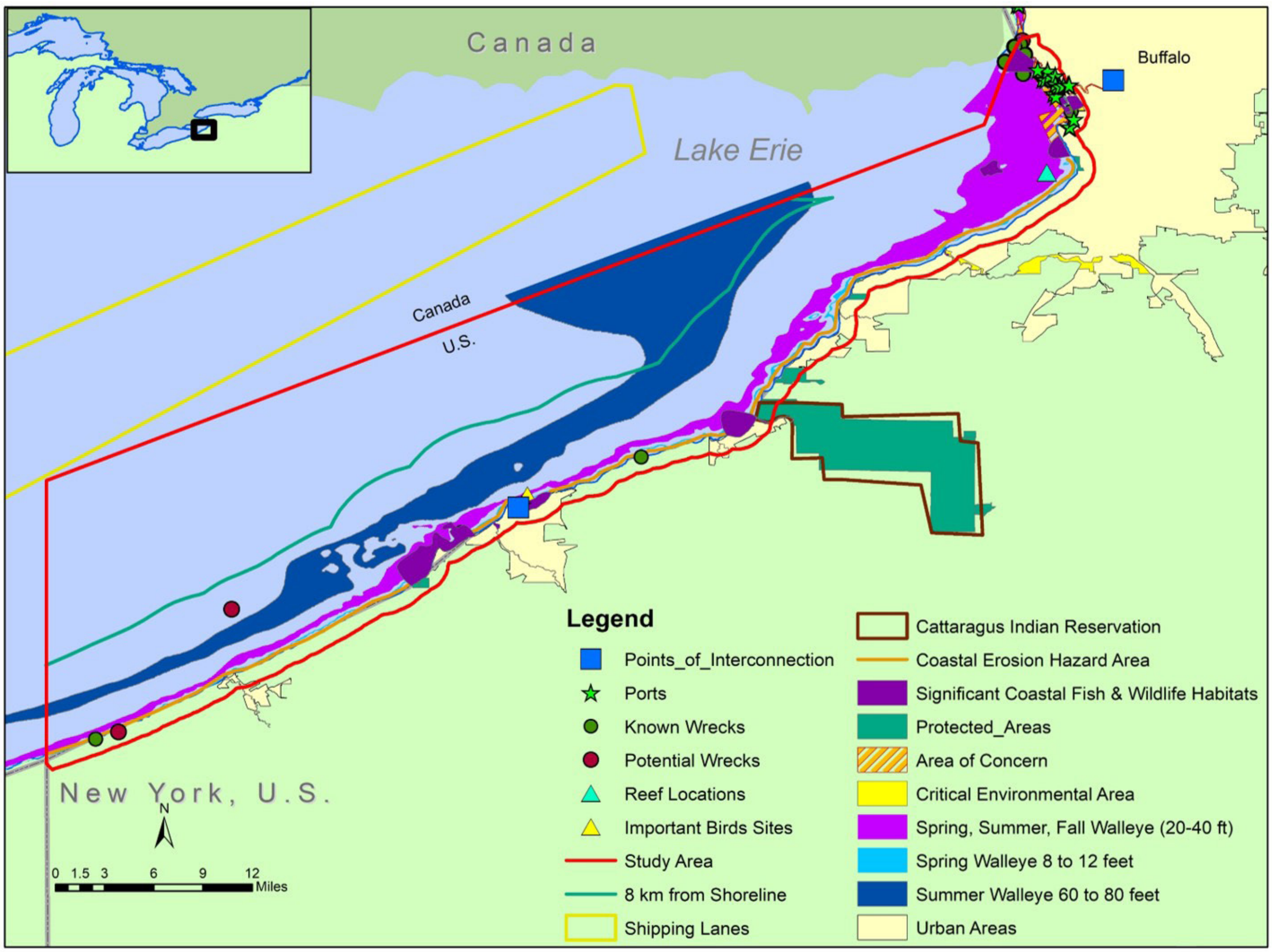
Figure 40: Lake Ontario Potential Risks for Great Lakes Wind in the Turbine and Cabling Zones



7.3.9 Lake Erie Relative Risk

Based on the available data, turbines placed more than 5 miles from shore in the Central West part of the Lake with cables to shore at the POI near Central West Lake Erie would likely have the least impact related to the receptors considered here, followed by turbine placement in the Southwest part with cables to shore at the POI near Central West (Figure 41). As noted above, POI choice is driven mainly by ability to receive power, so if that POI were infeasible for projects, additional mitigation for sensitive habitats and CEHA permitting could be applied to bring power to shore in other identified POI locations, with risk increasing for cabling to POIs moving eastward, as is the case with Lake Ontario. Alternatively, POIs outside the Environmental Study Area, further inland, may be used with cables extending larger distances on land to reach those POIs.

Figure 41: Lake Erie Potential Risks for Great Lakes Wind in the Turbine and Cabling Zones



7.3.10 Relative Risk Across the Environmental Study Area

In the Environmental Study Area, both Lake Erie and Lake Ontario have lower risk associated with turbine placement away from areas that have peninsulas, islands, and generally any short connection between land areas that can be migratory areas for birds and bats. In addition, low risk is associated with projects away from Walleye fishing habitat (in Lake Erie), reducing the suitability of some eastern and western areas of Lake Ontario and the eastern area of Lake Erie (the western area does not border land but rather extends into Pennsylvania waters). There is also some heightened risk in the western part of the Environmental Study Area in Lake Erie because of proximity of the Long Point peninsula extending out from shore in Canada. Lake Ontario has substantively more known and possible wrecks that could affect turbine placement and configuration and cables among turbines and to shore for interconnection. Both lakes have a substantive portion of the coastline that is designated as CEHA, making it likely that permits and mitigation associated with erosion areas will be needed to bring cables to shore, though cables may be routed through areas without CEHA and continue on land to substations and POIs. This land-based approach could increase risk in the lakes and onshore because of additional cabling disturbance. CEHA itself is not necessarily a risk relative to cable crossings to shore, as engineering choices can minimize potential effects to coastal erosion and generally crossings are achieved through horizontal directional drilling under the ground, but the legal designation of CEHA could affect how cable-crossings are routed because permitting will likely be more difficult in CEHA.

Few or low-resolution data are available to assess bird flight patterns, heights, and behavior; benthic organism and fish distribution; and distribution of human uses, such as fisheries, cultural uses, or recreation. Lake Ontario has more area in New York in which wind projects could be distributed, but the potential sanctuary designation, wrecks and military activities, and vessel corridors within Lake Ontario could potentially increase risk in Ontario relative to Lake Erie; however, Lake Erie has an abutting reservation and would have challenges for siting large-scale projects as far from shore as is possible in Lake Ontario because of the relatively limited size of New York State submerged land area in Lake Erie.

Overall, based on environmental and human use conflict risk assessment, it is feasible to develop wind in either lake, but different constraints apply to each, and filling data gaps and/or developing predictive models could help to reduce risk associated with receptors for which there are few or low-resolution data.

7.4 Assessment of Mitigation

The assessment of mitigation includes tables of stressors, potential impacts, and mitigation measures that can be used to avoid, minimize, offset, restore, and/or compensate for potential adverse impacts. Mitigation options are mainly based on those developed for ocean-based offshore wind. Mitigation measures were organized in four categories: benthic organisms, birds and bats, fish, and fisheries, as these receptors had the most available information for potential mitigation measures.

Not every impact can practicably be mitigated, so priorities related to the likelihood and severity of impacts and the vulnerability of receptors to population-level consequences or long-term impairments (such as reduced fisheries access) need to be considered in choosing mitigation measures for GLW if it moves forward. The Environmental Study Area has existing impairments, including water quality issues, invasive species, coastal erosion, and habitat loss that could potentially be considered in the context of offset mitigation measures. It is common for impacts to species like birds and bats to be addressed with offsets in terrestrial windfarms, along with directed mitigation measures, such as smart curtailments or lighting that reduces attraction and also meets FAA and other regulatory requirements. In addition, mitigation measures associated with the following are commonly used in offshore wind plans and authorizations to date:

- Seasonal construction activities.
- Trenching and burying cables.
- Horizontal directional drilling and trenchless crossings for cable from water to land.
- Sound abatement measures (like bubble curtains) for pile driving.
- Distances from shore meant to limit visibility of turbines from shore.
- Notices to mariners.
- Configuration determinations in collaboration with Coast Guard and Department of Defense.
- Fisheries compensation.

Pre-construction and post-construction monitoring are often also included in planning and authorization requirements. Each project's unique location and equipment would help determine project-specific mitigation that would address the issues raised by a given project.


Photo Credit: Getty Images

7.5 Assessment of Benefits

Like other renewable energy, Great Lakes Wind would reduce GHGs and air pollution by replacing fossil fuel-generated electricity. Reducing reliance on fossil-derived electricity and decarbonizing the electrical sector could reduce climate change related public health issues. Reductions in air pollution would contribute to better public health. GLW would not require water to generate electricity and could be an alternative that reduces industrial water use by displacing thermoelectric forms of power production.

Great Lakes Wind is supported by the federal government's Executive Order on **Tackling the Climate Crisis at Home and Abroad** and **NYS's Climate Leadership and Community Protection Act**, both of which commit to decarbonizing the energy sector and increasing offshore wind energy.

The U.S. government and NYS are committed to reaching zero emissions by 2050.

GLW could contribute to these commitments. NYS is committed to environmental justice, and NYS has made strong commitments to ensure that disadvantaged communities can benefit from offshore wind energy, with 40% of the overall benefits from clean energy programs going to disadvantaged communities for job creation, workforce development, low-income energy assistance, housing, and other benefits.

If GLW moves forward, it could provide opportunities to address inequalities in local and regional communities, for example, by offering job training; employing local residents during construction, operations, and maintenance; and investing in the communities. In addition, eliminating harmful air pollutants that can disproportionately affect disadvantaged communities would help to ensure better public health in these communities.

Photo Credit: Getty Images

8 Visual Impact Considerations

8.1 Viewshed Analysis

A Visual Impacts Study was prepared to support the assessment of GLW Feasibility ***(22-12j)***. The Visual Impacts Study:

- describes the standard procedure for conducting a visual impact assessment and how viewshed analyses would be used to help define the geographic extents of such assessments in the Great Lakes;
- describes the significant factors that affect viewshed calculations and limitations and what those factors mean for assessments of visual impact for GLW; and
- presents high-level viewshed analyses for select hypothetical turbine locations to provide a general sense of theoretical visibility in the region.

Potential visibility maps, a discussion of sensitive visual areas along the coastline, and a high-level assessment of visibility risks are presented below. Considerations for siting wind turbines for potential future development, including visual impact, distance from shore, and other parameters, are also discussed.

The Visual Impact Study focuses on NYS waters of Lakes Erie and Ontario. It is recognized that potential future offshore wind development in New York State's portion of the lakes may introduce visual impacts to Canada and neighboring states which would need to be evaluated and addressed as part of any proposed development plan.

At this time, there has been no site identification within Lake Erie or Lake Ontario for potential GLW development, and this GLW Feasibility Study is not conducting any site selection activities either. No specific turbine design, foundation technology option, or wind farm layout has been officially designated for use in New York State waters of the Great Lakes.

Without specific details of a preferred site, turbine design, and wind farm layout plan, most of the traditional steps in conducting a visual impact assessment cannot be addressed at this time. As a result, this Visual Impact Study was constrained to evaluate the potential geographic extents of visibility associated with GLW development in the lakes.

Considerations for siting wind turbines for potential future development, include visual impact, distance from shore, and other parameters.

The Visual Impact Study uses generic model parameters and six hypothetical single-turbine locations to conduct a viewshed analysis and establish a high-level understanding of theoretical visibility across the lakes and nearshore areas. The Visual Impact Study used a10 statute mi (16 km) minimum distance to shore to site hypothetical turbines in Lake Ontario ***(in alignment with the minimum distance to the turbine area in 22-12j Environmental, Multi-User, and Risk Benefit)***. Substantial lake area exists farther out in Lake Ontario for possible development, suggesting proposed developments could be farther from the lakeshore than modeled herein. In the narrow, east end of Lake Erie, a distance of 5 statute mi (8 km) from shore was applied when siting the modeled hypothetical turbines for the Visual Impact Study. These distances from shore (10 mi and 5 mi, respectively) do not represent any decision by New York State regarding placement of wind turbines should GLW development move forward in the future.

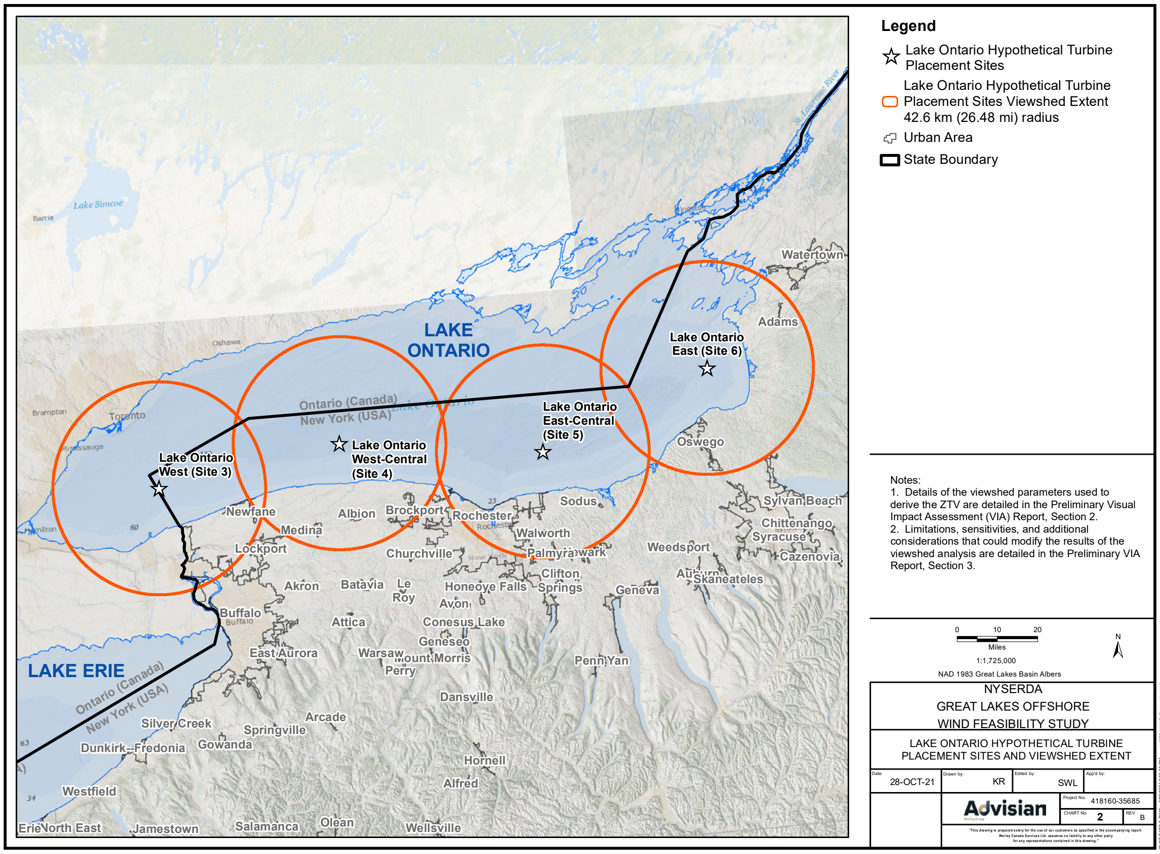
The viewsheds are calculated for a single turbine at various representative locations across the lakes, not an entire wind generation facility. The results demonstrate how local terrain and distance from shore can affect potential visibility inland. The Visual Impact Study shows that the modeled distances are not large enough to eliminate the turbines from the shoreline views, although the curvature of the Earth does begin to reduce visibility at those distances. The hub height (112 m) is commonly modeled in VIAs for wind turbines as a proxy for assessing night visibility because aviation obstruction lighting is typically mounted to the nacelle at hub hieght. Given the uncertainties in possible project placement, turbine model, and facility layout in this early stage of consideration, this high-level assessment does not evaluate multiple height viewshed scenarios.

There are limitations, caveats, and assumptions inherent in the high-level Visual Impacts Study. Turbine locations, fundamental geometric sensitivities of the viewshed model, definition of viewshed scenarios, extent of the viewshed model, elevation and screening sensitivities, and other visibility factors are among some of the key considerations that will impact the results of any viewshed calculation and estimate of visibility. Because of the uncertainties at this early phase associated with the location of any specific wind generation facility, turbine model, and elements such as the number of turbines and their layout, this high-level assessment does not evaluate multiple height viewshed scenarios, establish key observation points, analyze full windfarm visibility, or involve preparation of visual simulations. The Visual Impact Study also does not address radar and aviation interference.

8.2 Viewshed Results

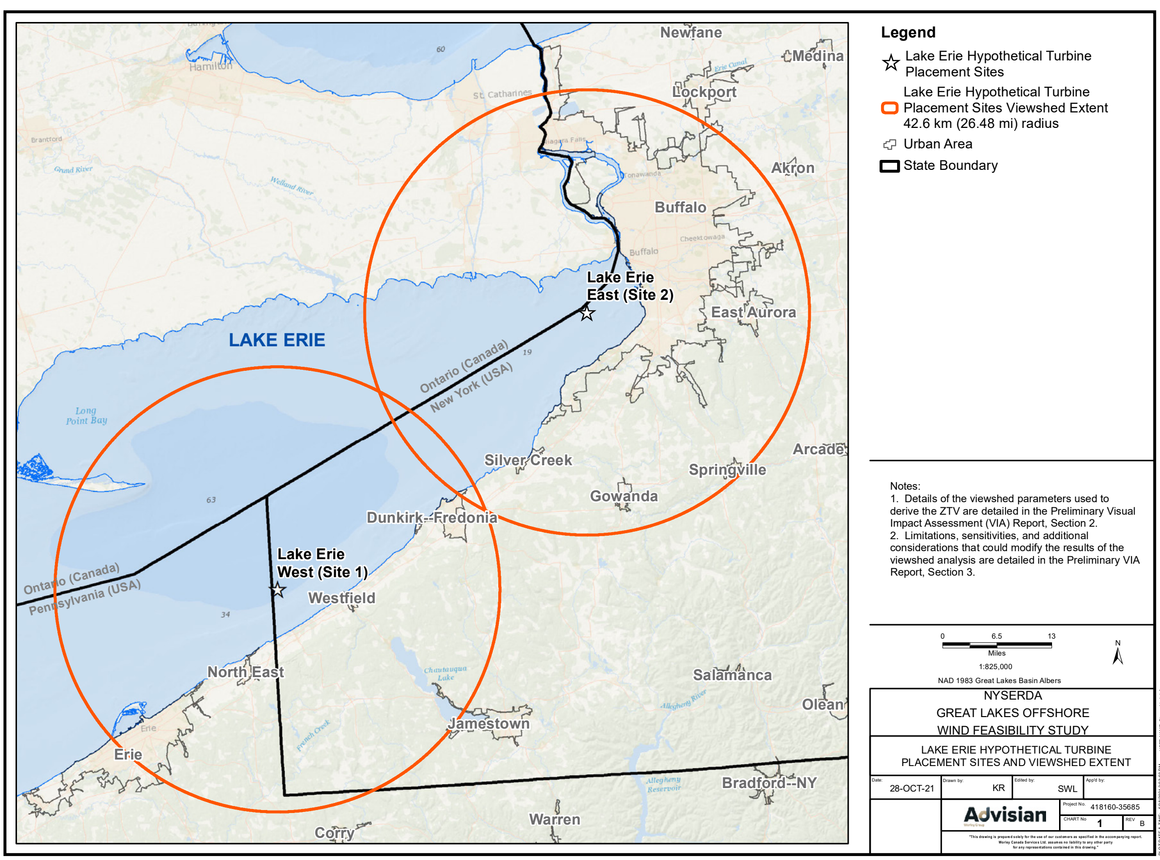
The four hypothetical turbine placement sites within Lake Ontario provide some insight into visibility differences along the lake within NYS waters. All four hypothetical single-turbine locations are sited at a hypothetical minimum distance from shore, 10 mi (16 km), and yield an illustrative “worst case” viewshed for turbine hub-height visibility (Figure 42). The two hypothetical turbine placement sites within Lake Erie provide some insight into visibility differences between the western and eastern portions of Lake Erie within NYS waters. Both single-turbine locations are sited at a hypothetical minimum distance from shore, 5 mi (8 km) and yield a “worst case” viewshed for turbine hub-height visibility (Figure 43). Siting a project farther from shore will reduce potential for visibility from shore, as will considering surficial features, structures, and vegetation through use of a refined digital surface model.

Figure 42. Lake Ontario Hypothetical Turbine Placement and Viewshed Extent



Imagery Source: Sources: Esri, GEBCO, NOAA, National Geographic, Garmin, HERE, Geonames.org, and other contributors
Esri, Garmin, GEBCO, NOAA NGDC, and other contributors
FILE LOCATION: E:\GIS\Projects\418160-35685\01_MXD\Final_Maps\RevB\NYSERDA_Lake_Ontario_Hypothetical_Turbine_Plaement_Sites_and_Viewshed_Extent.mxd

Figure 43. Lake Erie Hypothetical Turbine Placement Sites and Viewshed Extent



Imagery Source: Sources: Esri, GEBCO, NOAA, National Geographic, Garmin, HERE, Geonames.org, and other contributors
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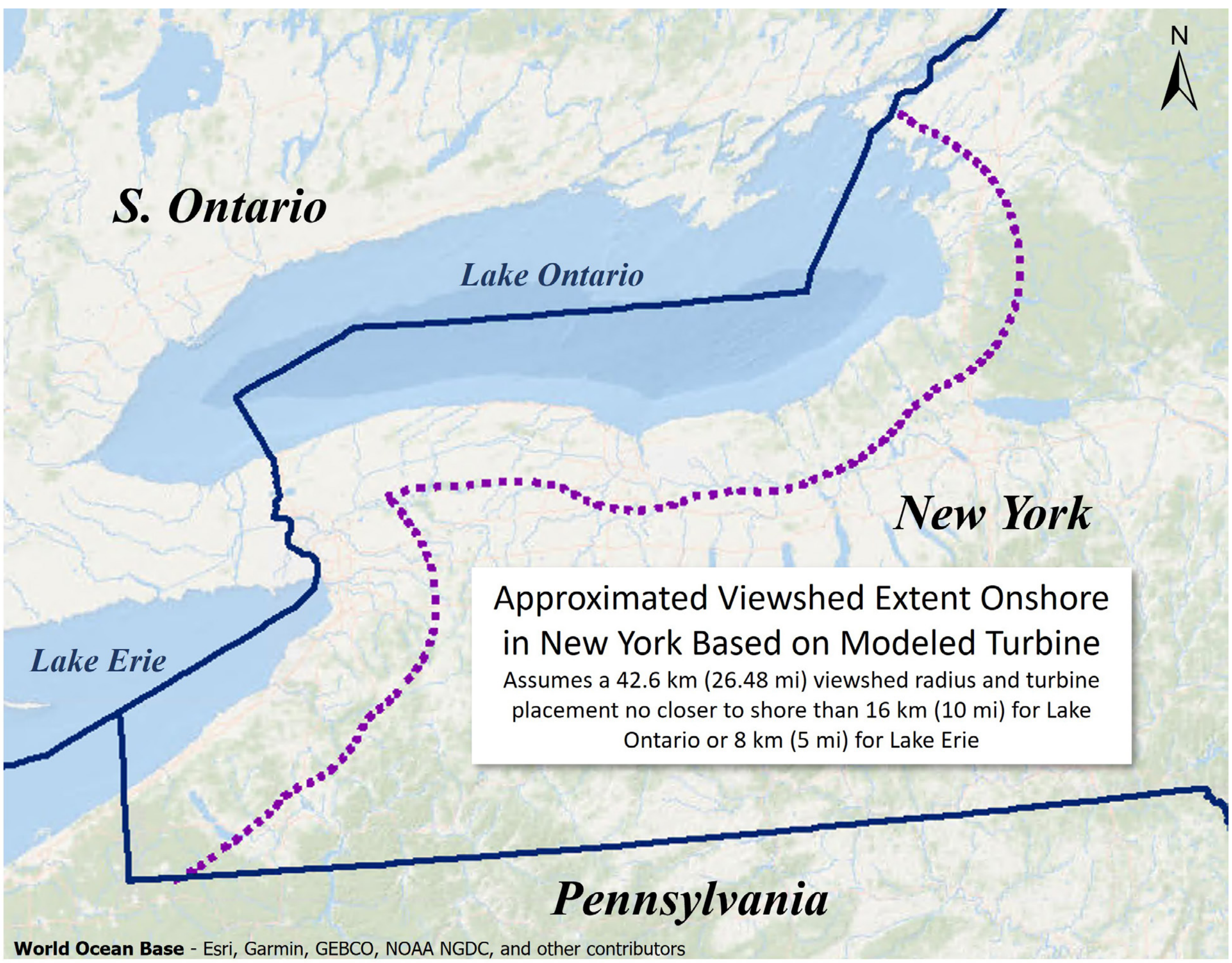
FILE LOCATION: E:\GIS\Projects\418160-35685\01_MXD\Final_Maps\RevB\NYSERDA_Lake_Erie_Hypothetical_Turbine_Plaement_Sites_and_Viewshed_Extent.mxd

8.3 General Extent of Visibility Investigation

Based on a reference 6-MW wind turbine with a hub height of 112 m, the viewshed radius was estimated to be 26.48 mi (~42.6 km). Observers closer than this distance could potentially see the turbines, but visibility is heavily dependent on many factors including whether or not there is any intervening topography or other screening elements, as well as other environmental variables. Assuming turbines are placed within Lake Ontario at a minimum distance of 10 mi (16 km) from shore, or a minimum of 5 mi.

(8 km) in Lake Erie, it is possible to get an idea of the general coverage a more comprehensive Visual Impact Assessment (VIA) might need to investigate for proposed projects. Figure 44 illustrates a generalized approximation of consolidated viewshed limits (modeled using hub height) for turbine placements in both Lakes that meet the hypothetical minimum standoff from shore.

Figure 44: Approximation of Consolidated Viewshed Extents Onshore into New York State, Based on Modeled Turbine Hub Height (GE Cypress 6.0-164) and Viewshed Parameters



This approximation is not an evaluation of potential visibility, as would be defined by the zone of theoretical visibility resulting from the viewshed calculations. Rather, the dashed line represents a composite of the approximate onshore limit of visual impact investigations based on the defined turbine and viewshed parameters presented herein. If turbines are placed farther into the lake, at increased distance from the shoreline, then the viewshed limits would move accordingly, maintaining the 26.48 mile visibility radius but reducing the land portion that is covered within the viewshed extents.

Photo Credit: Getty Images

8.4 Comprehensive Visual Impact Assessments

If New York State chooses to pursue wind development in the Great Lakes, the work performed in this study describes the maximum extent of the potentially impacted region for a project using 6-MW turbines. A more comprehensive Visual Impact Analysis (VIA) would be conducted once a site is selected. Developers would be required to submit detailed plans that specify the actual turbine model dimensions, the wind farm layout and turbine placement, and utilize high-resolution elevation and surface model data, as well as land use data specific for the geographic extent defined for visual impact assessment. Stakeholders would provide input into photo-realistic simulation studies by contributing to the selection of key observation points within the zone of theoretical visibility. These visual simulations, would represent views from the key observation points for different meteorological conditions, seasons, and times of day. These additional viewshed data would inform subsequent evaluations of viewer activities, stakeholder sensitivity levels, preferences, and concerns. These studies would include public outreach and communication to understand the unique visual qualities of key sites and what changes an offshore wind generation facility might introduce to the aesthetic and experiential qualities of the area. Additional assessments may also be required to address visual impacts to regions beyond New York State, including Canada.

As part of the Environmental Impact Statement for large-scale energy generation and transport facilities, a separate visual effects assessment for historical properties might be required. Radar and aviation interference studies may also be necessary to evaluate potential interferences. BOEM offers guidance on the methodology for conducting detailed VIAs, which could be applied to GLW in the absence of any other superseding regulatory guidance in its Outer Continental Shelf (OCS) Study Bureau of Ocean Energy Management 2021-032 (BOEM 2021).

Photo Credit: Getty Images

9 Conclusions

9.1 Assessment of Viability

This study was carried out in response to the October 2020 order by the New York State Public Service Commission for NYSERDA to assess the feasibility of developing offshore wind energy in the Great Lakes adjacent to New York State. It assesses the environmental, technical, maritime, economic, social issues as well as market barriers and costs of developing wind in the Great Lakes and identifies key challenges and opportunities in this region. Overall, the study did not find any unsurmountable barriers to GLW but illuminated many differences and unique challenges in comparison to offshore wind development in the open ocean. This section summarizes the key findings that support the study's general conclusion that GLW energy is technically feasible in some locations of the Great Lakes. Further, these findings estimate the cost and cost drivers of GLW development including insights on areas of uncertainty where additional research maybe needed.

Overall, the study did not find any unsurmountable barriers to GLW **but illuminated many differences and unique challenges in comparison to offshore wind development in the open ocean.**

As such, the key findings of this study are as follows:

Physical Site Characteristics

- Average annual wind speeds in the Great Lakes are on par with the mid-Atlantic regions where offshore wind is proliferating. The average wind speeds which can be up to 9 m/s (and sometimes higher) translate to net capacity factors well over 40% and are considered very good for wind energy production.
- Lake Erie is characteristically shallow and almost exclusively less than 60-m deep. It is best suited for fixed-bottom support structures. Lake Ontario is much deeper, and as a result floating technology should be considered the best option.
- Soils composition in both lakes is relatively soft which may preclude some foundation types like monopiles, but surface sediment thicknesses appear to be deep enough over the bedrock to allow multi-leg piled substructures.
- Both lakes have the potential to freeze but Lake Erie, due to its shallow waters, has more ice cover than Ontario. Turbines and their support structures need to account for ice floes (large sheets of ice drifting across the lakes) in their designs. The primary design concern is for the extreme ice year when ice floes may include extra-thick ice ridges, though data is lacking on the size and probability of these ice-ridge features.
- Extreme wave sea states in the Great Lakes are almost as large as the north Atlantic during the late fall storm season. Sea states during summer months are lower than the summer sea states on the north Atlantic, which may enable alternative installation vessels on the lakes such as modular barges.
- Water currents on the lakes are relatively benign and do not introduce a significant design challenge.

Infrastructure and Wind Plant Technologies

- Most conventional vessels used in offshore wind construction are too wide to transit the locks and canals of the Saint Lawrence Seaway and the Welland Canal and will not be able to access the Great Lakes. This limitation determines to a large extent the size of wind turbines that can be used in the Great Lakes.
- Using conventional methods, fixed-bottom turbines suited for Lake Erie may require installation out on the lake using the best available heavy lift, high elevation installation methods. The maximum fixed-bottom turbine size and weight are limited by the maximum lifting capacity of a GL vessel that can be developed or brought into the lakes.
- Floating wind turbines on Lake Ontario would require heavy lift, high elevation cranes at the port quayside. Lower vessel requirements on Lake Ontario may enable the use of larger turbines, such as those being procured for projects on the Atlantic.
- All ports considered for GLW would need significant upgrades before serving as a marshalling port for GLW construction, assembly, and service. Suitable ports on Lake Ontario include Oswego, and suitable ports on Lake Erie include Buffalo and Erie, PA.
- Novel float-out installation solutions that avoid the dependance on large, heavy lift vessels have been proposed for offshore projects (but have not yet been developed), and may be a practical alternative for GLW on Lake Erie, but the port upgrades would need to include these new technology-specific installation solutions.
- Fixed-bottom and floating wind turbine substructures would need to have slender waterline profiles to avoid ice jamming and to minimize ice loading. These substructures would need to be equipped with ice cones, at a small incremental cost, to further reduce ice loading.
- Substructures that may be feasible for water depths less than 60-meters (e.g., Lake Erie) include tripods, suction buckets, and gravity-base foundations. Substructures that may be feasible for water depths greater than 60 meters (e.g., Lake Ontario) include tilt-up or hybrid spars, and tension leg platforms.
- No floating wind turbines have yet been deployed in ice environments like the Great Lakes, but the study found no major perceived barrier to deploying floating wind turbines in the Great Lakes.

Electric Grid and Generation Potential

- Based on a conservative nameplate power capacity density of 3 MW/km,2 New York State's Lake Erie waters beyond 4 miles from shore could support up to 2 GW of wind energy generation, while New York's Lake Ontario waters beyond 4 miles from shore could support up to 18 GW. At 10 statute miles from shore, Lake Erie could support 280 MW and Lake Ontario could support 8 GW.
- Without significant transmission upgrades, the available POIs accessible from Lake Erie have a maximum transmission capacity headroom of 270 MW, while the POIs accessible from Lake Ontario have a maximum of 1,140 MW. The total nameplate ratings for wind facilities on Lakes Erie and Ontario may be equal to or greater than the aforementioned headroom capacities and can be as much as twice the headroom capacities.
- Higher headroom capacities can be achieved with transmission upgrades up to the level which can fully support the State's Clean Energy Standards. Several hundred million dollars would be needed to increase headroom to accommodate larger GLW projects.

Cost and Economic Impacts

- Analysis shows that wind plants beginning operations in 2030 would have an LCOE in the range of \$96/MWh to \$118/MWh in Lake Erie and between \$97/MWh and \$115/MWh in Lake Ontario. The lowest LCOEs were found in the eastern ends of the lakes close to ports and grid connections. By 2035, the median LCOE decreases to \$98/MWh in Lake Erie and \$96/MWh in Lake Ontario due to learning curves based on industry forecasts of global offshore wind deployment.
- Costs are expected to be higher in the Great Lakes than in the North Atlantic because vessel constraints require smaller turbines, supply chains are more isolated, and there is higher uncertainty and accessibility in maintaining turbines during winter months due to ice. These cost increasing factors can be mitigated, at least in part, through technology and experience which might lead to lower future costs than those modeled herein.
- The NREL JEDI model predicts the development of a 400 MW Lake Erie wind energy project could support 4,100 FTE job years and generate \$590 million in GDP for New York State during the construction phase for a base case scenario with significant state content. The model predicts up to 7,900 FTE job years and \$1.1 billion in GDP if 100% state content is assumed.
- The NREL JEDI model predicts that the development of a 400 MW Lake Ontario wind energy project could support 6,900 FTE job years and generate \$960 million in GDP for New York State during the construction phase for the base case scenario with significant state content. The model predicts up to 10,500 FTE job years and \$1.5 billion in GDP if 100% State content is assumed.
- Partnerships and collaboration among government, industry academic institutions, and unions is key to addressing GLW energy workforce needs efficiently and effectively—ensuring a higher rate of local labor while also ensuring this local labor is qualified with the necessary skills to obtain and retain jobs.

Regulatory, Environmental, and Permitting

- There are 15 major federal and State permitting or regulatory requirements for New York GLW. The federal processes for GLW are largely driven by or tied to the National Environmental Policy Act (NEPA) review process. At the New York State level, GLW projects with nameplate capacity of 25 megawatts (MW) and above are designated major renewable energy projects and would be under the jurisdiction of the New York State Office of Renewable Energy Siting (ORES) as required under New York State law (Section 94-c of New York State Executive Law). Legislation would have to be passed to allow the State to convey an easement. Without such legislation no structure would be allowed even if all permits, and regulatory requirements were obtained.
- Major utility transmission facilities (e.g., high-voltage electric transmission lines), defined as lines with a design capacity of 100 kV or more extending for at least 10 miles, or 125 kV and over, extending a distance of one mile or more, are subject to Article VII of New York State Public Service Law, in addition to ORES, which grants most approvals of transmission to the Public Service Commission (NYSPSC) for non-federal qualifying projects.
- Environmental, technical, and human conflicts increase with closer proximity to the shoreline (e.g., less than 4 miles), including potential avian interactions, surface ice, sediment toxicity, and viewshed issues. For purposes of this analysis, the area where turbines would most likely be installed was at least 10 mi (16 km) from shore in Lake Ontario and at least 5 mi (8 km) from shore in Lake Erie. These distances allowed the assessment of potential turbine stressors where substantial area for possible development still exists.
- The Visual Impact Study shows that the maximum possible distance that the 6-MW reference turbines, with hub heights of 112 meters, are potentially visible is 26.48 miles. Turbine visibility is reduced significantly by greater distances which reduces the negative impacts on the viewshed. Turbine (layout, size, and coloring), weather conditions and the curvature of the earth can contribute to obscuring the actual visibility of GLW.

Great Lakes Wind is technically feasible and is potentially economically feasible in some locations of the Great Lakes, however some major gaps in the available data were identified that contribute to high uncertainty.

Photo Credit: Getty Images

9.2 Potential Next Steps

This study investigated the feasibility of GLW in the waters of Lake Erie and Lake Ontario adjacent to the New York State. Based on the above key findings, the study indicates that GLW is technically feasible and is potentially economically feasible in some locations of the Great Lakes. However, some major gaps in the available data were identified that contribute to high uncertainty in many areas and should be addressed as part of future assessments, including a comprehensive plan for stakeholder engagement.

Some options for potential next steps that could reduce uncertainty and bring greater clarity to costs and benefits include the following:

- Vessel constraints due to navigation limits through the Saint Lawrence Seaway and the Welland Canal restrict the turbine size and complicate installation logistics, which results in higher costs and inefficiencies. More in-depth analysis is needed to investigate alternative substructure types, vessel alternatives, and corresponding port requirements. This issue has the potential to significantly improve the economics, with the potential for greater cost parity with offshore wind.
- Additional studies should be conducted to investigate the cost of potential port upgrades to support wind energy deployment and possible synergies with other states and other Great Lakes to share vessels, ports, and supply chain facilities on a regional basis. Regional upscaling will support supply chain investments and has the potential to significantly lower cost.
- Methods for accessing wind turbines and maintaining turbines on the Great Lakes will differ from offshore wind projects. A detailed investigation of operation and maintenance strategies, especially in winter months, is needed to lower uncertainty and O&M costs.
- There is a significant lack of data to characterize the worst case extreme ice condition at specific locations on the Lakes. In particular, the physical size, frequency, and speed of ridge ice is highly speculative and GL wind turbines will need better guidance for establishing a design basis.
- General assessment of wildlife behavior, in particular, aerial vertebrates, on the lakes suggests lower risk farther from shore but quantitative data necessary to inform possible mitigation is sparse and more information is needed.
- Due to smaller GL wind turbine sizes, projects can likely be sited closer to shore than offshore wind projects. However, due to the societal implications of viewshed impacts, a comprehensive Visual Impact Assessments should be required for specific projects if New York State proceeds with GLW development.

References

Allyn, Norman, and Ken Croasdale. 2016. “Ice Loads on Lake Erie Wind Turbine Foundations - A Review.” LEEDCo.

Beiter, P., Musial, W., Duffy, P., Cooperman, A., Shields, M., Heimiller, D. & Optis, M. (2020). “The Cost of Floating Offshore Wind Energy in California Between 2019 and 2032.” NREL/TP-5000-77384. https://doi.org/10.2172/1710181.

Beiter, P., Musial, W., Smith, A., Kilcher, L., Damiani, R., Maness, M., Sirnivas, S. et al. (2016). “A Spatial-Economic Cost-Reduction Pathway Analysis for U.S. Offshore Wind Energy Development from 2015-2030.” NREL/TP-6A20-66579. Golden, CO: National Renewable Energy Laboratory. https://doi.org/10.2172/1324526.

Bredesen, Rolv, René Cattin, Niels-Erik Clausen, Neil Davis, Pieter Jan Jordaens, Zouhair Khadiri-Yazami, Rebecka Klintström, et al. (2017). “Expert Group Study on Recommended Practices - Wind Energy Projects in Cold Climates.” IEA Wind Task 19. IEA Wind. https://iea-wind.org/wp-content/uploads/2021/09/2017-IEA-Wind-TCP-Recommended-Practice-13-2nd-Edition-Wind-Energy-in-Cold-Climates.pdf.

BOEM (2021) “Assessment of Seascape, Landscape, and Visual Impacts of Offshore Wind Energy Developments on the Outer Continental Shelf of the United States” BOEM-2021-032, https://www.boem.gov/sites/default/files/documents/environment/environmental-studies/BOEM-2021-032.pdf

Chamber of Marine Commerce. (2021). Wind powers robust project cargo shipping. https://www.marinedelivers.com/2021/04/wind-powers-robust-project-cargo-shipping/.

Coflin, K. C., B. Phu, C.F. M. Lewis, and B. J. Todd. 2017. “Seismic study of ridges on the lake floor in Rochester Basin, eastern Lake Ontario, New York: evidence for till composition.” Open File 8178, Geological Survey of Canada. doi:10.4095/299647.

Douglas-Westwood LLC. (2013). Assessment of Vessel Requirements for the U.S. Offshore Wind Sector (DOE-DWL-05370). https://www.osti.gov/biblio/1095807-assessment-vessel-requirements-offshore-wind-sector.

Environment Canada. (2019, September 26). Canadian Wave Data. https://www.meds-sdmm.dfo-mpo.gc.ca/isdm-gdsi/waves-vagues/index-eng.htm

Great Lakes Aquatic Habitat Framework. 2020. Data: an aquatic, geospatial database for the Great Lakes. Accessed February 22, 2021. https://www.glahf.org/data/.

Great Lakes St. Lawrence Seaway Development Corporation. (n.d.). The Seaway—Great Lakes St. Lawrence Seaway System. Retrieved June 16, 2021, from https://greatlakes-seaway.com/en/the-seaway/.

Great Lakes Wind Collaborative. (2010). The Role of the Great Lakes-St. Lawrence Seaway Ports in the Advancement of the Wind Energy Industry. Great Lakes Commission. https://www.glc.org/wp-content/uploads/2016/10/2010-role-ports-wind-energy.pdf.

Gronewold, A. D., Fortin, V., Lofgren, B., Clites, A., Stow, C. A., & Quinn, F. (2013). Coasts, water levels, and climate change: A Great Lakes perspective. Climatic Change, 120(4), 697–711. https://doi.org/10.1007/s10584-013-0840-2

Hawley, N., Beletsky, D., & Wang, J. (2018). Ice thickness measurements in Lake Erie during the winter of 2010–2011. Journal of Great Lakes Research, 44(3), 388–397. https://doi.org/10.1016/j.jglr.2018.04.004

Hewer, M. J., & Gough, W. A. (2019). Lake Ontario ice coverage: Past, present and future. Journal of Great Lakes Research, 45(6), 1080–1089. https://doi.org/10.1016/j.jglr.2019.10.006

Holbein, T. (2017). IEA Wind TCP Recommended Practice 13 2nd Edition: Wind Energy in Cold Climates.

Hutchinson, D. R., C.F. M. Lewis, and G. E. Hund. 1993. “Regional Stratigraphic Framework of Surficial Sediments and Bedrock Beneath Lake Ontario.” Geographie physique et Quaternaire 47 (3): 337-352. http://doi.org/10.7202/032962ar.

International Organization for Standardization. 2010. ISO 19906:2010 Petroleum and Natural Gas Industries - Arctic Offshore Structures. First edition 2010-12-15. Arctic Offshore Structures 19906. Geneva: ISO.

Jonkman, J., S. Butterfield, W. Musial, and G. Scott. (2009). Definition of a 5-MW Reference Wind Turbine for Offshore System Development. NREL/TP-500-38060. https://www.nrel.gov/docs/fy09osti/38060.pdf.

Karr, Dale G., Bingbin Yu, and Senu Sirnivas. 2015. “Bottom Fixed Platform Dynamics Models Assessing Surface Ice Interactions for Transitional Depth Structures in the Great Lakes: FAST8 – IceDyn.” DOE-MICHIGAN--0005478, 1325200. https://doi.org/10.2172/1325200.

Martini, I. P., & Bowlby, J. R. (1991). Geology of the Lake Ontario Basin: A Review and Outlook. Canadian Journal of Fisheries and Aquatic Sciences, 48(8), 1503–1516. https://doi.org/10.1139/f91-179

McCoy, T. 2014. “Creation of a Model for Interaction of Bottom-Fixed Wind Turbines with Surface Ice for Use with Common Simulation Codes.” DDRP0133-A. DNV GL -. Bai, X., Wang, J., Schwab, D. J., Yang, Y., Luo, L., Leshkevich, G. A., & Liu, S. (2013). Modeling 1993–2008 climatology of seasonal general circulation and thermal structure in the Great Lakes using FVCOM. Ocean Modelling, 65, 40–63. https://doi.org/10.1016/j.ocemod.2013.02.003

McNeilan & Associates, LLC. 2017. “Windfarm Ground Conditions Icebreaker Wind Demonstration Project Lake Erie.” McN&A Project No. 16-02, Norfolk, Virginia.

Morgan, N. A., B. J. Todd, and C.F. M. Lewis. 2020. Interpreted seismic reflection profiles, sediment thickness and bedrock topography in Lake Erie, Ontario, Canada and Michigan, Ohio, Pennsylvania and New York, U.S.A. Open File 8733, Geological Survey of Canada, 26. https://doi.org/10.4095/326715.

Musial, W., Duffy, P., Heimiller, D., & Beiter, P. (2021). “Updated Oregon Floating Offshore Wind Cost Modeling.” https://www.nrel.gov/docs/fy22osti/80908.pdf.

Musial, W., Spitsen, P., Beiter, P., Duffy, P., Marquis, M., Cooperman, A., Hammond, R., & Shields, M. (2021). “Offshore Wind Market Report: 2021 Edition.” U.S. Department of Energy. https://www.energy.gov/sites/default/files/2021-08/Offshore%20Wind%20Market%20Report%202021%20Edition_Final.pdf

National Geophysical Data Center. (1999a). Bathymetry of Lake Erie and Lake Saint Clair [Data set]. National Geophysical Data Center, NOAA. https://doi.org/10.7289/V5KS6PHK

National Geophysical Data Center. (1999b). Bathymetry of Lake Ontario [Data set]. National Geophysical Data Center, NOAA. https://doi.org/10.7289/V56H4FBH

NOAA. (2021). National Data Buoy Center. https://www.ndbc.noaa.gov/

NOAA-GLERL. (2021). Ice Cover. https://www.glerl.noaa.gov/data/ice/#historical

NREL. (2019). “FLORIS. Version 1.1.7.” 2019. https://github.com/wisdem/floris.NREL. (2021). US Offshore Wind Resource data for 2000-2019 [data set]. Retrieved from https://dx.doi.org/10.25984/1821404.

NYISO. (2021) 2021 Load & Capacity Data Report. https://www.nyiso.com/documents/20142/2226333/2021-Gold-Book-Final-Public.pdf/b08606d7-db88-c04b-b260-ab35c300ed64Rissanen, S., & Lehtomaki, V. (2016). Wind Power Icing Atlas (WIceAtlas). https://projectsites.vtt.fi/sites/wiceatlas/www.vtt.fi/sites/wiceatlas.html

Sea Ports of United States US. (n.d.). SeaRates. Retrieved June 16, 2021, from https://www.searates.com/maritime/united_states.html.

Shipwatcher News. (2020). “Current Great Lakes Fleet.” Shipwatcher News Great Lakes Ships (blog). https://greatlakesships.wordpress.com/current-great-lakes-fleet/.

Skamarock, W. C., Klemp, J.B., Dudhia, J., Gill, D. O., Liu, Z., Berner, J., Wang, W., Powers, J. G., Duda, M. G., & Barker, D. M. (2019). "A Description of the Advanced Research WRF Model Version 4." National Center for Atmospheric Research: Boulder, CO, USA.

Sleator, F. E. (1995). GLERL Great Lakes Ice Thickness Data Base, 1966-1979. https://doi.org/10.7265/N5KW5CXG.

Stiesdal. n.d. The TetraSpar full-scale demonstration project. Accessed June 22, 2021. https://www.stiesdal.com/offshore-technologies/the-tetraspar-full-scale-demonstration-project/.

Tajalli Bakhsh, T., Monim, M., Simpson, K., Lapierre, T., Dahl, J., Rowe, J., & Spaulding, M. (2020). Potential Earthquake, Landslide, Tsunami, and Geo-Hazards for the U.S. Offshore Pacific Wind Farms (OCS Study BOEM 2020-040). US Department of the Interior, Bureau of Ocean Energy Management.

Tegen, S., D. Keyser, F. Flores-Espino, J. Miles, D. Zammit, and D. Loomis. 2015. Offshore Wind Jobs and Economic Development Impacts in the United States: Four Regional Scenarios. NREL/TP-5000-61315. National Renewable Energy Laboratory (NREL), Golden, CO (US).

Timco, G., Croasdale, K., & Wright, B. (2000). An Overview of First-Year Sea Ice Ridges. National Research Council Canada. https://doi.org/10.4224/12327286

Timco, G., & Frederking, R. M. W. (1982). Comparative strengths of fresh water ice. Cold Regions Science and Technology, 6(1), 21–27. https://doi.org/10.1016/0165-232X(82)90041-6

Titze, D., & Austin, J. (2016). Novel, direct observations of ice on Lake Superior during the high ice coverage of winter 2013–2014. Journal of Great Lakes Research, 42(5), 997–1006. https://doi.org/10.1016/j.jglr.2016.07.026

U.S. Army Corps of Engineers. (2021). Water Level Data. https://www.lre.usace.army.mil/Missions/Great-Lakes-Information/Great-Lakes-Information-2/Water-Level-Data/

U.S. Department of Energy, U.S. Coast Guard, & U.S. Army Corps of Engineers. (2018). Final Environmental Assessment LEEDCo Project Icebreaker (EA-2045). Appendix C: Favorability Analysis Map. https://www.energy.gov/nepa/downloads/ea-2045-final-environmental-assessment

U.S. National Ice Center. (2021). Great Lakes Products. https://usicecenter.gov/Products/GreatLakesHome

Wang, J., Bai, X., Hu, H., Clites, A., Colton, M., & Lofgren, B. (2012). Temporal and Spatial Variability of Great Lakes Ice Cover, 1973–2010. Journal of Climate, 25(4), 1318–1329. https://doi.org/10.1175/2011JCLI4066.1

Wang, J., Kessler, J., Hang, F., Hu, H., Clites, A. H., & Chu, P. (2017). Great Lakes Ice Climatology Update of Winters 2012-2017: Seasonal Cycle, Interannual Variability, Decadal Variability, and Trend for the period (NOAA Technical Memorandum GLERL-170).

Welland Canal. (2021). In Wikipedia. https://en.wikipedia.org/w/index.php?title=Welland_Canal&oldid=1025632251.

Weston Geophysical. n.d. "Lake Erie Bathymetry and Sediments." Document / Page Pulled 8204280427.Daly, S. F. (2016). Characterization of the Lake Erie Ice Cover (ERDC/CRREL TR-16-5).

Wiser, R., Bolinger, M., Hoen, B., Millstein, D., Rand, J., Barbose, G., Darghouth, N., et al. (2021). "Land-Based Wind Market Report: 2021 Edition." U.S. Department of Energy. https://www.energy.gov/eere/wind/articles/land-based-wind-market-report-2021-edition-released.

Wiser, Ryan, Joseph Rand, Joachim Seel, Philipp Beiter, Erin Baker, Eric Lantz, and Patrick Gilman. 2021. "Expert Elicitation Survey Predicts 37% to 49% Declines in Wind Energy Costs by 2050." Nature Energy 6 (April). https://doi.org/10.1038/s41560-021-00810-z.

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End Notes

[1] http://documents.dps.ny.gov/public/MatterManagement/CaseMaster.aspx?Mattercaseno=15-E-0302

[2] Note that the Lake Erie viewshed distance is only 5 miles because the New York State part of the lake is narrow and a 10-mile distance would probably not be feasible for a large scale GL wind project.

[3] The study is generally site agnostic and reader should not assume that assessment of an area implies that the location is suitable for GLW development.

[4] Tip height = rotor diameter + 25 m clearance from mean lake height, regardless of currently available hub heights.

[5] "Initial Report on the New York Power Grid Study," NY Department of Public Service, NYSERDA, the Brattle Group and Pterra Consulting, January 19, 2021.

[6] "2019 CARIS Report," NYISO, July 2020.

[7] Usage of the term "capacity headroom" is consistent with the definition in NYS PSC Case 20-E-00197, "Staff Straw Proposal for Conducting Headroom Assessments," filed March 16, 2021.

[8] Prior analysis showed that the limiting conditions for capacity headroom in 2025–2030.

[9] "70x30" is shorthand for the requirement of New York State's Climate Act for a minimum of 70% of New York's end-use electrical energy requirements to be generated by renewable energy systems in 2030.

[10] The Zero Emissions Study is included as appendix E to the Power Grid Study.

[11] NYSERDA's Tier 4 solicitation is part of New York State's Clean Energy Standard and was intended to increase the penetration of renewable energy into New York City. Two projects were selected for contract awards. These are the Clean Path NY (CPNY) and Champlain Hudson Power Express (CHPE) projects.

[12] Capacity headroom values are not the same as installed capacity or nameplate rating. An additional calculation is needed to convert the optimal transfer values to the nameplate rating of a specific resource technology. Depending on the quality of the wind available on the lake, the ratio of the nameplate to headroom capacity can vary from 1.0 to 2.0.

[13] Quantities are rounded to the lower 10 MW.

[14] Simple upgrades assume that building a new line or transformer parallel to and of the same voltage level and rating as the constrained facility is sufficient to relieve the constraint. In practice, solutions to transmission constraints may start from this form of simple upgrade to other options such as reconductoring the line, adding a new line on a different right-of-way and/or connecting to different substations, uprating the voltage, rebuilding the line and non-wire and new technology solutions.

[15] Any project that proposes to use State ROW must apply for a NYSDOT highway work permit (Highway Work Permit) and use an occupancy agreement pursuant to 17 New York Codes, Rules, and Regulations (NYCRR) Parts 127 and 131 and NYS Highway Law Section 52. Depending on the impacted facility, FHWA may also have a role.

[16] Quantities are rounded to the lower 10 MW.

[17] Any project that proposes to use State ROW must apply for a NYSDOT highway work permit ("Highway Work Permit") and use an occupancy agreement pursuant to 17 New York Codes, Rules, and Regulations ("NYCRR") Parts 127 and 131 and NYS Highway Law Section 52. Depending on the impacted facility, FHWA may also have a role.

Endnotes (CONT.)

[18] Available on GitHub: https://github.com/JakeNunemaker/FORCE

[19] Note that a detailed treatment of feasibility, costs, and environmental impacts associated with the siting of transmission export cables is beyond the scope of the study. Transmission export cables are a critical component of developing Great Lakes Wind and the study findings did not indicate the export power system would present a major barrier.

[20] Note that the hub height wind speed used for the AEP calculation was the assumed hub height of 112 meters.

[21] More information and a public version of the JEDI model is available at: https://www.nrel.gov/analysis/jedi/.

[22] This IMPLAN economic dataset would be representative of economic conditions in New York State prior to the economic effects of the COVID-19 pandemic.

[23] Manufacturing and supply chain estimates also do not include jobs associated with building the facilities, only jobs associated with producing offshore wind components.

[24] Estimates do not include the jobs or economic impacts from any port infrastructure upgrades. If component production occurs at a port, the jobs associated with the production of those components are categorized under manufacturing and supply chain and not under ports and staging.

[25] The cost analysis doesn’t consider prevailing wage requirements that both Tier 1 and OSW projects face. The ORBIT model and JEDI uses aggregated wages based on a literature review of job postings and IMPLAN economic multiplier data for earnings based on similar industries. Offshore wages may be higher based on State policies.

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