



Electrification of Offshore Wind Marine Terminals

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Preface

This body of work represents a continuum of scholarly research from the Tufts University community regarding the challenges and opportunities emerging from the Great Energy Transition: the global shift to reliable low-carbon energy in response to ever-increasing energy demand. The foundation for this work stems from the pioneering activities undertaken by the Tufts Offshore Wind Program within the Tufts University Department of Civil & Environmental Engineering (CEE), in association with the Jonathan M. Tisch College of Civic Life at Tufts University (Tisch College). The concepts presented herein grew out of an initial analysis of the status of offshore wind port electrification undertaken as part of the Tufts University course CEE-293 entitled “*Offshore Wind Ports, Infrastructure & Logistics*” (Fall, 2023). During subsequent semesters of research, the authors of this report undertook detailed analysis and in-depth research into the challenges, successes, status and future direction associated with the electrification of ports, particularly those involved in the offshore wind industry. Follow-on analysis was also conducted as part of the Tufts University Course CEE-260 entitled “*Offshore Wind Ports and Supply Chain*” (Fall, 2024). The principal authors of this report, Sebastian Barajas Ortiz and Angelica Cheng, conducted the research and analysis and compiled this report as part of special independent study programs administered through the Tufts CEE and Tisch College over the period from 2023 through 2024. This work provides foundational analysis concerning the nascent arena of port and vessel electrification, an area of the energy transition research that is being advanced by the United Nations (UN), the UN Global Compact (UNGC), the International Maritime Organization (IMO), the Oceantic Network, and the American Association of Port Authorities (AAPA). The course of research undertaken by Mr. Ortiz was sponsored by the Tisch Summer Fellows program and conducted in association with the *Salem Alliance for the Environment* (SAFE), an organization based in Salem, MA that advocates for a just, equitable and sustainable future with a focus on environmental justice. This work will be shared with the above noted organizations and individuals for input, comment, and future development. This research on port and vessel electrification will continue at Tufts and will grow and diversify as the field develops.

Jay Borkland, Tufts University, November 2025

Tufts CEE Visiting Scholar (2023) and Lecturer (2024); Instructor for CEE-293 and CEE-260

UNGC Member & Contributing Editor/Author - Practical Guidance, Ocean Stewardship Program
Member AAPA; and Chair emeritus, Board of Directors, Oceantic Network;

Acknowledgements

The authors gratefully acknowledge Matt Shields and Michael Biglu of the National Renewable Energy Laboratory (NREL) for their review of this report and their helpful, detailed feedback.

Sebastian Barajas Ortiz:

In the summer of 2024, this author had the opportunity to join the Tisch Summer Fellows program through Tisch College at Tufts University. This program enabled work with the Salem Alliance for the Environment (SAFE), a non-profit dedicated to advocating for a just energy transition. SAFE's advocacy for port electrification was driven by concerns about the adverse effects of diesel-powered terminal equipment on air quality, particularly in local communities that are primarily made up of people of low income, who bear a disproportionate environmental burden. This report, developed throughout the summer of 2024, reflects the culmination of efforts to assist SAFE in addressing the unique challenges of electrifying the proposed offshore wind marine terminal scheduled to be constructed in Salem Harbor. Beyond the immediate goals in Salem, the aim of this research is to educate a diverse range of stakeholders: community advocates, policy makers, and industry professionals, on the complex landscape of port electrification. The hope is to unify these stakeholders under a common goal: understanding the hurdles ahead and identifying the next steps needed to advance electrification efforts at offshore wind ports across the U.S.

Sincere thanks to Joseph St. Pierre, Project Manager at Crowley Wind Services, and Gordon Carr, Director of the New Bedford Port Authority, for their time and willingness to share their expertise. Their insights into the day-to-day realities of port operations were crucial in grounding this report in practical, real-world insights. Finally, a special thanks to the team at SAFE who inspired the direction of this work through their dedication to environmental justice and advocating for cleaner, healthier communities. Their work on port electrification inspired the goals for this work.

Angelica T. Cheng:

This research was facilitated through the author's shared experience of an undergraduate course of study in Electrical and Electronics Engineering and a Masters program in Offshore Wind Energy Engineering, both at Tufts University. Additionally, insight gained from the Massachusetts Clean Energy Center (MassCEC) Team at the New Bedford Marine Commerce Terminal was pivotal in gaining an understanding of the workings of an operational and active Offshore Wind Marshalling Port. Special thanks to MassCEC's Tim Griffin, Jeanie Houde, Steven Rajnay, and Mike Meyran, for their collaboration and assistance. Their insights and resources were essential to the success of this study. Key strategic concepts regarding the development and operation of Offshore Wind ports was acquired from Mr. Joseph St. Pierre, Project Manager at Crowley Wind Services, who provided valuable input and support during the course of this project. His insights concerning the proposed Offshore Wind facility in Salem Harbor were greatly appreciated. Thank you also to Greg

Dolan, Ports Manager at Avangrid and former manager of the New Bedford Marine Commerce Terminal for his valuable contributions and support. Additionally, this author would like to express appreciation to John McAllister, principal Civil Engineer for McAllister Marine Engineering, for his insightful comments and direction. Thanks also to Rasmus Ager, Project Developer at Port Esbjerg, and Bill Jollimore, at the North Atlantic Ship Repair Company in Seaport, Boston, for their valuable insights and contributions to this project. Additionally, this author would like to acknowledge Per-Anders Lof, Electric Power Planning Systems Engineer at National Grid, for his invaluable guidance.

Lastly, the authors would like to recognize the broader coalition of stakeholders—from local communities to policy makers—who are working tirelessly to advance renewable energy solutions. It is through their collective efforts that we can hope to address the environmental and logistical challenges that lie ahead

Disclaimer

The Authors take full responsibility for the content and discussion presented herein. Any mistakes, omissions, oversight, and opinions expressed here are the sole responsibility of the individuals involved in the production of this work. The research team is happy to receive further feedback as this document reaches a wider audience.

Executive Summary

Offshore wind is the renewable energy of choice in the U.S. Northeast, where states are currently developing over \$20 billion in new assets in partial fulfillment of long-term, gigawatt-scale procurement targets. This industry requires the development of new port infrastructure that will host a wide variety of vessels. Integrating electrification into these facilities is critical for reducing emissions and promoting environmental justice. Diesel exhaust from ships at berth and cargo-handling equipment at ports emit PM, NO_x, SO_x, and VOCs that are linked to asthma, cardiovascular disease, and premature mortality; impacts are concentrated in port-adjacent neighborhoods. In the U.S., about 49.5 million people live within 5 km of ports, and roughly half are people of color and/or low-income. Ports are vital components of the economy, but the diesel they rely on today harms the communities next to them. Electrifying these ports is a practical way to keep the benefits of ports while sharply reducing the health burden on nearby residents.

This report explores the feasibility of offshore wind marine terminal electrification, focusing on two key areas: 1) transitioning from diesel-powered terminal equipment— forklifts, drayage trucks, and cranes— to electric alternatives, and 2) implementing shore power systems that allow vessels to connect to the onshore electrical grid. Real-world results show the scale of benefit: the Port of Long Beach reports ~90% lower diesel PM, ~62% lower NO_x, and ~97% lower SO_x after sustained shore-power adoption alongside equipment programs (see Case Study: Port of Long Beach). The focus of this report is primarily on ship-to-shore power systems, as vessels idling at berths represent a significant source of emissions.

To date, shore-power adoption has centered on container and cruise ports. Offshore-wind terminals, by contrast, present a unique set of challenges that cluster around three themes—non-uniform vessel interfaces, the ability of local grids to deliver multi-megawatt power, and the near-term business case. These challenges elevate design and retrofit risk and often make utility interconnection the schedule driver.

These primary barriers fall into three interrelated areas:

1. **Standardization and vessel variability.** Offshore wind fleets arrive with different voltages, frequencies, and cable/interface requirements. Without common technical standards, ports face higher design and retrofit risk, and actual plug-in rates remain low (as seen in New Bedford's underutilized shore power).
2. **Power capacity and delivery.** Multi-megawatt electrical loads — both for shore power and for heavy-lift equipment — can exceed what local distribution networks can currently supply. Bringing that capacity online often depends on utility interconnection timelines, which can become the critical path. Utilities may also be reluctant to invest quickly when near-term demand is uncertain.

- 3. Economics and adoption dynamics.** Shore power infrastructure can cost on the order of \$1–4 million per berth, and large electric cargo-handling equipment still carries a price premium over diesel. At the same time, many available grant programs do not fully cover core needs like transformers, substations, or first-of-a-kind offshore wind equipment. Vessel owners face their own retrofit costs and reliability questions. Together, these factors reinforce the chicken-and-egg problem: ports hesitate to build systems without confident vessel demand, and vessel operators hesitate to invest without a reliable network of compatible ports.

Taken together, these challenges create real friction. Inconsistent technical requirements increase design and retrofit risk. Limits on available electrical capacity and long interconnection timelines drive schedule risk. Uncertain utilization weakens the near-term business case. For these reasons, coordinated standards, targeted funding, and clear at-berth requirements are paramount to successfully electrifying new marine terminals.

Developing standards for shore-power compatibility, enforcement, and widescale adoption has been challenging, yet workable models exist. International examples—such as Port Esbjerg’s use of established shore-power standards and the sustained public investment at the Port of Long Beach—show that outcomes are strongest when interoperable interfaces are paired with practical delivery steps and clear operating expectations. In near-term practice, pathways include aligning interfaces by referencing recognized standards (e.g., IEC/IEEE 80005) in permits, tariffs, and procurement; coordinating early with utilities to set interconnection milestones and sequence feeder/substation upgrades; and phasing initial high-utilization berths with modular converter and cable systems that can expand as demand grows. These technical steps work best when matched with the business case: make plugging in the default through transparent tariffs or at-berth expectations, target funding to grid bottlenecks (transformers, substations, converters), and secure vessel commitments to plug in when compatible. Collaboration among ports—publishing standard designs and commissioning checklists and sharing utilization data—creates a network effect that reduces stranded-asset risk, improves shore-power availability, and makes vessel retrofitting more feasible. Together, these approaches strengthen the case for electrifying offshore-wind terminals while advancing cleaner, healthier communities. This report outlines the current challenges of electrifying offshore wind ports and highlights potential pathways forward. It is intended to provide stakeholders with the insights needed to navigate these challenges and support the successful electrification of offshore wind terminals.

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1. Introduction

Offshore wind is the renewable energy of choice in the U.S. Northeast, where states are currently developing over \$20 billion in new assets in partial fulfillment of long-term, gigawatt-scale procurement targets. This new U.S. industry depends heavily on port infrastructure for supply chain, construction, and operations. Questions have been raised about the environmental impacts of operations at offshore wind ports. Although these terminals are built to service the buildout of renewable energy, the vessels and equipment necessary to facilitate their work still rely on diesel power, which produces harmful emissions in nearby communities.

Diesel engines are durable and widely used, and even when operating on cleaner marine fuels that are typically used in port. Combustion emits VOCs, PM, SO_x, and NO_x that degrade local air quality and harm health. The EPA and the World Health Organization have classified diesel engine exhaust as a probable human carcinogen.^{1,2} Table 1 summarizes the associated environmental and health concerns related to these emissions.

The adverse effects of port emissions are not uniformly distributed; they largely impact the immediate surrounding communities. Black, Indigenous, and People of Color live near US ports at a disproportionate rate (see Appendix 2). These port communities have borne the brunt of the entire country's energy infrastructure and other industrial activity, and cleaning up the air and water in these communities is part of a just transition to renewable energy.

While the benefits of clean energy are clear, it is essential to address environmental justice concerns, ensuring that historically marginalized communities are not unfairly burdened by the negative impacts of the energy transition. Port electrification directly addresses these issues by shifting port operations from diesel-powered to electric-powered systems.

This transition involves two major adaptations to port operations: 1) installing shore power to enable vessels to connect to the onshore electrical grid while docked at a port, and 2) adopting electric equipment such as trucks and cranes.

¹ Environmental Protection Agency. *Health Assessment Document for Diesel Exhaust*. EPA. (2017, March 21). <https://cfpub.epa.gov/ncea/risk/recordisplay.cfm?deid=17881>

² International Agency for Research on Cancer. "Diesel and Gasoline Engine Exhausts and Some Nitroarenes." <https://publications.iarc.fr/129>

Table 1: Summary of the effects of major emissions from diesel engines³

Emission	Description
VOC	Volatile Organic Compounds (VOCs) are air toxics that cause eye and respiratory irritation, headaches, dizziness, visual disturbances, and memory issues
PM	Particulate matter (PM) emissions can lead to aggravate asthma, increase respiratory symptoms like coughing and painful breathing, and reduce lung function. These impacts can lead to premature death.
SOx	Sulfur oxides (SOx) irritate the nerves in the respiratory tract, leading to coughing, chest tightness, and restricted airways. These effects are particularly pronounced in people with asthma or chronic lung conditions, where the airways are already inflamed and sensitive.
NOx	Nitrogen oxides (NOx), including nitrogen dioxide (NO ₂) and nitric oxide (NO), are key contributors to harmful atmospheric reactions that result in particulate matter, smog, and acid rain. These compounds pose significant health risks, causing respiratory conditions such as asthma, emphysema, and bronchitis, worsening heart disease, damaging lung tissue, and leading to premature death

This report outlines the feasibility of electrification for offshore wind ports. While there has been more success with port electrification at container ports in the United States, electrifying offshore wind terminals is a new feat with a different set of challenges. More literature is needed so that communities who are experiencing new port construction can have access to a shared and cohesive understanding of what port electrification encompasses and the barriers to implementation.

Section Two presented herein describes the context of decarbonization in the maritime sector generally and an overview of port electrification. Section Three provides an overview of the challenges that offshore wind ports face in terms of electrification. Section Four reviews global case studies of electrification initiatives at both container and offshore wind ports, highlighting the insights and lessons learned from these efforts. Section 5 discusses

³Ericsson, Patrik. "Shore-side power supply-a feasibility study and a technical solution for an on-shore electrical infrastructure to supply vessels with electrical power while in port." (2008). <https://sustainableworldports.org/wp-content/uploads/ABB-Master-thesis-shore-side-power-supply-2008.pdf>

existing policies and initiatives for port electrification, specifically in Europe and in California. Section Six covers the status of the future electrification of an upcoming offshore wind port, the Salem Offshore Wind Terminal, and concludes with key considerations and recommendations for advancing port electrification research. Note that in September 2025, federal officials cancelled \$34 million for Salem's pier, stalling near-term work; the pathways and recommendations here are designed to be ready-to-implement if projects resume under future policy conditions.

2. Maritime Sector Decarbonization

Port electrification is one component of a comprehensive need to decarbonize port and other maritime operations. The maritime sector is a major contributor to global greenhouse gas emissions, accounting for approximately 2.89% of global emissions as of 2018.⁴ If no decisive action is taken, emissions from international shipping could increase to between 90-130% of 2008 levels by 2050.⁵ If the sector were considered a country, it would rank among the top ten largest global emitters.⁶ While the sector's global GHG footprint is driven largely by heavy fuel oil used for main propulsion at sea, electricity in port is typically supplied by auxiliary diesel generators operating on marine distillate fuels; offshore-wind service vessels (e.g., SOVs, CTVs) predominantly use 4-stroke diesel engines. As a result, shipping contributes both to global climate change and to localized air pollution in port areas.⁷

2.1 Marine-Side Electrification and Decarbonization

The International Maritime Organization (IMO), a specialized agency of the United Nations established in 1948, regulates global maritime shipping. It sets standards for safety, security, and environmental performance, aiming to promote sustainable shipping practices. The IMO's regulations cover fuels and ship operations at sea and in port—including the auxiliary power that vessels use while berthed—providing the framework within which port-side electrification measures (like shore power) operate. Central to its agenda is the reduction of greenhouse gas emissions, aligning the maritime sector with international climate goals.

In July 2023, the IMO adopted a revised greenhouse gas (GHG) strategy that targets net-zero emissions from international shipping by or around 2050. This strategy includes interim targets to reduce carbon intensity by at least 40% by 2030 and 70% by 2040, relative to 2008 levels.⁸ Additionally, the strategy aims to increase the adoption of zero- or

⁴ Fourth IMO GHG Study 2020 . International Maritime Organization. (2020).

[https://www.wcdn.imo.org/localresources/en/OurWork/Environment/Documents/Fourth IMO GHG Study 2020 Executive-Summary.pdf](https://www.wcdn.imo.org/localresources/en/OurWork/Environment/Documents/Fourth%20IMO%20GHG%20Study%20Executive-Summary.pdf)

⁵ Fourth IMO GHG Study. (2020).

⁶ U.S Department of Transportation. (2023, September). Decarbonizing the Maritime Shipping Industry.

<https://www.transportation.gov/sites/dot.gov/files/2023-09/OSTX-Momentum-Toolkit-Maritime-Shipping.pdf>

⁷ Annex 15 2023 IMO STRATEGY ON REDUCTION OF GHG EMISSIONS FROM SHIPS. International Maritime Organization. (2023, July 7).

[https://www.wcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/MEPCDocuments/MEPC.377\(80\).pdf](https://www.wcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/MEPCDocuments/MEPC.377(80).pdf)

⁸ *Annex 15 2023 IMO STRATEGY*. International Maritime Organization. (2023).

near-zero GHG emission technologies, fuels, and energy sources, with the goal that they represent at least 5%, striving for 10%, of the total energy mix by 2030.⁹

During the UN Global Compact's (UNGC) High-Level Ocean for the Future meeting in September 2024, maritime business leaders and cargo owners gathered at the UN Headquarters in New York to address the urgency of global maritime decarbonization. In a joint statement, they called for a strengthened regulatory framework from the International Maritime Organization (IMO) that is just, inclusive, ambitious, and aimed at accelerating the adoption of zero- and near-zero greenhouse gas (GHG) fuels.¹⁰ The leaders emphasized that the maritime sector, which is extensively regulated by the IMO, is at a critical juncture: achieving ambitious environmental targets while maintaining efficient global trade. The statement underscored the necessity of innovative policies and financial mechanisms to bridge the cost gap between traditional fossil fuels and alternative fuels, which are currently 2-5 times more expensive.¹¹ The business leaders also highlighted that scaling up production capacity and infrastructure for alternative fuels is crucial for the sector's transition to a sustainable economy. Additionally, they stressed the need to scale up production capacity and infrastructure from 2023 strategies for alternative fuels to facilitate a greener supply chain transition.

Meanwhile, at the national level, DOE, DOT, EPA (and HUD) published An Action Plan for Maritime Energy and Emissions Innovation in December 2024 to guide U.S. maritime decarbonization; under the current administration, international carbon-pricing proposals at the IMO have been opposed and delayed, but the domestic plan has not been formally rescinded as of this writing.^{12,13} This initiative aligns with global efforts but also reflects a growing need to prepare domestic industries for evolving regulations. While current U.S. maritime decarbonization efforts primarily focus on the shipping sector, the offshore wind industry must also enhance its electrification initiatives to keep pace with future regulatory requirements.

⁹ *Annex 15 2023 IMO STRATEGY*. International Maritime Organization. (2023).

¹⁰ *Joint statement from Maritime Industry Leaders: UN Global Compact*. UN Global Compact. (2024, September). <https://unglobalcompact.org/news/5293-09-23-2024>.

¹¹ *ADOPTION OF THE INITIAL IMO STRATEGY ON REDUCTION OF GHG EMISSIONS FROM SHIPS AND EXISTING IMO ACTIVITY RELATED TO REDUCING GHG EMISSIONS IN THE SHIPPING SECTOR*. International Maritime Organization. (2018, April). <https://www.scribd.com/document/395130413/250-IMO-Submission-Talanoa-Dialogue-April-2018>.

¹² U.S. Department of Energy; U.S. Department of Transportation; U.S. Environmental Protection Agency; U.S. Department of Housing and Urban Development. *An Action Plan for Maritime Energy and Emissions Innovation*. (2024, December).

https://www.energy.gov/sites/default/files/2024-12/doe-eere-modal-reports_maritime-energy-emissions-innovation-action-plan.pdf

¹³ U.S. Department of State. *Taking Action to Defend America from the U.N.'s First Global Carbon Tax (the International Maritime Organization's Net-Zero Framework)*. (2025).

<https://www.state.gov/taking-action-to-defend-america-from-the-uns-first-global-carbon-tax-the-international-maritime-organizations-imo-net-zero-framework-nzf>

2.2 Power Systems

To understand how port electrification can effectively reduce emissions, it is useful to first explore the components of power systems and how the electrical grid operates. Figure 1 provided by the Pacific Northwest National Laboratory breaks down the grid into generalized sections¹⁴. Centralized generating stations (e.g., coal, nuclear, or renewables), depicted in red, generate power which is then sent through generation step up transformers to increase voltage for long-distance transmission via transmission lines (green). Upon reaching local areas, the power is reduced in voltage by substation step down transformers (purple) for distribution. This local distribution involves feeders, which further split the power into specific zones for end users (blue). Most port electrification technologies connect at this local distribution level, either directly to the substation or to the distribution feeders.

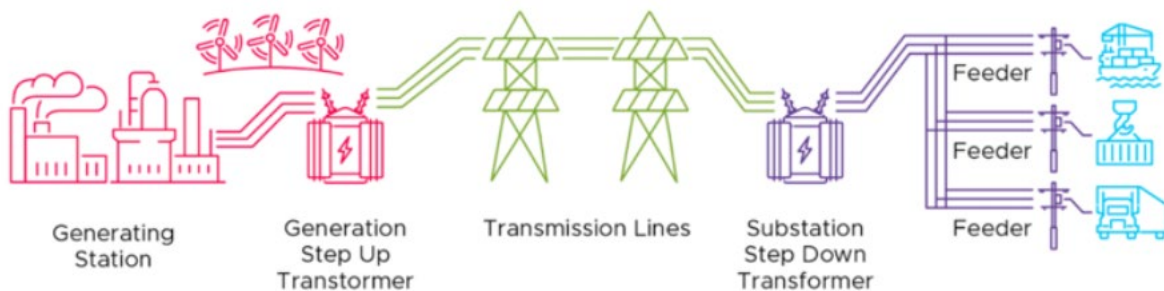


Figure 1: Power System Components¹⁴

2.3 Shore-Side Electrification

In most cases, when vessels are at berth (docked at port), they shut down their main propulsion engines and rely on auxiliary engines operating on marine diesel fuels (e.g. MGO/MDO), not heavy fuel oil, to power essential on-board systems like lighting, radars, sensors, and communication devices. Other electrical loads that vary depending on the ship include cranes, HVAC, and refrigeration. Shore power systems, also known as cold ironing, offer an alternative to running auxiliary engines by connecting vessels directly to the onshore grid, thus significantly reducing emissions at ports. While the push for diesel-electric, hybrid, and full-electric battery-driven vessels is growing in the decarbonization landscape, the massive batteries and charging infrastructure required for these technologies are not yet fully viable. In this context, shore power systems not only reduce

¹⁴ Pacific Northwest National Laboratory. *Port Electrification Handbook*. (2024). <https://www.pnnl.gov/projects/port-electrification-handbook>

current emissions but also serve as a transitional technology, providing the necessary charging infrastructure for current and future electric vessels.

Generally, shore power systems consist of three components: the electrical substation, cable management system (CMS), and ship's electrical equipment on board (See Fig. 2). Electricity from the grid is converted into the appropriate voltage and frequency for the vessel through the substation. Then, power flows through the cable management system (CMS), which consists of the cables that plug into the vessels. On-board vessels must be retrofitted with electrical equipment including a switchboard, power monitoring and control systems, and transformers in the engine room so the vessel receives power from the shore.

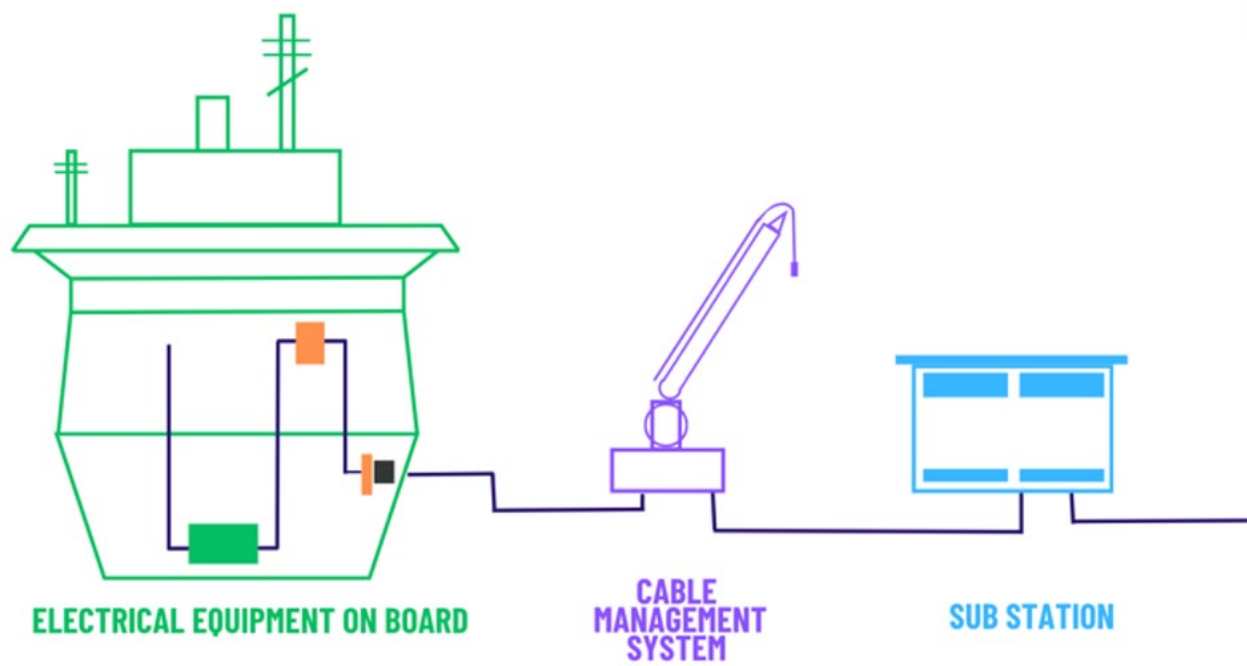


Figure 2: Simplified Shore Power System

There are two categories for shore power systems in the United States: high-voltage shore connection (HVSC) and low-voltage shore connection systems (LVSC). HVSC systems operate at either 6.6 kV or 11 kV and service large cruise, container, and reefer vessels. LVSC systems typically service smaller vessels such as fishing boats, workboats, ferries and tugboats at an operating voltage range between 220-480 V. Early shore power systems primarily relied on LVSC, often requiring multiple cables to supply sufficient power. HVSC systems have gained popularity due to their ability to handle higher power loads with fewer cables, making them easier to manage. To combat the heavier cables used by these systems, CMS technologies equipped with cranes allow for easier handling of cables (See Fig 3). HVSC systems require onboard transformers to match the vessel's voltage level. Both LVSC and HVSC systems may also include frequency converters to accommodate vessels operating on different frequency systems (60 Hz or 50 Hz), adding to the overall

cost. Offshore wind vessels typically require lower power levels, making LVSC systems a suitable and potentially more cost-effective option. However, vessels like the UHL Felicity, frequently utilized in the offshore wind industry for their heavy-lift capabilities, may require HVSC due to higher power demands needed to operate their cranes while at berth (See Fig. 4). The choice between HVSC and LVSC systems ultimately depends on the vessel's size, power requirements, and the specific port's infrastructure.



Figure 3: Shore Power Cable Management System¹⁵



Figure 4: UHL Felicity heavy lift vessel carrying wind components at New Bedford¹⁶

¹⁵ Image Credits: *Call for evidence on shore power: Response from Tyndall Centre, University of Manchester.* Tyndall Centre for Climate Change Research. (2024, May 15). <https://tyndall.ac.uk/reports/call-for-evidence-on-shore-power-response-from-tyndall-centre-university-of-manchester/>

¹⁶ Image Credits: McDermott, J. *New Bedford once lit the world with whale oil. now it wants to do the same with wind power.* AP News. (2023). <https://apnews.com/article/offshore-wind-new-bedford-vineyard-wind-893a59e441e5cf74333b230c5d722fee>

Different connection topologies, such as centralized AC, distributed AC, and DC distribution, can also influence the reliability and cost of shore power systems. Centralized AC, with its single converter, is more vulnerable to failures, while distributed AC offers greater reliability but at a higher cost. DC distribution, which allows integration with renewable energy sources and energy storage systems, offers flexibility but also requires careful monitoring to prevent voltage variations. These topologies play an important role in optimizing the efficiency and reliability of shore power systems.¹⁷

The International Organization for Standardization (ISO), International Electrotechnical Commission (IEC), and the Institute of Electrical and Electronics Engineers (IEEE) have established international standards on shore power to promote global compatibility between ports and vessels. These standards are known as IEC/ISO/IEEE 80005 and provide guidelines on the design, installation, and testing of different shore power systems based on the type of shore power connection system and vessel. IEC/ISO/IEEE 80005-1 are applied to HVSC systems that require more than 1 MVA. LVSC systems that are above 250A or 125A per cable and operate at voltages greater than 300V are covered by IEC/ISO/IEEE 80005-3. Some low voltage European ports have designed their systems to meet this standard, but currently, there are no LVSC in the US that comply with these standards.¹⁸

2.4 Electrification of Port Equipment

Onshore port equipment, such as forklifts, drayage trucks, and cranes, traditionally powered by fossil fuels, are increasingly being replaced by electric alternatives. These alternatives may either be battery-powered or directly connected to the grid, especially for more stationary equipment like heavy-lift cranes. Onshore equipment can be categorized into cargo handling equipment (CHE), essential for transferring offshore wind components on and off vessels and for general port operations, and the vehicle fleet, which includes light, medium, and heavy-duty vehicles either entering and exiting the terminal or used exclusively within it. Electrifying both CHE and the vehicle fleet is crucial for significantly reducing emissions at ports.

To effectively electrify, ports must first assess their current equipment inventory to identify assets that are the heaviest emitters, nearest to end-of-life, or easiest to convert to electric. This process involves evaluating fuel usage, calculating current emissions, and considering equipment age. Some equipment, even if only requiring repowering (an engine

¹⁷ Section Paraphrased from Abu Bakar, N. N., Bazmohammadi, N., Vasquez, J. C., & Guerrero, J. M. *Electrification of onshore power systems in maritime transportation towards decarbonization of Ports: A review of the cold ironing technology*. *Renewable and Sustainable Energy Reviews*, 178, 113243. (2023). <https://doi.org/10.1016/j.rser.2023.113243>

¹⁸ European Maritime Safety Agency (EMSA). *Quick Reference Guide for Development of Shore-Side Electricity/OPS In Maritime Ports*. (2022). Retrieved May 4, 2024, p.g. 4 from <https://maritimecyprus.com/2022/07/31/emsa-guidance-for-shore-side-electricity/>

upgrade), may be worth replacing entirely with an electric counterpart to meet future emissions regulations. Certain operational demands, such as those of stationary or confined-area equipment like ring cranes, are better suited for direct grid connection, providing reliable electricity without the need for charging. Figure 5 shows a concept of Mammoet's SK6000, a 6000t electric ring crane being built now. However, mobile CHE and other vehicles will require energy storage, typically in the form of batteries, introducing requirements related to charging scheduling and infrastructure.



Figure 5: Mammoet SK6000 electric ring crane¹⁹

Electrifying CHE presents new electrical load requirements, which must be carefully planned to ensure sufficient capacity, including considerations for potential electricity regeneration during operations.²⁰ Although electric CHE is generally more expensive than

¹⁹ Image Credits: *Mammoet SK6000* . (n.d.). Mammoet. Retrieved August 26, 2024, from <https://www.mammoet.com/news/worlds-largest-electric-crane-now-being-built/>.

²⁰ Pacific Northwest National Laboratory. *Port Electrification Handbook*.

fossil-fueled alternatives, federal funding such as the EPA’s Clean Ports Program can help offset these costs.²¹

Electrified light-duty vehicles, such as passenger vehicles and pickup trucks, offer zero tailpipe emissions and can contribute to reduced localized air pollution. These vehicles require reliable charging infrastructure, with options ranging from Level 1 and Level 2 AC charging to DC fast charging.²² Medium- and heavy-duty electric vehicles (MD/HD EVs), including drayage and terminal trucks, are also becoming more common, though their electrification depends on operational demands and available charging solutions due to higher power demands. Ports must consider spatial constraints when planning on-site charging infrastructure, particularly for fleets that have traditionally fueled offsite.

The shift towards electrified port equipment is essential for meeting environmental targets, improving air quality for port workers and neighboring communities, and aligning with state regulations like Massachusetts’ Low Emission Vehicle (LEV) Program, which mandates the adoption of cleaner trucks statewide.²³ The following is an inventory of equipment typically seen at offshore wind ports. All of the items below are not yet available as electric models on a commercial level, but pilot projects of these concepts have been in use.

2.4.1 Crawler Cranes

Mounted on an undercarriage, a wheeled structure, crawler cranes are not only ideal for heavy-duty lifting applications, but also are mobile and can carry components around the site. Crawler cranes are used commonly in European offshore wind ports, and some US ports are considering this strategy as well as less self-propelled modular transporters (SPMTs) would be needed on site. The first battery-powered crawler crane in the world LR1160.1 was manufactured by Liebherr but only has a maximum load capacity of 160t²⁴. Cranes suitable for heavy-lifting at an offshore wind port must have capabilities above 1000t.

²¹ Pacific Northwest National Laboratory. *Port Electrification Handbook*.

²² Pacific Northwest National Laboratory. (2024).

²³ Mass.gov. *Massachusetts low emission vehicle (LEV) program*. (n.d.). <https://www.mass.gov/guides/massachusetts-low-emission-vehicle-lev-program#-summary-of-massachusetts-requirements->

²⁴ LR 1160.1 unplugged. (n.d.). <https://www.liebherr.com/en/usa/products/mobile-and-crawler-cranes/crawler-cranes/lr-crawler-cranes/details/lr1160unplugged.html>



Figure 6: Crawler crane²⁵

2.4.2 Ring Cranes

Characterized by its ability to handle heavy loads while making rotational movements along its ring-shaped track, ring cranes are another suitable option for lifting wind turbine components.²⁶ The New Bedford Marine Commerce terminal is currently using the Mammoet PTC35, which is a hybrid crane rated at 1600t.

²⁵ Image Credits: Terex CC6800-1. (2024). Construction Index, from <https://www.theconstructionindex.co.uk/the-digger-blog/view/terex-cc6800-1-used-for-offshore-work-at-hooksiel-wind-farm>

²⁶ Trowbridge, M. Lim, J., Shane, Phillips., Knipe, Ashley. *California Floating Offshore Wind Regional Ports Assessment*. Bureau of Ocean Energy. (2023). Management <https://www.boem.gov/sites/default/files/documents/renewable-energy/studies/BOEM-2023-010.pdf>



Figure 7: Mammoet PTC35 at New Bedford²⁷

2.4.3 Self-Propelled Modular Transporter (SPMT)

SPMTs are motorized platform vehicles that are also used to move heavy loads between the quayside and storage areas. Typically, offshore wind components are placed on storage frames around the site, allowing for SPMTs to roll underneath the components to pick up the frame. A common SPMT model may have a carrying load capacity of 30 metric tonnes per axle.

²⁷ Image Credits: Mammoet's PTC35 Ring Crane with a 1600 Metric Ton Capacity. (2023). Heavy Truck Photos, from https://www.instagram.com/heavytruckphotos/p/C0y0VngLuFN/?img_index=1



Figure 8: SPMT²⁸

2.5 Port Microgrids

Port microgrids are decentralized power systems that significantly enhance the resilience and efficiency of port operations. These systems integrate distributed energy resources (DERs) such as renewable energy sources, energy storage systems, and traditional power generation to create a reliable and sustainable power supply. Port microgrids can operate independently or in conjunction with the main grid.²⁹ As ports transition to electrified operations, including shore power and electric port equipment, more ports are installing microgrids to manage increased power demands and ensure a reliable and stable energy supply.

A key component of port microgrids is their ability to operate in isolation, ensuring that critical port operations continue even during disruptions to the main grid.³⁰ This capability is particularly important for ports that rely heavily on electrified systems (e.g. ports undergoing electrification), where any interruption in power could lead to significant operational delays. Microgrids can vary in complexity, from a simple diesel generator

²⁸ Image Credits: Anster SPMT. (2017). Anster Trailer, from <https://www.anstertrailer.com/wp-content/uploads/2017/04/anster-spmt-1080x647.jpg>

²⁹ Department of Energy. *Microgrids help electrify ports, increase reliability and meet clean energy goals.* (2024, July 18). <https://www.energy.gov/oe/articles/microgrids-help-electrify-ports-increase-reliability-and-meet-clean-energy-goals>

³⁰ Department of Energy. *Microgrids help electrify ports, increase reliability and meet clean energy goals.* (2024, July 18). <https://www.energy.gov/oe/articles/microgrids-help-electrify-ports-increase-reliability-and-meet-clean-energy-goals>

serving a single facility to more advanced systems covering multiple buildings and power sources. These systems are designed to prioritize critical loads, such as security systems and essential port operations, to ensure continuous power supply.

Energy storage systems (ESS) are crucial components of port microgrids, particularly for managing transitions between grid-connected and isolated operations. Battery energy storage systems (BESSs), typically using lithium-ion or lead-acid technologies, store energy during low-demand periods or when renewable energy is plentiful and discharge it during peak times or grid outages. These systems support energy arbitrage by shifting electricity use to off-peak periods, reduce demand charges by smoothing power consumption, and providing critical backup power during outages.³¹ BESS deployment may not always offer the best economic return from a pure energy cost perspective, but they are often justified by their ability to provide backup power, avoid costly infrastructure upgrades, or extend the benefits of other technologies, such as storing on-site solar energy.

One prominent challenge in port microgrids is the significant spatial requirements for renewable energy generation. While some larger ports may have space for on-site, large-scale renewable generation, most are limited to rooftops or small areas. To address this, port microgrids are pointing to offshore generation technologies, such as floating photovoltaic (PV) systems or offshore wind, to increase electricity production without competing for land. This approach would be especially vital in regions like New England, where land is scarce and valuable. Offshore generation systems can be installed on bodies of water, including reservoirs, lakes, or the sea, maximizing exposure to sunlight and wind. A notable example is China's Anhui Province, home to the world's largest floating solar farm, with a capacity of 40 MW, situated on a former coal mining site now submerged underwater.³² This project underscores the potential of floating renewable energy technologies to effectively utilize otherwise unusable spaces. An example of a port microgrid system with multiple energy generation sources can be seen in Figure 9 below.

³¹ Pacific Northwest National Laboratory (2024).

³² Daley, J. *China turns On the World's Largest Floating Solar Farm*. (2017, June 7).<https://www.smithsonianmag.com/smart-news/china-launches-largest-floating-solar-farm-180963587/>

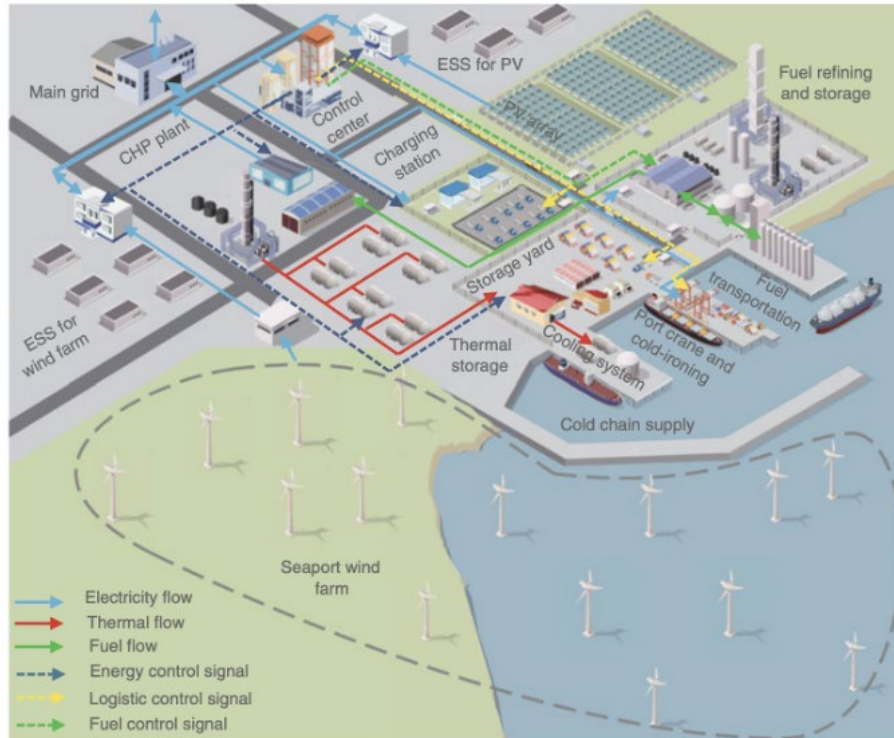


Figure 9: Multi-energy port microgrid³³

3 Challenges to Electrifying Offshore Wind Ports

While much of the existing electrification efforts at ports globally have focused on container ports, offshore wind ports present a unique set of challenges that go beyond the barriers typically faced by other types of ports. The specialized nature of OSW operations, including the handling of large turbine components and the diverse range of vessels required, introduces additional complexities in the electrification process. This section explores the challenges faced by OSW ports in their electrification efforts and analyzes how these challenges may be addressed to support the broader transition to cleaner port operations.

Table 2 provides a summary of challenges, and these are discussed further in the remainder of this section.

³³ Image Credits: Fang, S., & Wang, H. (2021). Multi-energy management of maritime grids. *Springer Series on Naval Architecture, Marine Engineering, Shipbuilding and Shipping*, 155. https://doi.org/10.1007/978-981-33-6734-0_7

Table 2: Summary of challenges associated with the electrification of offshore wind terminals

Challenge	Key Issues	Implications
Standardization & Vessel Variability	<ul style="list-style-type: none"> - Wide variety of OSW vessel types and roles (fleet changes over a project). - Mismatched voltages/frequencies (50/60 Hz) and cable/connector types. 	<ul style="list-style-type: none"> - Higher design/retrofit risk; need for frequency converters and modular cable systems. - Lower actual plug-in/utilization if interfaces don't match.
Power capacity & delivery	<ul style="list-style-type: none"> - Utility may be unable/unwilling to provide required multi-MW capacity - Heavy-lift modes can draw up to ~10× current standard shore power operations. 	<ul style="list-style-type: none"> - Substation/feeder/transformer upgrades and long interconnection lead times; schedule risk.
Financial (Ports)	<ul style="list-style-type: none"> - High capital cost for shore power (~\$1–4M per berth, vessel-dependent). - Lack of applicable grants for OSW-specific gear - Expensive and limited commercial availability of high-power electric equipment (e.g., heavy-lift cranes). 	<ul style="list-style-type: none"> - Long paybacks and weak near-term business case without targeted funding - Phase high-utilization berths first; pair with tariffs/at-berth expectations.
Financial (Vessels)	<ul style="list-style-type: none"> - Vessel retrofitting costs are high - Vessel owners have risk concerns about grid power - Risk of stranded assets 	<ul style="list-style-type: none"> - Owners defer retrofits unless a reliable network of compatible ports exists and usage is predictable.
Adoption Dynamics	<ul style="list-style-type: none"> - Ports hesitate to build without assured usage; vessel owners hesitate to retrofit without a network. - Underutilization observed when only a few ports offer shore power (e.g., New Bedford). 	<ul style="list-style-type: none"> - Regional coordination, standards, and financing tools raise utilization and de-risk retrofits.

3.1 Standardization & Vessel Variability

One of the most pressing challenges in the electrification of offshore wind (OSW) ports is the significant variability among offshore wind vessels, which results in varied voltages, frequencies, and cable types. This lack of uniformity is particularly evident when examining the extensive range of vessel types required for offshore wind projects. To illustrate the diversity of vessel roles needed during construction, Table 3 summarizes the anticipated vessel types required for the construction of Vineyard Wind 1.

Table 3: Anticipated vessel types required for constructing Vineyard Wind 1³⁴

Vessel Type	Count	Vessel Type	Count
Crew Transfer	23	Cable Laying Vessel	1
Fall Pipe	1	Cable Laying Support	2
Heavy Cargo	11	Purpose Built Offshore Vessel	1
DP-2 Support	2	Rock/Mattress Placement Vessels	1
Multipurpose Support Vessel	2	Heavy Lift Vessel	4
Tug	16	Jack-up crane Vessel (WTIV)	2
Barge	5	Service Operation Vessel	1
Floating Crane Vessel	1	Fishing Vessel	6
Floatel Vessel	1	Multi-role Survey Vessel	2
Total Amount of Types	17	Total Amount of Vessels	82

The wide range of vessel types at offshore wind ports makes designing and implementing shore power systems more complex. Ports serving a consistent type of vessel, such as ferries or container ships, benefit from more straightforward shore power system design

³⁴ Information summarized from Vineyard Wind LLC. *Volume I Vineyard Wind Project*. (2020). <https://www.boem.gov/sites/default/files/documents/renewable-energy/Vineyard-Wind-COP-Volume-I-Section-1.pdf>

and implementation. Significant expenses can be saved if shore power systems are designed for less flexibility, such as supporting a single frequency or cable type. For instance, if a shore power system is planned to support only one frequency—either 50 Hz or 60 Hz—costs associated with power frequency converters and other components can be reduced.³⁵ Unlike container ports, where vessel fleets are relatively consistent and standardized, offshore wind ports must accommodate a broad range of vessels, each with distinct power requirements, frequencies and cable standards. Even among vessel types identified in Table 2, huge differences still exist due to varying manufacturers or simply the role of vessels (See Fig. 10). In the U.S., where a multitude of manufacturers provide vessels, this issue is particularly pronounced. As the amount of vessels in a fleet increases, shore power design must be increased in flexibility to tailor to the specific needs of the vessels it serves, increasing both the complexity and cost of these systems.

Offshore wind terminals generally serve two distinct roles. Marshaling ports handle construction logistics—receiving, staging, pre-assembly, and heavy-lift load-out of turbine components—over a short 2–3-year window with many different vessels cycling through. O&M ports support day-to-day operations for the life of the project and rely on a small, stable fleet (mainly SOVs and CTVs). As a result, standardization challenges concentrate at marshaling ports and are typically less acute at O&M bases. At O&M ports, the same ships (SOVs/CTVs) tend to call for twenty to thirty years. By contrast, marshaling ports must accommodate a wide range of vessels with different voltages, frequencies, and cable/interface requirements—often before the final fleet is known—so shore-power systems have to be designed for flexibility to match actual vessel demands. The short construction window (two to three year period), also makes the cost-effectiveness of shore power quite difficult. For an 800 MW project, there may only be a need for 1 SOV. A 1500 MW project may require one SOV and a few CTVs. At a marshaling port, the fleet size ranges between 31 to 98 vessels. CTVs and SOVs can also be involved in the construction phase of a project. A list of offshore wind vessels and their roles is described in Appendix 1.

The challenge of designing shore power systems to accommodate a large and diverse offshore wind fleet can be mitigated through the standardization of voltages, frequencies, and cable types. Port Esbjerg exemplifies the benefits of such standardization. Although the ISO/IEC/IEEE 80005-3 standard was not widely enforced at the time of installation, Port Esbjerg adopted it early, becoming one of the first offshore wind terminals in Europe to implement shore power technology. Faced with uncertainty and a lack of established operating specifications, Port Esbjerg proceeded with the LVSC system requirements outlined by the standard. This early adoption not only streamlined their shore power systems but, in conjunction with EU regulations, it exerted pressure on manufacturers and vessels to adapt the standards. As a result, the standard influenced other ports to follow suit. Shore power system manufacturers across Europe have also begun to standardize

³⁵ Bakar et al. *Electrification of Onshore Power Systems*. (2023).

their cables following Cavotec’s designs to ensure compatibility among various shore power systems.³⁶



Figure 10: Comparison of survey vessels *Encourager* and *Horizon Geobay* serving *Vineyard Wind 1*^{37,38}

3.2 Power Capacity & Delivery

The electrification of ports and design of shore power systems is often constrained by the power capacity that local utilities can provide. Many ports were originally built with electrical infrastructure capable of supporting only minimal loads, such as lighting and small office operations. As a result, significant upgrades are often necessary to support the high power demands of shore power systems and heavy equipment serving offshore wind operations. However, local utilities may struggle to provide the required capacity due to existing electrical infrastructure limitations. Beyond this, local utilities may also be uncertain in the market of shore power and may not want to risk investing in infrastructure upgrades.

Low voltage shore power systems suffice for many offshore wind vessels, covering basic needs like lighting. However, power demands escalate significantly for cargo operations such as cranes in heavy lift mode. For instance, a heavy lift vessel might require up to ten times the current draw compared to standard operations. As wind turbines scale up, reaching capacities of 15 MW or more, the power demands for heavy-lift equipment at ports increase dramatically. The commercial availability of electrified port equipment that meets these high power needs is limited. Few cranes worldwide can handle such large

³⁶Rasmus, A., & Cheng, A. T. *Phone interview about Port Electrification at Esbjerg*. (2024, May 30). Shore Power Vessel Needs. personal.

³⁷ Image Credits: Vineyard Wind. *Offshore Wind Mariner Update No. 39*. (2021, October 27). <https://www.vineyardwind.com/mariners-updates/39>

³⁸ Image Credits: *Horizon Geobay*. Horizon Geosciences. (n.d.). <https://horizon-geosciences.com/vessels/horizon-geobay/>

turbines, and even fewer are electric, as electrification at this scale draws far more power than traditional equipment.

To meet these growing power requirements, ports must work closely with their electric utilities to manage and expand power capacity. Understanding a port’s load profile—including critical and total loads, as well as usage patterns—can help guide strategies to optimize electricity use and reduce overall power demands. Additionally, ports should explore energy efficiency upgrades and consider non-traditional infrastructure solutions, such as microgrids, to increase on-site power capacity. Table 4 provides example electrical loads for a few vessels utilized in offshore wind construction and operations.

Table 4: Sample of technical specification of vessels

Vessel	Voltage (V)	Current Draw (A)	Hotel Loads (kW)
Tug ³⁹	440/480 V	150-200 A	66 kW - 96 kW
Barge ⁴⁰	400 V	75 A	30 kW
Heavy Lift Vessel ⁴¹	400 V	600 A	240 kW

3.3 Financial challenges

Likely the most significant barrier to the electrification of offshore wind ports is the financial burden associated with installing shore power systems and electrifying equipment. The costs associated with installing shore power systems are substantial, encompassing transformers, switchboards, control panels, and the extensive underground cable conduits required for these systems. Costs at the Port of Long Beach ranged from \$1 million to \$4 million per shore power installation (per berth).⁴² For high voltage shore power systems, the supply of high voltage itself has also been indicated as a significant cost. Since offshore wind ports are going to more likely use low voltage, this may not be as

³⁹ St. Pierre, J., & Cheng, A. T. *Phone interview about Shore Power Plans at Salem.* (2024, March 8). Electrification at Salem Terminal. personal.

⁴⁰ Norbuis, J., & Cheng, A. T. *Email Exchange about Vessel Power Needs.* (2024, April 17). Re: Shore Power Study. personal.

⁴¹ Felde, L., & Cheng, A. T. *Email Exchange about Vessel Power Needs.* (2024, April 16). Re: Shore Power Study. personal.

⁴²World Ports Sustainability Program. *Onshore Power Supply.* (2019) WPSP, from <https://sustainableworldports.org/ops/costs/investments/>

applicable.⁴³ Beyond this, electrified alternatives of on-site equipment can be up to twice as expensive as their fossil fueled counterparts.⁴⁴

A major factor exacerbating these costs in the United States is the lack of applicable grants or funding opportunities, particularly for OSW-specific infrastructure. Existing grants, like the EPA's Clean Ports Grant, often focus on container ports and exclude critical first-of-a-kind equipment needed for offshore wind ports since a lot of the equipment is yet to be electrified. These grants also fail to cover essential infrastructure upgrades such as new substations or transformers, which account for the majority of electrification expenses.⁴⁵

In addition to the infrastructure costs on land, there are costs associated with retrofitting ships. Newly built ships may be equipped with transformers and socket outlets for shore connection, but existing vessels must undergo expensive retrofitting to utilize shore power. Retrofitting costs can range from \$300,000 to \$1–2 million per vessel.⁴⁶ Thus, the financial challenge is twofold: ports must not only invest heavily in onshore infrastructure, but ship operators must also bear the cost of retrofitting their fleets. The financial risk is compounded by the long payback periods and the uncertainty around whether the environmental and operational benefits will offset the high upfront investments.

To tackle the financial hurdles associated with electrification, a variety of strategies have been employed. Economic incentives such as construction subsidies, tax deductions or exemptions, rebate programs, and environmental penalties are being increasingly utilized. For example, ports in California have mandated the use of shore power for visiting ships, requiring vessels to be retrofitted and the port infrastructure to be expanded.⁴⁷ This kind of regulation not only creates a stronger market for shore power but also accelerates the electrification process by making it a legal requirement. In Europe, many ports have benefitted from EU funding for high-voltage shore power (HVSC) development, reducing the financial burden on ports.⁴⁸ Limiting shore power installations to a small number of high-occupancy berths can also reduce initial costs, allowing for phased expansion based on demand and budget availability.⁴⁹

In terms of financial frameworks, governments and local authorities can enhance the adoption of shore power through various financial mechanisms, such as providing grants, offering incentives, or sharing some of the financial risks. Implementing pollution penalties for vessels that do not utilize shore power could further encourage compliance. A combined strategy that integrates both financial support and regulatory penalties may be

⁴³ World Ports Sustainability Program. *Onshore Power Supply* (2019).

⁴⁴ Pacific Northwest National Laboratory. (2024).

⁴⁵ Pacific Northwest National Laboratory. (2024).

⁴⁶ Bakar et al. *Electrification of Onshore Power Systems*. (2023).

⁴⁷ Bakar et al. *Electrification of Onshore Power Systems*. (2023).

⁴⁸ Bakar et al. *Electrification of Onshore Power Systems*. (2023).

⁴⁹ Bakar et al. *Electrification of Onshore Power Systems*. (2023).

particularly successful. By blending financial aids with carefully planned infrastructure investments and robust regulatory policies, ports can manage the substantial costs of shore power systems.

3.4 Adoption dynamics: Chicken-and-Egg Problem

The chicken-and-egg problem presents a significant challenge to the adoption of shore power systems at offshore wind ports. High upfront costs for retrofitting vessels discourage shipowners from investing in shore power systems, particularly when only a few ports are equipped with the necessary infrastructure. Additionally, concerns about the reliability of grid electricity and the potential for stranded assets if vessels switch to alternative fuels further deter vessel owners.⁵⁰ At the same time, ports are reluctant to invest in shore power infrastructure without assurance of sufficient vessel usage to justify the expenditure. This creates a feedback loop that impedes progress in port electrification.

Even if a port installs the necessary shore power infrastructure, shipowners may not see a compelling economic reason to retrofit their vessels if only a few ports offer shore power, leading to underutilization of the newly installed systems. This was clearly seen in the New Bedford Marine Commerce Terminal where the challenge was exacerbated by the diversity of vessels and their varying power demands.

To address the chicken-and-egg problem, a coordinated approach involving government and industry is essential. Governments can mandate shore power requirements at ports or offer subsidies to reduce infrastructure cost. A regional approach to shore power creates a network effect: as more ports install shore power systems, vessels within the region are more likely to retrofit because the risk of stranded assets diminishes and increased shore power availability allows vessels can plug in more frequently, leading to significant long-term fuel savings. This collective approach not only makes retrofitting economically viable but also accelerates the transition to cleaner port operations.

Overall, the challenges faced by U.S. offshore wind ports can be effectively addressed through targeted policies that establish a clear and compelling business case for port electrification. By implementing regulations that mandate shore power requirements and offering subsidies to reduce infrastructure costs, the transition to electrified ports can be accelerated. Such policies will not only help overcome the financial and technical barriers but also create a supportive environment that encourages investment in shore power systems and vessel retrofitting. Establishing a robust business case will ensure that the benefits of electrification are realized. Knowing this, the next section will overview existing policies supporting shore power use and electrification.

⁵⁰ St. Pierre, J., & Barajas, S., *Phone interview about Shore Power Plans at Salem*. (2024, July). Electrification at Salem Terminal. personal.

4 Electrification Case Studies

The concept of port electrification, including the adoption of shore power and other technologies, has evolved significantly since its early applications. Initially, the use of shore power was most prevalent among the U.S. Navy. In 1999, the Incentivized Shipboard Energy Conservation (iENCON) program was introduced to promote emissions reductions during naval operations both during travel and while at berth. In comparison to commercial vessels, navy ships have smaller power demands and are at-berth for longer periods of time. At the Port of San Francisco, the average electric hotel load ranged between 497 kW to 790 kW among five naval ships, utilizing shore power during repairs in 2013.⁵¹ Meanwhile, large container and cruise ships have power demands that are three to thirty six times greater, depending on its gross tonnage.⁵² Because of this, retrofitting naval vessels has been more cost effective in comparison to large commercial vessels through shore power use versus bunker fuel costs.

Following these early initiatives, electrification expanded into the commercial sector, with a significant focus on high-voltage shore power (HVSC) systems over the past two decades. This shift was driven by the need to address the high power demands of some of the most polluting vessels at berth, such as large cruise ships, container ships, and refrigerated vessels. HVSC systems are designed to meet these vessels' substantial energy needs while minimizing power losses. The California Air Resources Board (CARB) played a crucial role by mandating shore power use for certain vessels, leading to widespread adoption in the state and further efforts to electrify. Globally, the movement towards port electrification has gained momentum, with international ports embracing similar strategies. For example, the EU's Fit for 55 program highlights shore power as a key component in broader decarbonization efforts. These initiatives reflect a growing trend towards integrating cleaner technologies and reducing the environmental impact of port operations.

This section will explore specific case studies of electrification at various ports, highlighting their approaches, successes, and challenges. By examining these examples, we can gain insights into the obstacles and potential solutions of port electrification.

4.1 Electrification at the Port of Long Beach

As a central hub for US-Asia trade, the Port of Long beach occupies 3200 acres of land southwest of Downtown Long Beach, 25 miles from Downtown Los Angeles.⁵³ Together

⁵¹ EPA. *Shore Power Tech Assessment*. (2022).

⁵² European Maritime Safety Agency (EMSA). *Quick Reference Guide for Development of Shore-Side Electricity/OPS In Maritime Ports*. (2022). Retrieved May 4, 2024, p.g. 4 from <https://maritimecyprus.com/2022/07/31/emsa-guidance-for-shore-side-electricity/>

⁵³ Port of Long Beach. *Facts at a Glance - Port of Long Beach*. (n.d.). Retrieved February 22, 2024, from <https://polb.com/port-info/port-facts-faqs/#facts-at-a-glance>

with the Port of Los Angeles, these ports share the San Pedro Bay. While to this day, they are still the largest sources of emissions in the metropolitan Los Angeles area, both ports have made tremendous progress in adopting cleaner environmental and electrification practices. In fact, the Port of Long Beach was awarded the title “Best Green Seaport” by industry peers in 2018. Since the adoption of the Green Port Policy in 2005, Long Beach was able to meet all its 2023 emission reduction targets that were outlined in the San Pedro Bay Ports Clean Air Action Plan. Overall, the port observed a 90% reduction in diesel particulate matter, 62% reduction in nitrogen oxides, and 97% decrease in sulfur oxides.⁵⁴

⁵⁴Port of Long Beach. *Port of Long Beach meets 2023 Air Goals*. (2021, October 28). <https://polb.com/port-info/news-and-press/port-of-long-beach-meets-2023-air-goals-10-28-2021/>

PORT OF LONG BEACH
BRIEF HISTORY

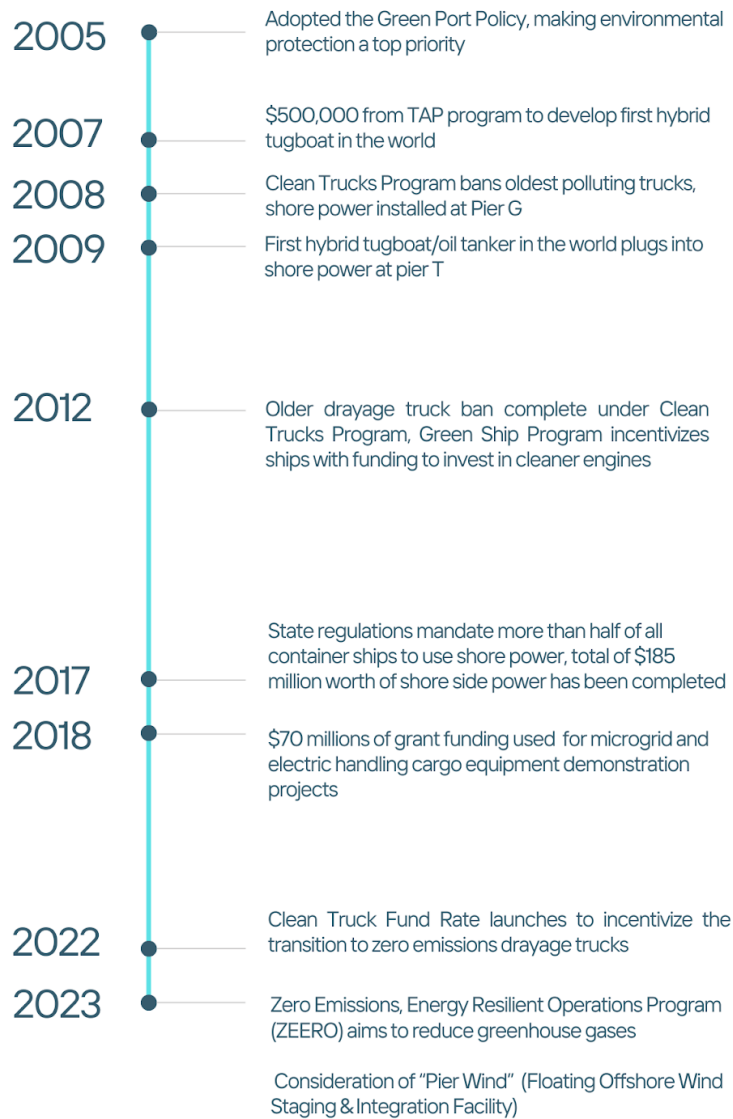


Figure 11: Timeline of Long Beach’s Environmental Programs⁵⁵

The timeline provided in Figure 11 emphasizes Port of Long Beach’s key programs relevant to the electrification of equipment and utilization of shore power. It should be noted that the vast majority of the programs are aimed at electrification onshore rather than shore power.

⁵⁵ Information in original graphic summarized from *The Green Port Through the Years*. polb. (n.d.). <https://polb.com/port-info/green-port/>

Long Beach has 16 high-voltage shore power berths with a total maximum capacity of 16 MW. The first was installed for tanker vessels in 2000. Fifteen remaining plugs are utilized by container vessels while one is used for cruise ships. There is one low voltage shore power system with a maximum capacity of 0.3402 MW and was originally installed for Foss' Carolyn Dorothy hybrid tugboat, which began service in 2009. Installation and infrastructure costs to develop these shore power systems cost more than \$185 million.

Looking forward, the port is continuing to accelerate their efforts towards reducing greenhouse gasses 40% below 1990 levels by 2030 and 80% below 1990 levels by 2050. One initiative includes increasing rail capacity to decrease the number of truck trips needed to move cargo. This project involves doubling the size of the rail system to 171 acres and tripling the volume of the rail capacity. The project has been awarded a total of \$643 million in federal, state, and local grant funding thus far.⁵⁶ Moreover, the port will continue with the electrification of cargo handling equipment and trucks as outlined in their goals for their whole fleet to be zero-emissions by 2030 and 2035 respectively. Much of the existing electric terminal equipment is part of one of six demonstration projects that were granted funding in 2017 after an update to the Clean Air Action Plan. \$80 million was awarded by the California Energy Commission and the California Air Resources Board to support these initiatives. Lastly, in 2022, the port began constructing a microgrid that includes a 300 kW PV solar panel array, which is expected to reduce the port's reliance on diesel backup generators and save \$60,000 annually in electricity costs.⁵⁷

Regarding transportation, The Clean Trucks Program has been estimated to reduce emissions from the older, heavy polluting diesel trucks by 90%. Currently, there are 36 zero-emission trucks in a fleet of more than 23,000 serving the Ports of Long Beach and Los Angeles.⁵⁸ To incentivize the transition to cleaner trucks, \$60 million has been made available for the purchase of Class 8 drayage trucks through the Clean Truck Fund Rate.⁵⁹

⁵⁶ Port of Long Beach. *Port of Long Beach prepares for "year of rail" in 2024.* (2024, January 17). Polb. <https://polb.com/port-info/news-and-press/port-of-long-beach-prepares-for-year-of-rail-in-2024-01-17-2024/https://polb.com/port-info/news-and-press/port-of-long-beach-prepares-for-year-of-rail-in-2024-01-17-2024/>

⁵⁷ Hitchens, K. *Port of Long Beach, Schneider Electric start construction on \$12.2 million microgrid project.* (2022). Microgrid Knowledge. <https://www.microgridknowledge.com/google-news-feed/article/11427396/port-of-long-beach-schneider-electric-start-construction-on-122-million-microgrid-project>

⁵⁸ Munoz, A. *Port of Long Beach announces step toward zero-emissions trucking.* ABC7 Los Angeles. (2022, November 20). <https://abc7.com/port-of-long-beach-zero-emissions-trucking-california-cargo-trucks/12469982/>

⁵⁹ Port of Long Beach. *Charging station to power electric trucks in Port.* (2023, November 30). <https://polb.com/port-info/news-and-press/charging-station-to-power-electric-trucks-in-port-11-30-2023/#:~:text=The%20announcement%20comes%20as%20the,be%20zero%2Demissions%20by%202035>

Long Beach has also set targets to have 100 public charging stations for electric trucks by 2026. Plans are to install 55 chargers throughout 2024.⁶⁰

Table 5: Summary of electrification demonstration projects funded in 2017⁶¹

Demonstration Project	Equipment Included	Cost	Grant
Zero-Emissions Terminal Equipment Transition	<ul style="list-style-type: none"> ● 9 Electric Rubber-Tire Gantry Cranes ● 12 Yard Tractors ● 4 Hybrid and Electric Drayage Trucks 	\$13.7 million	\$9.7 million
Sustainable Terminals Accelerating Regional Transformation Project (START)	<ul style="list-style-type: none"> ● 34 zero emission Cargo-Handling equipment ● 2 Clean Container Ships ● 1 Electric-Drive Tugboat ● 5 Electric Trucks ● 2 Heavy-Duty Truck Charging Outlets 		\$50 million
Port Advanced Vehicle Electrification (PAVE)	<ul style="list-style-type: none"> ● Battery-Electric Yard Tractors and Forklifts and Charging Infrastructure 	\$16.8 million	\$8 million
Microgrid	<ul style="list-style-type: none"> ● 300 kW Solar Array ● 250kW Battery Energy Storage System 	\$7 million	\$5 million
C-Port Zero Emissions Demonstration	<ul style="list-style-type: none"> ● 3 Battery-Electric Top Handlers ● 1 Hydrogen Fuel Truck ● 1 Battery Electric-Yard Truck 	\$5.3 million	
Port Community Electric Vehicle Blueprint	<ul style="list-style-type: none"> ● Blueprint for path to zero emissions 		\$200,000

⁶⁰ Port of Long Beach. *Port partners power ahead with truck charging stations*. (2024b, January 30). <https://polb.com/port-info/news-and-press/port-partners-power-ahead-with-truck-charging-stations-01-30-2024/>

⁶¹ Port of Long Beach. (n.d.). *Fact Sheet Grant-Funded Zero-Emission Demonstration Projects*. Retrieved February 12, 2024,.

The Port of Long Beach’s electrification efforts underscore several key lessons. First, successful port electrification in the U.S. often relies on robust public funding and supportive policies. The substantial grants and incentives (see Table 5) provided enabled the port to implement advanced electrification technologies and infrastructure, demonstrating the importance of financial and policy backing in driving such initiatives. Second, the port’s achievements in reducing greenhouse gas emissions and improving air quality highlight the substantial environmental impact of electrification. The significant reductions in diesel particulate matter, nitrogen oxides, and sulfur oxides not only advance environmental goals but also contribute to better health outcomes for the local community.

4.2 Electrification at Port Esbjerg

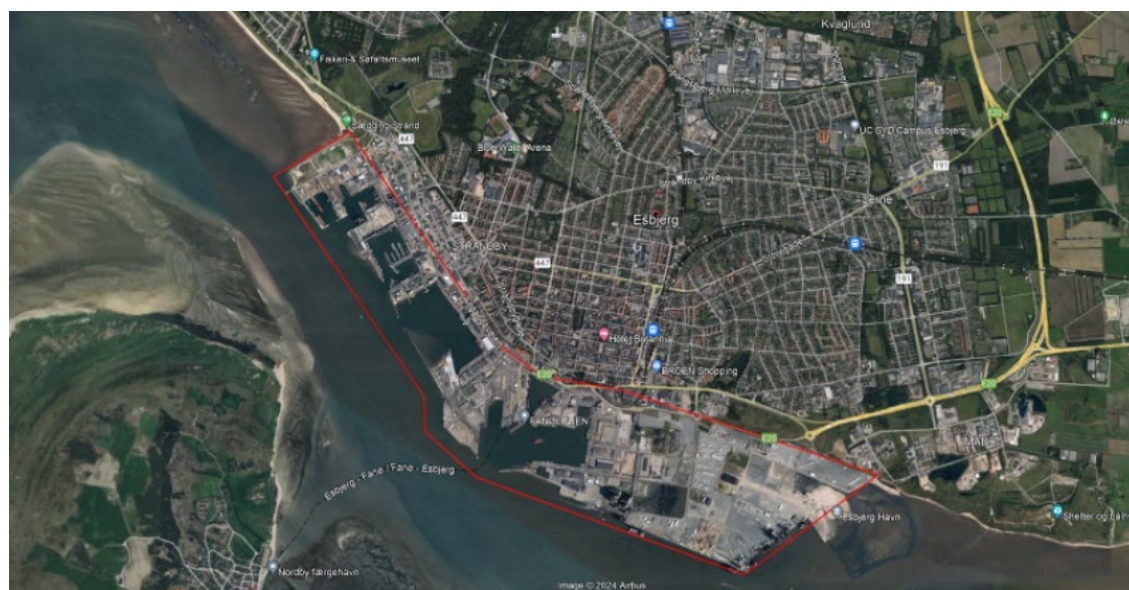


Figure 12: Port of Esbjerg⁶²

At 1111 acres, the Port of Esbjerg sits on the Southwest Coast of the Jutland Peninsula in Denmark. Port Esbjerg has been involved in the installment of 80% of offshore wind capacity in Europe, totaling 23.6 GW.⁶³ Historically, Port Esbjerg was a large fishing port that eventually transitioned into an oil and gas hub in the North Sea through the 1970s. By the beginning of the millennium, the offshore wind industry started to take root as Esbjerg became the center of operations for the installation of the first large-scale offshore wind

⁶² Image Credits: Google Earth, Retrieved on February 20, 2024

⁶³ Port Esbjerg. (n.d.). Offshore Wind, Port Esbjerg, from <https://port esbjerg.dk/en/business-areas/offshore-wind#:~:text=The%20Port%20of%20Esbjerg%20is,wind%20farm%2C%20Horns%20Rev%20>

farm Horns Rev I in 2002. Horns Rev II was later installed in 2009 with a total capacity of 209 MW, and today, the project supplies power for the entirety of port Esbjerg.⁶⁴

In 2020, Esbjerg established a partnership with Honeywell to develop a plan that targets a 70% reduction in carbon emissions 2030, primarily through the use of shore to ship power units, digitalization of energy consumption to track energy consumption, investments in electrical vehicles and equipment, and efficient management of water consumption and heating. 95% of all vehicles at Esbjerg are electric vehicles and the port aims to electrify the rest of the fleet by 2025.⁶⁵ The main barrier in fully electrifying the fleet is a lack of capacity onsite from the grid. This is also a reason why operating equipment like cranes have not been electrified.⁶⁶

Esbjerg joined the global “Getting to Zero Coalition” in 2020, which is an alliance that is committed to reducing greenhouse gasses from international shipping by 50% by 2050 compared to 2018 levels. One of the primary strategies involves transitioning to zero emission vessels by 2030.⁶⁷ As part of these commitments, Esbjerg is also making ambitious strides for carbon neutrality by the end of the decade through the establishment of primarily three new systems to address major sources of greenhouse gas emissions. The establishment of a micro green electricity grid will be used for delivering green shore power to ships, cranes, and handling equipment. A green energy grid will deliver e-fuels such as ammonia, methanol, and hydrogen for ships. A new waste management system will sort solid and fluid waste streams where it will be treated for reuse.

⁶⁴ Port Esbjerg. *Port Esbjerg History*. (n.d.). <https://port esbjerg.dk/en/about-us/history>

⁶⁵ Nastu, Jennifer. *Port Esbjerg Powers Docked Vessels with Wind Turbines Instead of On-board Diesel Generators*. (April 8, 2021). Environmental Energy, from <https://www.environmentenergyleader.com/2021/04/197901/>

⁶⁶ Rasmus, A., & Cheng, A. T. *Phone interview about Port Electrification at Esbjerg*. (2024, May 30). Shore Power Vessel Needs. personal.

⁶⁷ Port Esbjerg. (n.d.). *Sustainable Initiatives*. Port Esbjerg, from <https://port esbjerg.dk/en/our-focus/sustainable-initiatives#:~:text=Port%20Esbjerg%27s%20sustainability%20strategy&text=The%20Port%27s%20sustainability%20strategy%20focuses,of%20our%20port%2Drelated%20operations>

PORT OF ESBJERG
BRIEF HISTORY

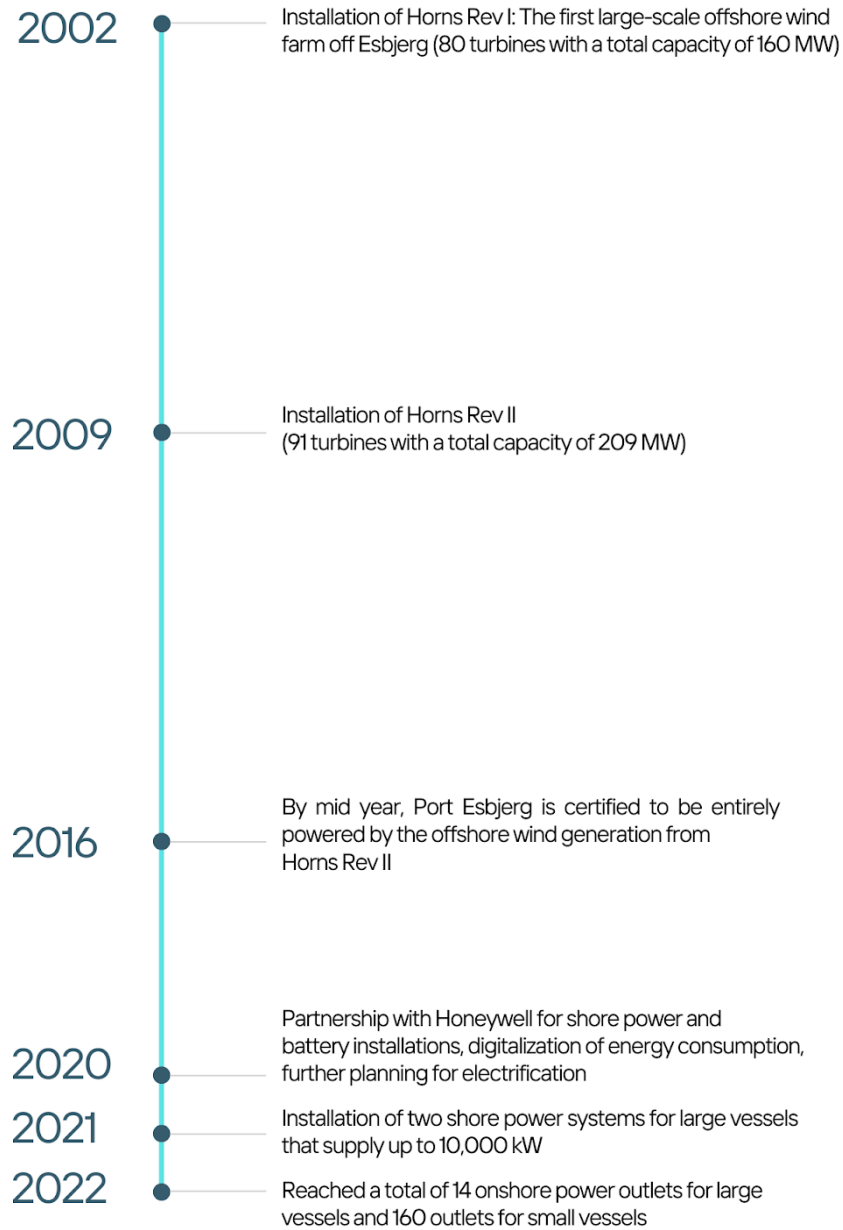


Figure 13: Port of Esbjerg timeline

Since a majority of emissions do come from vessels calling at port, the port's environment initiatives have mainly been focused on the installation of shore power systems.⁶⁸ Currently, Esbjerg has 174 shore power connections, which all comply with the IEC 80005-3 standard.⁶⁹ In 2021, the port installed its first two shore power systems at Geminikaj quay 719/720. They have a capacity to supply up to 10,000 kW each at 500A.⁷⁰ These units provided power to two major offshore wind installation vessels the Sea Installer and Sea Challenger for monitoring systems, pumps, ventilation, and crew welfare facilities.⁷¹ This led to a reduction of carbon emissions by almost 30%.⁷²

The Port Esbjerg team has advanced these efforts by installing what they call shore-to-ship power units which connect vessels directly to offshore wind turbines, ensuring that docked vessels can operate on renewable energy. The shore-to-ship power has a capacity of 1,300 Amp/1.5 MW that can also support huge installation vessels (See Fig. 14).⁷³ By the end of 2022, Esbjerg installed 12 more onshore power outlets for large vessels and 160 outlets for small vessels.⁷⁴ The outlets for small vessels operate at 380V. The power supplied is not sufficient for turning off auxiliary engines onboard but only used to do maintenance on board. On average, each outlet for its large vessels costs about \$2-3 million while the outlets for small vessels are \$1 million. Overall, 60-80% of vessels plug into shore power at Esbjerg. The main reasons why a vessel may not be able to plug in is because either no shore power is available or the vessel has not been retrofitted.

⁶⁸Port Esbjerg. *Getting to Zero Plan*. (2021, September).

https://portesbjerg.dk/downloads/getting_to_zero_plan_4_0-1-uk.pdf

⁶⁹ Port Esbjerg. (rep.). *Port Esbjerg Annual Report 2022*. (2022).pg. 2&7., from https://portesbjerg.dk/pdflibrary/Annual_Report_2022_final.pdf

⁷⁰ Nordic Innovation. (n.d.). *Appendix IV: Status on onshore power supply in Danish ports*, from <https://pub.nordicinnovation.org/On-Shore-Power-Supply-in-the-Nordic-Region/appendix-iv-status-of-on-shore-power-supply-in-danish-ports-.html>

⁷¹ Russel, Tom. *Installation vessels use shore-to-ship power in Esbjerg*, from <https://www.4coffshore.com/news/installation-vessels-use-shore-to-ship-power-in-esbjerg-nid20967.html> (October 2, 2021).

⁷² Port Esbjerg. (rep.). *Port Esbjerg Annual Report 2021*. pg. 2, from https://portesbjerg.dk/downloads/rapport_2021_uk.pdf (2021).

⁷³ Kulovic, N. *Maersk drilling connecting rigs to green shore-to-ship power while docked at Esbjerg*. (2022, January 28). *Offshore Energy*. <https://www.offshore-energy.biz/maersk-drilling-connecting-rigs-to-green-shore-to-ship-power-while-docked-at-esbjerg/>

⁷⁴ Port Esbjerg. (rep.). *Port Esbjerg Annual Report 2022*. pg. 2, from https://portesbjerg.dk/pdflibrary/Annual_Report_2022_final.pdf (2022).



Figure 14: World's largest installation vessel *The Voltaire* using shore-to-ship power at Port Esbjerg⁷⁵

To enhance electrification efforts, Port Esbjerg's Micro Green Energy Grid is intended to address the power capacity challenges associated with shore power. This microgrid operates as a demand-driven system, intelligently adjusting power distribution based on real-time needs.⁷⁶ It includes components such as transformers, which convert electricity from the grid's standard 50 Hz to the 60 Hz needed by most ships, and fuel cells, which can generate electricity from hydrogen, biodiesel, or biogas when grid power is insufficient or unavailable.⁷⁷ This ensures that ships, cranes, and other port operations receive the necessary green electricity without overloading the system.

⁷⁵ Image Credits: *The world's largest installation vessel was readied in Esbjerg before job to install giant North Sea wind turbines - esbjerg havn*. Port Esbjerg. (2023, June 23). <https://portesbjerg.dk/en/news/the-worlds-largest-installation-vessel-was-readied-in-esbjerg>

⁷⁶Port Esbjerg. *Getting to Zero Plan*. (2021, September). https://portesbjerg.dk/downloads/getting_to_zero_plan_4_0-1-uk.pdf

⁷⁷Port Esbjerg. *Getting to Zero Plan*. (2021, September). https://portesbjerg.dk/downloads/getting_to_zero_plan_4_0-1-uk.pdf

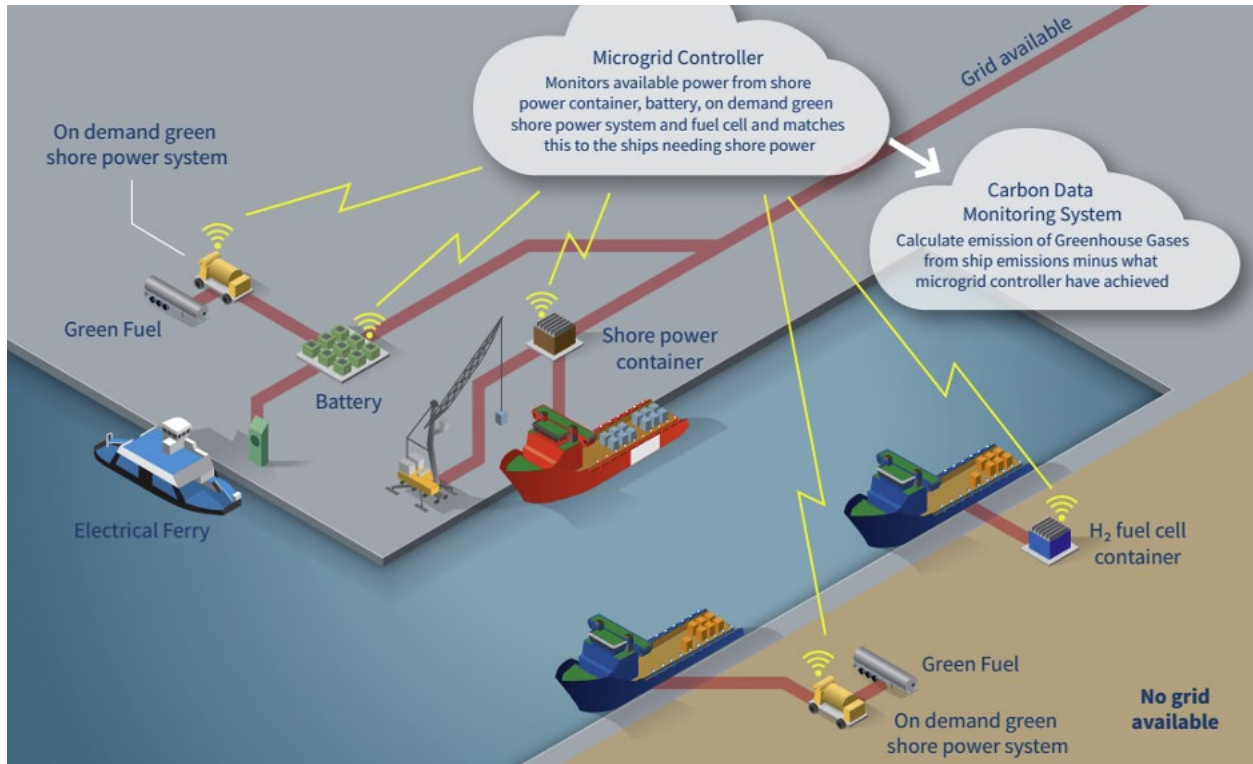


Figure 15: Port Esbjerg microgrid system⁷⁸

The experience at Port Esbjerg highlights several important lessons for port electrification. First, the digitalization of electricity consumption has proven essential in optimizing daily operations, allowing the port to track and manage energy use more effectively. Additionally, by adhering to the IEC/IEEE 80005 shoreside connection standards, both Port Esbjerg and European vessels ensure compatibility, which is critical for seamless shore power adoption. The decision to mainly work with a single manufacturer, Cavotec, has also streamlined installations, reduced costs, and supported the standardization process. Finally, the implementation of a microgrid has played a crucial role in addressing grid capacity limitations, enabling the port to sustain its electrification efforts even as demand grows.

4.3 Electrification in New Bedford

New Bedford Marine Commerce terminal is the first offshore wind marshaling port in the country. It is currently serving the buildout of Vineyard Wind 1. The city New Bedford is one

⁷⁸Port Esbjerg. *Getting to Zero Plan*. (2021, September). https://port esbjerg.dk/downloads/getting_to_zero_plan_4_0-1-uk.pdf

of 20 towns in Massachusetts that meets all the EJ designation criteria.⁷⁹ As shown in Figures 16-17, a majority of the neighborhood blocks surrounding the New Bedford port are EJ communities.

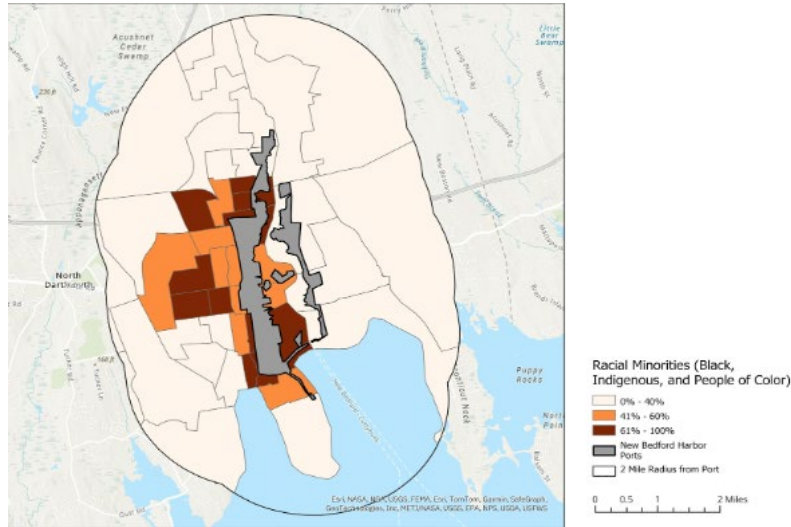


Figure 16: Percentage of minorities around New Bedford

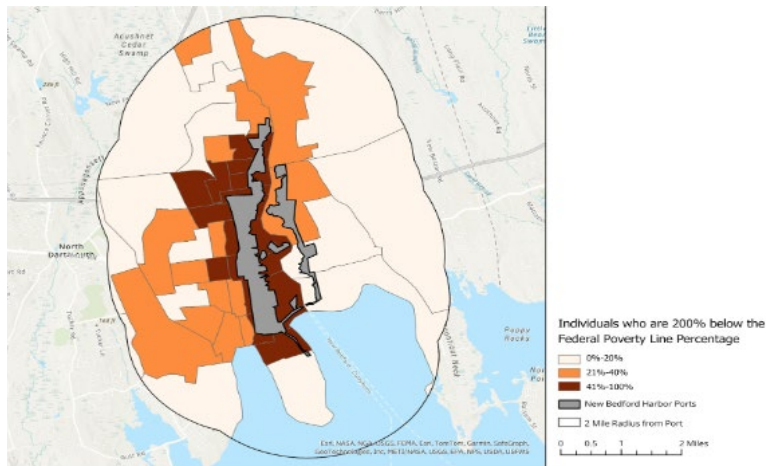


Figure 17: Percentage of low income around New Bedford

At the 26 acre port, two shore power connections were completed at the commerce terminal in 2015. The total cost was \$400,000 for the procurement of the equipment, installation, and changes to the design of the terminal to accommodate the shore power.⁸⁰

⁷⁹ Mass Gov. *Cities and Towns that Include Environmental Justice Communities*. (July 2016). MA Executive Office of Energy and Environmental Affairs, from <https://www.mass.gov/files/documents/2016/07/ta/ej-cities-towns.pdf>

⁸⁰ Morant, George. *Re: Costs of Shore Power Systems*. personal communication. (2024).

Both connect points are a three phase system that operate at 240V or 480V and can draw up to 3000A of current. So far only Alpine’s RV shearwater vessel has made use of the shore power. The low utilization rate is due to the mismatch in operating voltage and frequency of the vessels as well as the physical cable. There is also simply a lack of incentive for vessel operators to plug in since there is no mandate for shore power use. The MassCEC team has discussed strategies to encourage shore power via economic incentives, including updating the terminal tariff such that quayside charges are reduced when vessels commit to shore power. The terminal hopes that as port electrification becomes more widespread, there will be greater motivation for operators to retrofit their ships once they are able to receive power from the shore at more ports.

Table 6: Existing shore power at the New Bedford Marine Commerce Terminal

Shore Power Berth	Operating Voltage (V)	Current Draw (Amps)
Connection Point 1	240, 480	3000
Connection Point 2	240, 480	3000

Recently, the terminal applied to the Clean Ports Grant to fund their planning phase of electrification. As of now, there are no concrete plans for expanding shore power in the near future. Much of the focus has been on building a flexible distribution system of the grid power to different loads all over the site. Some of the loads include powering internal systems within turbine components such as the towers and nacelles. Both components require power for preservation and commissioning. Preservation mostly consists of running dehumidifier units to control moisture. The dehumidifiers must run at all times even during transportation to the project site. Commissioning involves running tests to ensure functionality. In a nacelle, the rotor⁸¹ and yaw system⁸² is tested. Diesel generators are currently used on-site as the port does not have capacity to power all components as necessary. Each turbine will also have backup batteries for when they are installed offshore at the project site. The commerce terminal has a small storage area for 3500 batteries, where every unit will be charged before deployment. Other electrical loads include lighting for blade racks and general lighting all over the site at night.

⁸¹ Rotor connects to the generator through a shaft.

⁸² Yaw systems contain a wind direction sensor to orient the turbine towards the wind.

Table 7: Summary of additional loads at the New Bedford Marine Commerce Terminal

Load	Description	Technical Specifications
Blade Rack	To provide lighting	20A Circuit
Towers	Preservation and Commissioning Power	Preservation: 8 Dehumidifier Units (230V, 8A circuit each)
Nacelles	Preservation and Commissioning Power	Preservation: 8 Dehumidifier Units (230V, 16A circuit each) Commissioning: 125A Circuit
Backup Batteries	Backup power system for offshore wind turbines at project site	Each battery is 44V
Trailers	Offices and conference rooms for workers at terminal	

Although there have been challenges to immediately implement electrification for loads at the pre-assembly area, there are plans to deploy solar and green technologies for a new office and warehouse onsite. While all equipment at the terminal is rented, there will be a preference to acquire electric forklifts and other small light duty equipment. Charging points will be installed for this fleet of terminal equipment.

The New Bedford Marine Commerce Terminal's efforts in shore power and electrification offer several valuable lessons. Firstly, the importance of optimizing the location of connection points for power distribution. The utilization of space at a port changes between different offshore wind projects or even within the lifetime of a single project, affecting where turbine components are stored and where equipment is needed. The terminal has found that creating a flexible electrical distribution system is the best approach to address these changes. For example, having above-ground wires instead of underground conduits allows for easier relocation of connections. Secondly, the low utilization of shore power at New Bedford is largely due to a lack of standardization in voltages, frequencies, and cables, underscoring the need for standardized systems to improve compatibility and usage rates. Additionally, the absence of regulatory mandates

diminishes vessel operators' incentives to retrofit their ships, highlighting the role of policies in driving adoption. Lastly, effective load profiling is essential to understand capacity requirements and anticipate future demand, thereby avoiding reliance on additional diesel generators.

4.4 Key Takeaways from Case Studies

The case studies of the Port of Long Beach, Port Esbjerg, and New Bedford illustrate crucial lessons for advancing port electrification and shore power adoption. Standardization across electrical infrastructure emerges as a critical factor for successful implementation. At the Port of Esbjerg, adherence to the IEC 80005-3 standard ensured compatibility and facilitated widespread shore power use, highlighting the importance of uniform technical standards. The Port of Long Beach's extensive investment in high-voltage shore power systems and microgrids underscores the role of robust public funding and supportive policies in driving effective electrification. The substantial financial backing allowed Long Beach to significantly reduce emissions and achieve ambitious environmental goals. Conversely, New Bedford's experience reveals the challenges of low shore power utilization due to mismatched technical specifications and a lack of incentives. This highlights the necessity of aligning infrastructure with vessel requirements and creating economic incentives to drive adoption. Together, these case studies demonstrate that standardization and policy drive shore power adoption and port electrification in general.

5 Electrification Policies and Programs

The foundation for marine vessel policy on a global scale is rooted in the International Maritime Organization's (IMO) initiatives, which have called upon member states to voluntarily commit to reducing greenhouse gas emissions from vessels. The IMO's efforts include various regulations to limit sulfur emissions and promote cleaner technologies.⁸³ In particular, Europe and North America have mandated that ships at berth must use fuel with a sulfur content of no more than 0.1%, which significantly decreases sulfur dioxide (SO₂) emissions from ships.⁸⁴ However, this approach is not without its limitations. Research indicates that while low-sulfur fuels effectively reduce SO₂ emissions, they result in only marginal reductions in nitrogen oxides (NO_x)—about 10%—leaving a substantial portion of

⁸³International Maritime Organization. *Annex 15 2023 IMO STRATEGY ON REDUCTION OF GHG EMISSIONS FROM SHIPS*. (2023). <https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/annex/MEPC%2080/Annex%2015.pdf>

⁸⁴ International Maritime Organization. *Ships face lower sulphur fuel requirements in emission control areas from 1 January 2015*. (2015, January 1). <https://www.imo.org/en/MediaCentre/PressBriefings/Pages/44-ECA-sulphur.aspx#:~:text=Ships%20face%200.10%25%20sulphur%20fuel,up%20until%2031%20December%202014.>

NO_x emissions unaddressed.⁸⁵ Given these limitations, the implementation of more comprehensive solutions, such as shore power, have become increasingly important.

Current port electrification policies are crucial in addressing the challenges faced by offshore wind ports. By creating a clear and compelling business case for electrification, these policies help overcome barriers such as high costs and standardization issues. This section provides an overview of existing policies, particularly those in California and Europe, and highlights how they can effectively support the transition to cleaner port operations.

5.1 California Electrification Policy

In California, stringent environmental regulations have been a driving force behind the widespread adoption of shore power in its ports. The California Air Resources Board (CARB) has played a central role in this transformation through initiatives like the Goods Movement Emission Reduction Program, also known as the Proposition 1B (Prop. 1B) Program. This program offered nearly \$1 billion worth of financial grants to ports, shipping lines, and other entities involved in the movement of goods, encouraging investment into electrified equipment such as forklifts, drayage trucks and light-duty vehicles.⁸⁶ The Prop. 1B Program is designed to achieve "early or extra emission reductions" that go beyond what is required by existing laws or regulations, targeting emissions from heavy-duty diesel trucks, locomotives, ships at berth (e.g., shore power), commercial harbor craft, and cargo-handling equipment at ports and rail yard facilities. By providing financial backing for upgrading equipment and installing electrical infrastructure, the program not only ensures compliance with emission reduction goals but also drives the adoption of electrified technologies across California's ports. As a result, the program has been associated with significant reductions in NO₂ and PM_{2.5} for all enrolled counties, beyond the reductions already experienced due to other regulations.⁸⁷

In addition to the Prop 1B Program, California has implemented the Ocean-Going Vessel At-Berth Regulation to further reduce emissions from ships at its major ports. Approved in December 2007, this regulation mandates that container ships, passenger ships, and refrigerated-cargo ships at six key ports—Los Angeles, Long Beach, Oakland, San Diego, San Francisco, and Hueneme—must achieve an 80% reduction in at-berth emissions of

⁸⁵ Qi, J., Wang, S., & Peng, C. *Shore power management for Maritime Transportation: Status and Perspectives*. Maritime Transport Research, 1, 100004. (2020). <https://doi.org/10.1016/j.martra.2020.100004>

⁸⁶ California Environmental Protection Agency. *Prop 1B Goods Movement 2015 Program Guidelines for Implementation*. (2015). https://ww2.arb.ca.gov/sites/default/files/2020-06/prop_1b_goods_movement_2015_program_guidelines_for_implementation.pdf

⁸⁷ M, J., Y, M., J, S., & J, M. *Goods movement actions improved air quality and health outcomes among California Medicaid enrollees*. (2019). *Environmental Epidemiology*, 3(Supplement 1), 182–183. <https://doi.org/10.1097/01.ee9.0000607808.31715.66>

nitrogen oxides (NO_x) and diesel particulate matter (PM) by 2020.⁸⁸ The regulation requires ships to either use shore power or apply approved alternative control technologies to meet these emission reduction targets. Initially, the compliance requirements were phased in, starting with a 10% reduction in 2010 and escalating to 80% by 2020.⁶⁴ This gradual escalation allows for a smoother transition, enabling port operators and shipping lines to adapt to new technologies and infrastructure investments over time. The success of these regulations highlights the effectiveness of combining stringent emission standards with financial backing.

5.2 European Electrification Policies

Recent developments in EU taxation policies and regulations have significantly impacted the deployment of shore-side power systems for maritime vessels. As part of the EU's Fit for 55 package—an initiative to cut GHG emissions by 55% from 1990 levels by 2030—several key regulations are driving the shift towards cleaner maritime and port operations. Launched in 2023, the program's impacts are still emerging and have yet to be fully studied. The following paragraphs highlight some of these key regulations.

The Energy Taxation Directive (ETD) has been revised to better align with current EU climate and energy objectives. Historically, the ETD has favored fossil fuels, but the updated directive aims to rectify this by imposing higher taxes on the most polluting fuels and providing incentives for renewable and low-carbon alternatives. For maritime operations, this includes taxing fossil fuels used in navigation while initially exempting sustainably produced alternative fuels and shore-side electricity.⁸⁹

The Alternative Fuels Infrastructure Regulation (AFIR) is an update to the Alternative Fuels Infrastructure Directive (AFID), focusing on increasing the availability of shore-side power in EU ports. By 2025, inland TEN-T core ports, which are part of a major European transport network, must have at least one shore-side power system installation, and by 2030, maritime TEN-T core ports must provide shore-side power for large vessels, potentially covering up to 90% of demand.⁹⁰ The regulation also addresses the need for hydrogen, methanol, and ammonia refueling points. However, it does not mandate vessel retrofitting for shore power in the shipping industry, which may perpetuate the "chicken-and-egg" problem.⁹¹

⁸⁸ California Environmental Protection Agency. At-berth Ocean-Going Vessels Regulation. (2008). <https://sustainableworldports.org/wp-content/uploads/CARB-FACTS-ABOUT-At-Berth-Ocean-Going-Vessels-Regulation.pdf>

⁸⁹ Sustainable Ships. *5 most important EU rules and regulations for Maritime Industry*. (2023, April 13). Sustainable Ships. <https://www.sustainable-ships.org/stories/2023/overview-rules-regulations-maritime-eu>

⁹⁰ Sustainable Ships. *5 Most Important EU Rules*. (2023).

⁹¹ Sustainable Ships. *5 Most Important EU Rules*. (2023).

Beginning in April 2025 the EU Emission Trading System (EU ETS) will require vessels to pay for CO2 emissions from 2024 onwards, increasing fuel costs by €200 to €300 per metric ton. The ETS aims for a 62% reduction in allowances by 2030 and a 100% reduction by 2038.⁹² This system is expected to incentivize the adoption of low-carbon technologies such as shore power and significantly impact operational costs for shipowners.

Looking into specific national incentives, under Council Implementing Decision (EU) 2015/993, Denmark has implemented a reduced tax rate on shore-side electricity until June 2027.⁹³ This scheme is vital for the economic feasibility of shore power in Danish ports, as it helps offset the high costs of installing shore-side infrastructure. Beyond this, the tax incentivizes vessels to retrofit as it makes shore-power significantly cheaper than traditional fuels. Danish ports have recognized the importance of this tax relief in supporting shore power expansion, stating that without it, there would be no business case for shore power.⁹⁴

These regulations and initiatives reflect a comprehensive approach to reducing maritime emissions and enhancing shore power infrastructure across Europe. The phased implementation of many EU regulations facilitates a smoother transition towards shore power and cleaner port operations. Programs like Denmark's tax scheme help create a strong business case for shore power, while the EU Emission Trading System, although not directly funding shore power, fosters a broader market for electrification and low-carbon technologies. This multifaceted approach ensures that both ports and vessels can effectively adapt to new technologies.

5.3 Port Collaboration to Promote Shore Power

Port collaboration plays a significant role in enhancing shore power adoption and overall electrification efforts. Programs like the European Sea Ports Organization's "EcoPorts" illustrate how cooperative efforts among ports can advance environmental management through shared knowledge and joint initiatives.⁹⁵ By collaborating and installing compatible shore systems, ports can encourage ships to retrofit their fleets and leverage the network effect to increase shore power utilization.

This is exemplified by the partnership created between the Shanghai Municipal Transportation Commission (formerly Port of Shanghai) and the Port of Los Angeles which

⁹² Sustainable Ships. *5 Most Important EU Rules*. (2023).

⁹³ Nordic Innovation. *Status on onshore power supply in Danish ports*. (n.d.).

<https://pub.nordicinnovation.org/On-Shore-Power-Supply-in-the-Nordic-Region/appendix-iv-status-of-on-shore-power-supply-in-danish-ports-.html>

⁹⁴ Nordic Innovation. *Status on Onshore Power Supply in Danish Ports*

⁹⁵ Qi, Wang, and Peng. *Shore Power Management for Maritime Transportation*. (2020).

reduced risks of high installation costs through the network effect.⁹⁶ Expanding such bilateral collaborations to a multilateral level could further enhance shore power adoption and address the challenges of standardization and fear of stranded assets.

Policy is crucial for advancing shore power adoption and overcoming barriers in port electrification. Effective policies, such as tax incentives, grants, and regulations, create a strong business case and address challenges high costs and standardization issues. Successful examples, like California's Proposition 1B Program and EU regulations, showcase how targeted policies drive progress. Additionally, port collaboration, exemplified by programs like EcoPorts, enhances shore power adoption by facilitating knowledge sharing and joint initiatives, demonstrating that cooperative efforts can further accelerate electrification.

6 Electrification of the Salem Offshore Wind Terminal

This section was developed from pre-2025 materials (design briefs, public filings, and press releases) describing the planned Salem Offshore Wind Terminal. In September 2025, federal officials cancelled \$34 million in pier funding, forcing the Terminal to seek alternate funding sources. As of the publication of this document, a temporary pause in the start of construction is in effect. The analysis that follows reflects those plans that currently exist and is intended to be a “ready to implement” when the Terminal acquires its funding and resumes construction of the project. The technical pathways and recommendations remain valid for the Salem Terminal and are comparable for other terminals.

The Salem Wind Terminal is scheduled to begin construction in 2026. Located at the former Salem Harbor Station, a coal-fired power plant that was shut down in 2014, the 42 acre terminal will transition the lot from its fossil fuel past to a key logistics and operations hub for offshore wind projects. The terminal will handle the pre-assembly, transportation, staging, and storage of wind turbine components. Due to its strategic location near wind energy lease areas in the Gulf of Maine and south of Massachusetts, the terminal is poised to play a crucial role in the expansion of offshore wind energy in the Northeast throughout the next couple of decades (See Fig. 18).

⁹⁶ Cannon, C., Gao, Y., & Wunder, L. Port of Los Angeles—Shanghai Municipal Transportation Commission ecopartnership on Shore Power. (2015). *Journal of Renewable and Sustainable Energy*, 7(4). <https://doi.org/10.1063/1.4928175>



Figure 18: The Salem Offshore Wind Terminal and Wind Energy Areas

A significant milestone for the Salem terminal came in February 2024, when a \$9 million Community Benefits Agreement (CBA) was finalized with Crowley, a vessel management and services company. This agreement highlights Salem’s commitment to addressing environmental justice concerns, with substantial investments aimed at supporting historically disadvantaged communities.⁹⁷ The funding will be allocated across various initiatives, including education, specialized training for emergency responders, bilingual outreach programs, and climate action funding.

⁹⁷ Souza, Scott. *Salem Reaches \$9 Million Offshore Wind Community Benefits Agreement*. (Feb 23, 2024). Patch, from <https://patch.com/massachusetts/salem/salem-reaches-9-million-offshore-wind-community-benefits-agreement>

Table 8: Funding breakdown of Salem’s community benefit agreement⁹⁸

Investment	Funding
Education investments	\$4 million
Scholarships and education opportunities for offshore wind or maritime careers (preferably for Salem residents)	\$400,000
Specialized training and equipment for Salem Police and Fire Crews regarding marine operations	\$1 million
Bilingual employment outreach and education programs (mostly among Salem High School students and other marginalized populations)	\$187,500
Essex Street, Web Street Renovations	\$850,000
First Responder training, equipment, and support	\$2.5 million
Climate action funding	\$500,000
Alternative fireworks for community celebrations	\$250,000
Port Electrification (Shore power, Installation of 10 electric Vehicle (EV) Charging stations)	Not prescribed

The Salem Wind Terminal’s development is particularly significant given its location within an Environmental Justice (EJ) zone. Salem meets all criteria for EJ designation. Within a two-mile radius of the terminal, there are 25,861 racial and ethnic minorities, comprising 22.2% of the local population. Additionally, approximately 13.9% of residents in this area live below 200% of the federal poverty line. See Figures 19-20 and Table 9 for a breakdown of Salem demographics. The blocks closest to the terminal are designated as EJ communities which highlights the importance of addressing historical environmental and social disparities through the terminal’s development.

⁹⁸ Souza. *Salem \$9M Offshore Wind Benefits*. (2024)

Table 9: Breakdown of Demographics in communities surrounding Salem Port

Port	Racial Minorities (Count)	Racial Minorities (%)	Below Poverty Line (Count)	Below Poverty Line (%)	Total Population
Salem	25,861	22.2%	16,210	13.9%	116,735

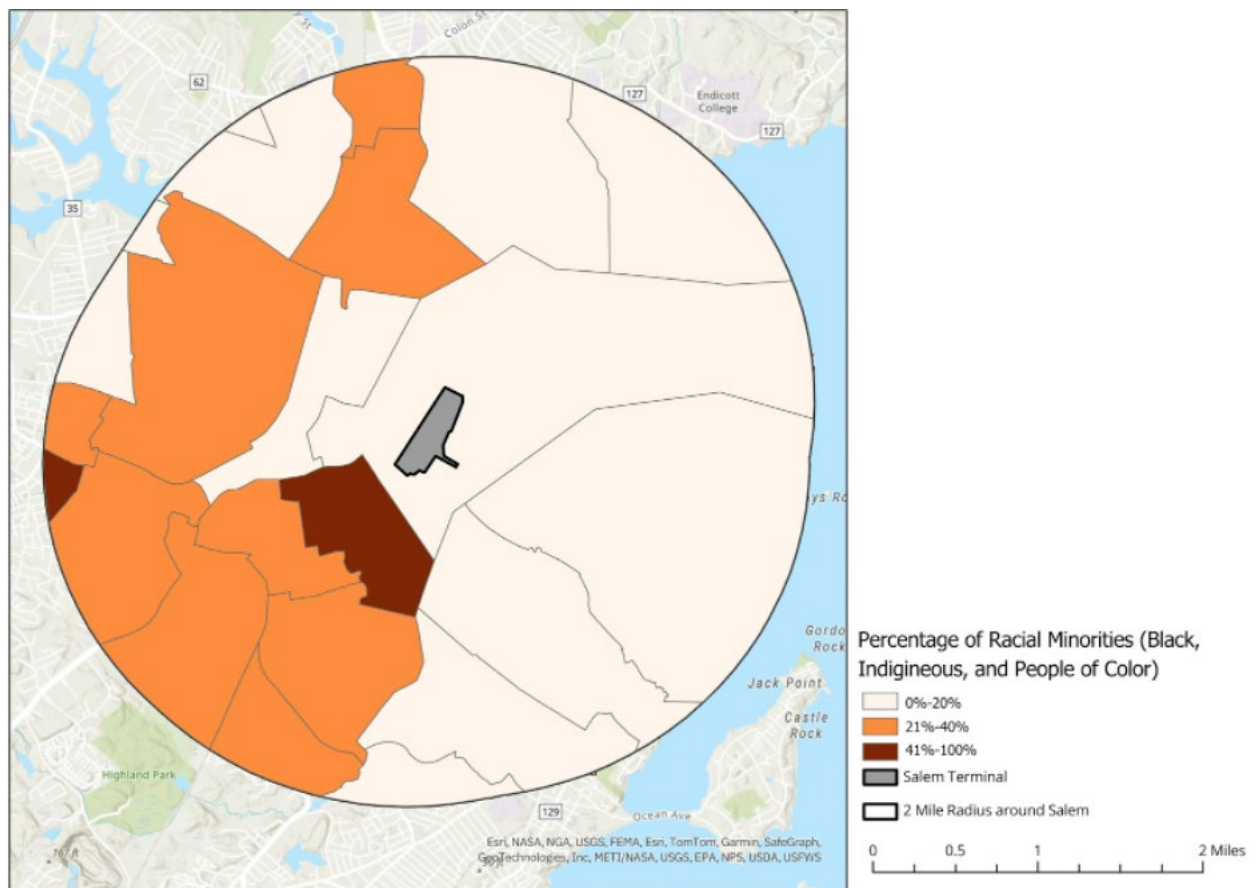


Figure 19: Percentage of minorities around Salem

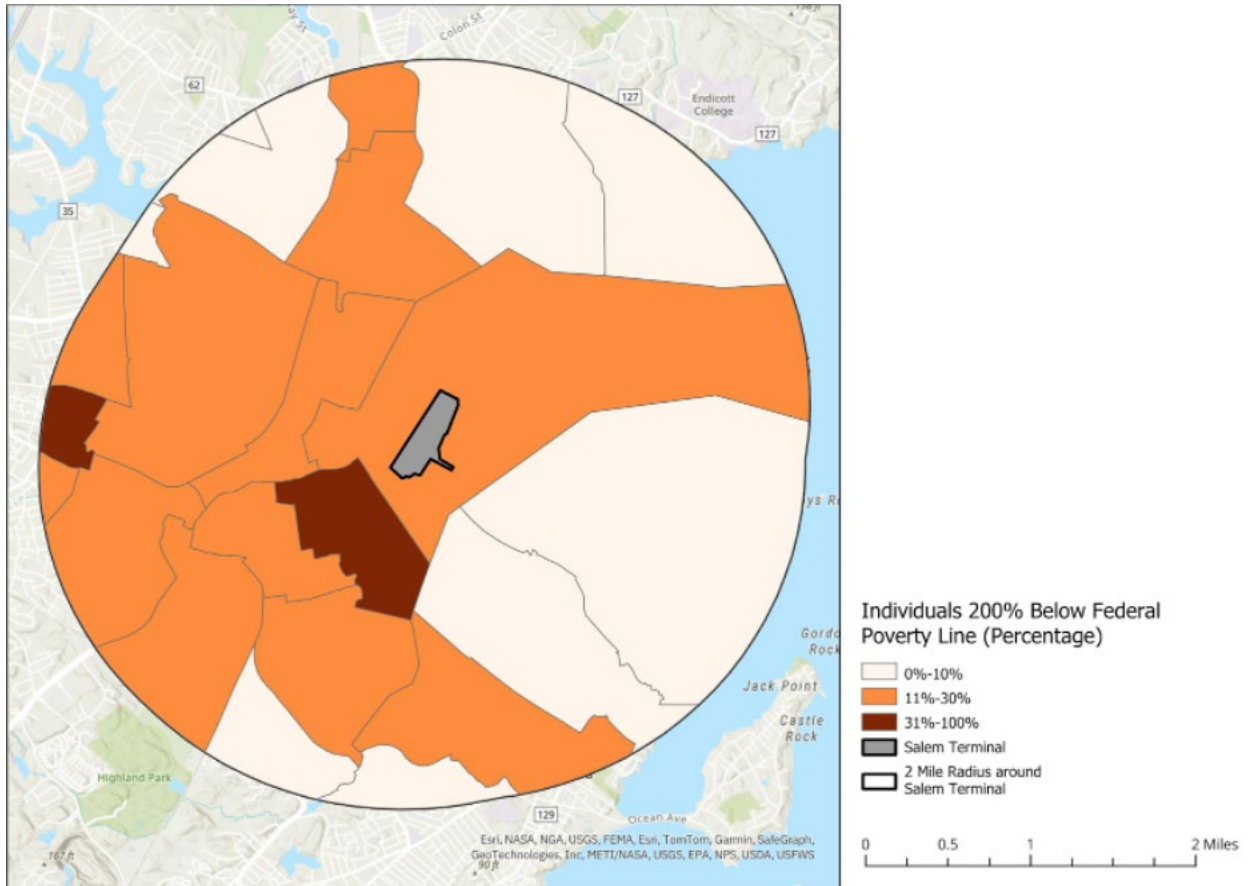


Figure 20: Percentage of low income around Salem

6.1 Status of Electrification of the Salem Offshore Wind Terminal

Electrification at the Salem Wind Terminal is a key focus for local environmental advocacy groups, with the terminal setting an ambitious goal to achieve 100% electrification by 2040. This target will be overseen by a working group established within the Community Benefits Agreement (CBA), who should hold Crowley, the developer, accountable for meeting this objective. To support this goal, the terminal will install 10 electric vehicle (EV) charging stations for yard vehicles, pickup trucks, and forklifts. Additionally, through the EPA Clean Ports Grant, Crowley plans to acquire electric manlifts, cherry pickers, bobcats, and other electric equipment.

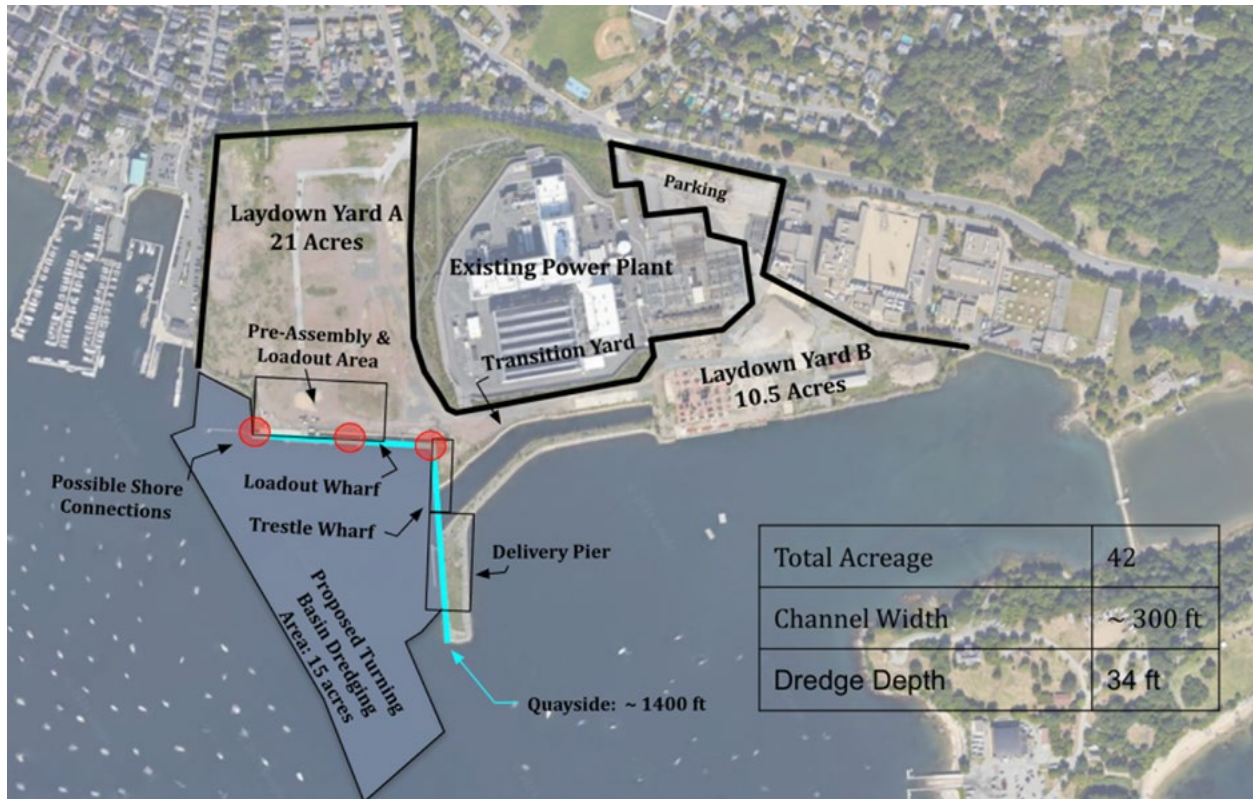


Figure 21: Salem Offshore Wind Terminal planned layout⁹⁹

In terms of shore power installations, the terminal will begin with installing a 480 kV system that will be immediately available from the first day of operations for their tugs and barge vessels. The port will initially receive 4 MW of power, with plans to secure an additional 4 MW in collaboration with National Grid, the local utility company. The extra capacity will enable the terminal to provide shore power to 2-3 larger vessels, including heavy left vessels, once the electrical specifications have been confirmed.¹⁰⁰ The port is currently being constructed to be able to receive those extra 4 MW of power once available.

A timeline of electrification efforts is shown in Figure 22. The construction of the Salem terminal will amount to approximately \$300 million. \$50 million will be dedicated for the electrical infrastructure.¹⁰¹ Despite these ambitious goals and clear objectives toward electrification, the Salem Wind Terminal will still encounter the same challenges faced by other ports in their electrification efforts, particularly those involved in offshore wind.

⁹⁹ Salem Offshore Wind. Information in original graphic summarized from *Salem Wind Port Site Plan Review*. (2023, July 20). <https://www.salemoffshorewind.com/wp-content/uploads/sites/12/2023/11/SWP-PlanBrdMtg-Final-20230720-R1.pdf>

¹⁰⁰ St. Pierre & Cheng. *Phone interview on Salem Shore Power Plans*. (2024).

¹⁰¹ St. Pierre & Cheng. *Phone interview on Salem Shore Power Plans*. (2024).

Issues of standardization, power capacity, and the chicken-and-egg situation still persist today, with standardization and the chicken-and-egg dilemma remaining particularly unaddressed and in need of focused solutions.

BENCHMARKS FOR 100% PORT ELECTRIFICATION

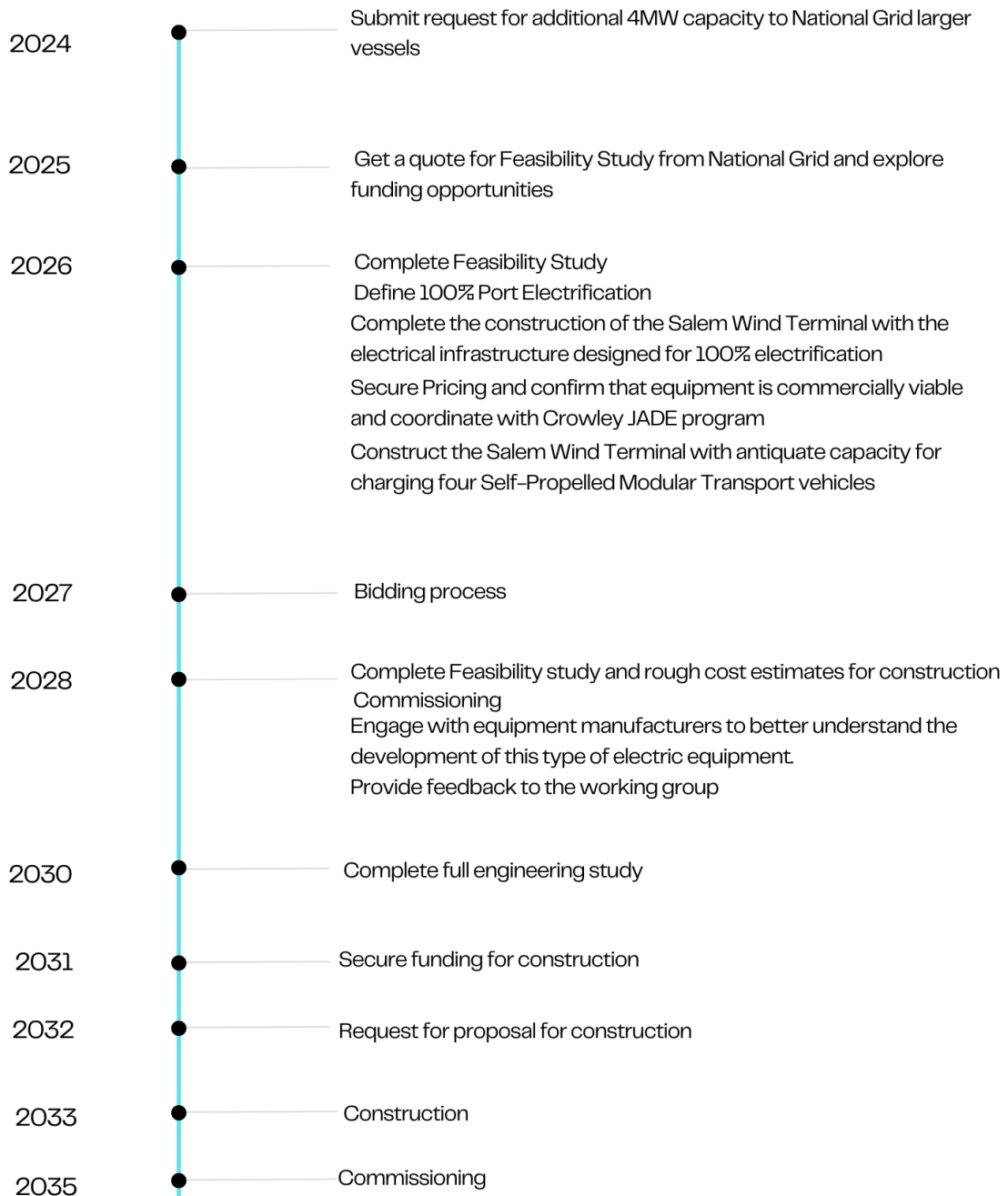


Figure 22: Timeline of proposed Salem Offshore Wind Terminal electrification efforts

6.2 Recommendations and Future Research Opportunities

To facilitate the successful implementation of shore power at the Salem Offshore Wind Terminal, several key strategies are recommended. First, the terminal should foster collaboration with other ports in the Northeast, particularly the New Bedford Marine Commerce Terminal. By creating a regional network of ports, Salem can streamline shore power installations and set technical standards, making vessel retrofitting more practical and reducing overall installation costs. Furthermore, a coordinated effort can strengthen regional policy advocacy and develop a stronger market for electrification technologies, thereby enhancing the business case for electrification and ensuring a more effective push for electrification. Stakeholders should push for policies such as tax incentives, shore power mandates, and grants to cover initial costs. Implementing these policies in phases, similar to approaches in California and Europe, will ease the transition, mitigate market competition issues, and provide time for the industry to adapt and grow. Additionally, standardization is crucial; Salem should work with industry and regulatory bodies to promote shore power standards like ISO/IEC/IEEE 80005. Standardization will simplify vessel retrofitting and ensure compatibility with shore power infrastructure across various ports, avoiding the low utilization issues seen in other ports.

Future research is needed to refine the Salem Offshore Wind Terminal's electrification strategy, address challenges, and drive public policy with evidence-based insights for stronger regulations and incentives. An important avenue of research is an emissions analysis. First, an emission modeling analysis should be done, using software like AERMOD, to locate areas of concern in the areas surrounding the terminal. These areas of concern should guide the placement of at least five air quality monitors around the terminal to assess diesel emissions accurately. Data collected will establish baseline emissions and should be compared to emissions during terminal operations. Publicly sharing these findings and underscoring the health and environmental impacts of diesel pollution will leverage public pressure to advocate for policy changes that support electrification efforts and shore power investment.

Additionally, developing a comprehensive electrical load profile is crucial. This involves estimating energy consumption needs based on projected port operations and equipment use. The load profile should identify major energy consumers, assess both the power demands and emissions of anticipated equipment and vessels, and consider the potential electric alternatives to equipment. Insights from similar ports, such as New Bedford Marine Commerce Terminal, can guide this process given that the vessels and equipment expected at the Salem Offshore Wind Terminal will be similar to those used in New Bedford. Once the load profile is established, a techno-economic analysis can be conducted to evaluate the financial aspects of various electrification strategies, including infrastructure and equipment upgrades, as well as operational costs. This analysis will be crucial in informing the business case for electrification and any policy to drive it. The Pacific Northwest National Laboratory's Port Electrification Handbook offers guidance and tools for conducting this analysis effectively.

By following recommendations and pursuing further research, the Salem Offshore Wind Terminal can improve its electrification strategy, achieve significant environmental benefits, and become a model for other ports. Ultimately, building a robust business case for electrification will drive the regional adoption of cleaner port operations and help overcome many of the current obstacles to electrification.

7. Conclusions

Electrifying offshore-wind terminals is both a public-health imperative and a practical pathway to reduce port-adjacent emissions while enabling future regulatory compliance. The evidence and case studies in this report point to three load-bearing obstacles—non-uniform vessel interfaces, limits on deliverable electrical capacity, and a fragile near-term business case—and to equally clear remedies: align on interoperable standards, de-risk utility interconnection and on-site delivery, and couple infrastructure with policies that make plugging in the default.

Ports like Long Beach and Esbjerg demonstrate that sustained public investment, interoperable designs (e.g., IEC/IEEE 80005 references), and clear operating expectations produce measurable air-quality gains and reliable utilization. By contrast, New Bedford’s experience shows how mismatched voltages/frequencies and absent incentives suppress adoption—underscoring the need for coordinated standards and at-berth requirements.


In the U.S. context, coordinated regional action is the fastest route through the chicken-and-egg problem: phase high-utilization berths first; publish common specifications and commissioning checklists; align tariffs and terminal rules so vessels that are capable are expected to plug in; and target scarce funding to grid bottlenecks (transformers, feeders, converters) and first-of-kind OSW equipment. These steps both protect environmental-justice communities and lower retrofit risk for vessel owners.

Finally, while near-term OSW port development has slowed under current federal priorities, the pathways laid out here are intentionally “shovel-ready” for future policy conditions. The same design choices, standards, and financing tools will apply when stalled projects resume—at Salem and elsewhere—and early planning with utilities and OEMs will shorten timelines when momentum returns. Together, these conclusions provide a practical blueprint for ports, utilities, and policymakers to deliver cleaner terminals, healthier communities, and a ready foundation for the next phase of U.S. offshore wind.

Appendix 1: Offshore Wind Vessels

Project Lifetime Vessels

Project Lifetime Vessels are involved throughout the 35 year lifespan of a project (construction, operations and maintenance)

Vessel	Role	Power Demand (kW)
<p>Crew Transfer Vessel (CTV)¹⁰²</p> 	<p>CTVs transport technicians and light equipment to the site of a project. They are present in the construction as well as the operations and maintenance phases of an offshore wind project. Generally, CTVs are utilized for sites that are at a relatively closer distance to the shore (approximately 1.5 hours away), where personnel are deployed for day-trip maintenance visits and inspections¹⁰³. Seating is up to 36 persons¹⁰⁴. Ørsted has utilized WINDEA, one of the first hybrid CTVs for a wind farm in Germany. Based on its technical specifications, the power demand for CTVs in general is estimated to be 360 kW¹⁰⁵.</p>	<p>360 kW</p>

¹⁰² Image Credits: *Crew Transfer Vessel*. (2019). Orsted. Photograph. from https://encrypted-tbn0.gstatic.com/images?q=tbn:ANd9GcQGmxeNhxyOTxfr1djqhl_9N_RNU0pHKymuuVPLITXnmw&s

¹⁰³ American Clean Power. (n.d.) cleanpower. *Offshore Wind Vessel Needs* from https://cleanpower.org/wp-content/uploads/2021/09/OffshoreWind_Vessel_Needs_240214.pdf

¹⁰⁴ United States Coast Guard. *Types Offshore Wind Support Vessels*. (n.d.). The Deputy Commandant for Operations, from <https://www.dco.uscg.mil/OCSNCOE/ORE-Support-Vessels/Types/#:~:text=Wind%20Turbine%20Installation%20Vessel%20>

¹⁰⁵ Memija, Adnan. *Ørsted's 'First' Hybrid CTV Inaugurated*. (June 2, 2023). Offshore Wind Biz, from <https://www.offshorewind.biz/2023/06/02/orsteds-first-hybrid-ctv-inaugurated/>

Service Operation Vessel (SOV)¹⁰⁶



SOVs are involved in construction and maintenance with the main purpose of wind turbine servicing and repair work. They are larger than CTVs as they are equipped with a small crane that is typically 10 tons and can accommodate more than 40 personnel. Additionally, they have a motion compensated “walk to work” gangway, allowing the vessel to directly connect to the transition piece platform of the wind turbine³⁷. Shore power demand is estimated to be 600 kW based on Damen Shipyards Service Operation Vessel 7017.¹⁰⁷



600 kW

¹⁰⁶ Image Credits: *Windea La Cour*. gCaptain. Photograph. (2016). Retrieved on March 11, 2024, from <https://gcaptain.com/worlds-first-x-stern-windea-la-cour-goes-to-work-at-north-sea-wind-farm/>

¹⁰⁷ Damen. *Service Operations Vessel 7017*. (February 23, 2023). from <https://media.damen.com/image/upload/v1678116757/catalogue/offshore/sov/sov-7017/product-sheet-sov-7017.pdf>

Survey Vessels

Survey Vessels are used to survey the environmental, geophysical, and geotechnical properties of a site

Vessel	Role	Power Demand
<p style="text-align: center;">Environmental Survey¹⁰⁸</p> 	<p>Two to four vessels are usually deployed to conduct fisheries and benthic surveys along with LIDAR buoys.³¹ Based on Boskalis' M/V Horizon Surveyor, a multi role geophysical and environmental survey vessel, the general power demand is estimated to be 360 kW.¹⁰⁹</p>	<p>360 kW</p>
<p style="text-align: center;">Geophysical Survey¹¹⁰</p> 	<p>One to six vessels are typically deployed to collect data on the seabed characteristics, which helps determine optimal locations to install turbines and lay cables. Based on Boskalis' M/V Horizon Surveyor, a multi role geophysical and environmental survey vessel, the general power demand is estimated to be 360 kW.³⁶</p>	<p>360 kW</p>

¹⁰⁸ Image Credits: Aspect Surveys. *Proteus*. Photograph. (March 2021). Retrieved March 11, 2024, from <https://www.aspectsurveys.com/wp-content/uploads/2021/03/proteus-holding-2-600x464.jpg>

¹⁰⁹ Image Credits: Horizon Geoscience. *Survey Vessel M/V Horizon Surveyor*. (n.d.). Boskalis. Retrieved March 11, 2024, from https://boskalis.com/media/jocinccg/horizon_surveyor.pdf

¹¹⁰ Image Credits: Rik Van Marle. *Geophysical Survey Vessel*. Photograph.(June 7, 2016). Retrieved March 11, 2024, from <https://photos.marinetraffic.com/ais/showphoto.aspx?photoid=2690925>

Geotechnical Survey¹¹¹



One to six vessels are typically deployed to map seabed features and uncover any unexploded ordnances. This informs the best export cable routes within the lease area. Based on Boskalis' Horizon Geobay, the general power demand is estimated to be 1500kW.¹¹²


1500 kW

¹¹¹ Image Credits: Offshore Wind Biz. *Horizon Geobay Executes Inch Cape Site Survey 2*. (June 2018). Retrieved on March 11, 2024, from <https://cdn.offshorewind.biz/wp-content/uploads/sites/6/2018/12/05033406/horizon-geobay-executes-inch-cape-site-survey-2.jpg>

¹¹² Horizon GeoScience. *Horizon Geobay*. Boskalis. (n.d.). from https://boskalis.com/media/f03djk5c/horizon_geobay.pdf

Cable Laying Vessels

Cable Laying Vessels are used to install cables from turbines to offshore substation and onshore grid



Vessel	Role	Power Demand
<p>Cable Laying Vessel / Multipurpose¹¹³</p> 	<p>Vessels are needed to support the laydown of the cables that deliver electrical power from the turbines to the shore. Certain vessels specialize in installing array cables, which connect the turbines in a lease area together and transmit the electrical power to an offshore substation. Other vessels are then needed to install export cables, which transfers power from the offshore substation to the onshore substation. Based on Boskalis' multi purpose cable lay vessel Boka Ocean, the general power demand is estimated to be 580 kW.¹¹⁴</p>	<p>580 kW</p>

¹¹³ Image Credits: Boskalis. *Boka Ocean Cable Lay Vessel/Construction Support Vessel*. (March 2024). Photograph. Retrieved on March 11, 2024, from <https://boskalis.com/media/hfuh0y5f/boka-ocean-versie-010324.pdf>

¹¹⁴ Boskalis. *Boka Ocean Cable Lay Vessel/Construction Support Vessel*. (March 2024). from <https://boskalis.com/media/hfuh0y5f/boka-ocean-versie-010324.pdf>

Development, Construction, & Decommissioning

These vessels are involved in the installation of Wind Turbines in the Lease Area and the decommissioning of the project

Vessel	Role	Power Demand
<p style="text-align: center;">Feederling spread</p> <p style="text-align: center;">Barges¹¹⁵</p> 	<p>Feederling spreads involve a barge, pulled by a tug boat for the purposes of transporting components to installation vessels at the lease area. Barges are large decks with motion compensation systems to carry cargo. They do not have a motor and require either a towboat or tugboat to move. They have an average power demand of 375 kW.⁴⁷</p>	<p style="text-align: center;">375 kW</p>
<p style="text-align: center;">Ocean Going Tug¹¹⁶</p> 	<p>Tug boats assist larger vessels in and out of a port by towing, pushing, and guiding. They have an average power demand of 170 kW.⁴⁷</p>	<p style="text-align: center;">170 kW</p>

¹¹⁵ Image Credits: Boskalis. *Semi-submersible ocean going barges*. (n.d.). Photograph. Retrieved on March 11, 2024, from <https://boskalis.com/media/0fodvjtt/giant-6-2.jpg?anchor=center&mode=crop&width=700&height=450&upscale=false>

¹¹⁶ Image Credits: Steven Watkins. *Boka Sherpa*. (n.d.). Photograph. Retrieved on March 11, 2024, from https://www.marinetraffic.com/getAssetDefaultPhoto/?photo_size=800&asset_id=261326&asset_type_id=0

Coaster (Supply Chain Transportation)¹¹⁷



The main role of coaster vessels is to ferry cargo across domestic waters of a nation. For the purposes of an offshore wind terminal, this means the coaster will be involved in the construction phase of a project and will transport components between US manufacturing and marshaling sites. The first plug-in hybrid coaster vessel Electramar was launched in 2023 by Finland-based company ESL Shipping. The technical specifications for this model is used to estimate the general power demand of coasters, leading to a maximum hotel-load approximation of 1.9 MW¹¹⁸.

1.9 MW

Floating Heavy Lift Foundation Vessel¹¹⁹



These vessels are used to install substations, transition pieces, and used for the pile driving of foundations. Some heavy lift vessels may be a jack up rather than float. The average power demand is 4 MW.⁴⁷

4 MW

¹¹⁷ Image Credits: Marine Insight. *Coaster in the port of Dordrecht, the Netherlands*. (2020). photograph. Retrieved February 14, 2024, from <https://www.marineinsight.com/wp-content/uploads/2020/09/coaster-vessel-2.jpg.webp>.

¹¹⁸ AtoB@c Shipping. (n.d.). *Electramar Plug-in Hybrid Power*, from (<https://www.atobatc.se/hubfs/Documents/Vessel%20details%20with%20drawing/ELECTRAMAR%20details%20v1.pdf?hsLang=en>)

¹¹⁹ Image Credits: Boskalis. *Bokalift 2*. (n.d.). Photograph. Retrieved on March 11, 2024, from <https://www.projectcargojournal.com/wp-content/uploads/2023/05/Bokalift-2-heads-to-its-new-job-in-the-US.jpeg>

Wind Turbine Installation Vessel¹²⁰



The WTIV is responsible for turbine installation at the project site, carrying a large crane on board. The cranes must be designed to have enough lift capacity and reach. WTIVs are also utilized in O&M, replacing nacelles, generators, and gear boxes. The largest existing capable WTIV Vole au Vent operates in a water depth of 50m, lifts up to 1,500 MT, and has a leg length of 90m. This makes it suitable for a 15 MW and 150m GE-Haliade X wind turbine. However, future capability at 50 m will be up to 3000 MT after the construction of the United Kingdom's Voltaire Vessel.¹²¹ The power demand is estimated to be approximately 4 MW¹²².

4 MW

Rock Dumping/Scour Protection Vessel¹²³



Scour protection rock on top of cables, monopile foundations, and other seabed infrastructure. Based on Boskalis' subsea rock installation vessel, the general power demand is estimated to be 1440 kW.¹²⁴

1440 kW

¹²⁰ Image Credits: NOV. *Dominion Energy awards NOV with design and equipment order for GustoMSCTM NG-1600X-SJ.* (2020). photograph. Retrieved February 12, 2024, from https://edge.sitecorecloud.io/nationaloil37c5-novinc-prod-e309/media/nov/images/about/news/news-details/jones-act-compliant-wind-turbine-installation-jackup-vessel/20201102-gustomsc-ng1600xsj-dominion-energy_web.jpg.

¹²¹ Bocklet, Charles. Herbosa, Christian. Loweth, Greg. Griswold, Matthew. Quickel, Lauren. Gideon, Roan. Borkland, Jay. Weitz, Rocky. Kates-Garnick, Barbara. Hines, Eric. (rep.). *Wind Turbine Installation Vessels: Global Supply Chain Impacts on the U.S. Offshore Wind Market*, pg. 28. (June 28, 2021). from <https://dl.tufts.edu/pdfviewer/9k41zt70h/rn301f830>

¹²² St. Pierre, J., & Cheng, A. T. *Phone interview about Shore Power Plans at Salem.* (2024, March 8). Electrification at Salem Terminal. personal.

¹²³ Image Credits: Boskalis. *Fallpipe Vessel Seahorse* (May 2023). photograph, from https://boskalis.com/media/wqefg04f/fallpipe_vessel_seahorse.jpg?anchor=center&mode=crop&width=320&height=180&upscale=false

¹²⁴ Boskalis. *Seahorse Subsea Rock Installation Vessel.* (May 2023). from https://boskalis.com/media/zidl1udb/subsea-rock-installation-vessel-equipmentsheet-seahorse_16052023.pdf

Dredging Vessels¹²⁵



Typically, two to four dredging vessels are used to remove boulders and level the seafloor in preparation for cable and turbine installation.³¹

Depends on type.

Safety/Scout Vessel¹²⁶



Keeps watch of ongoing marine traffic around construction and surveying areas to inform mariners of safety zone boundaries. These vessels are often fishing passenger ships, so the general power demand is estimated to be 500 kW.¹²⁷

500 kW

¹²⁵ Image Credits: Royal IHC. *IHC Beaver at Sea*. (n.d.) Retrieved on March 11, 2024, from https://www.royalihc.com/sites/default/files/styles/twig_image_landscape_894_500/public/images/IHC%20Dredging/Vessels/CSD/Beaver/IHC%20Beaver%20at%20sea.webp?h=048d7df5&itok=zprOWBCB

¹²⁶ Image Credits: NFFO services. *Guard Vessel G.V. Aurelia*. (January 2021). Photograph. Retrieved on March 11, 2024, from https://www.nffoservices.com/wp-content/uploads/2021/01/20190714_162548-scaled.jpg

¹²⁷ European Maritime Safety Agency. (rep). *Quick-Reference Guide for Development of Shore-Side Electricity/OPS in Maritime Ports*, from p.g. 4. (July 19, 2022).

Noise Mitigation Vessel¹²⁸



In order to protect marine mammals from noise that is induced from pile driving during monopile installations, these vessels produce a bubble curtain to suppress sound waves.³¹

Accommodation Vessel¹²⁹



Provides housing for crew and technicians at site. However, some of the construction vessels may have a multi-purpose role as accommodations vessels equipped with enough cabins for the crew. Based on Chevalier Floatels' DP Galyna and DP Gezina vessel, the general power demand is estimated to be 1.8 MW.¹³⁰

1.8 MW

¹²⁸ <https://images.oedigital.com/images/maritime/w600/bubble-curtain-noise-mitigation-system-140992.jpg>

¹²⁹ Image Credits: CFBV. *DP Gezina*. (July 2018). Photograph. Retrieved on March 11, 2024, from <https://www.cfbv.com/wp-content/uploads/2018/07/DPGezina-18072018-1.jpg>

¹³⁰ Chavalier Floatels. *DP Gezina & DP Galyna*. CFBV. (March 2016). from <https://www.cfbv.com/wp-content/uploads/2016/03/DP-GEZINA-DP-GALYNA-Brochure-.pdf>

Construction Support Vessel¹³¹



Cargo vessel to supply fuel and support equipment needed for other construction vessels. Based on Boskalis' Construction Support Vessel Southern Ocean, the general power demand is estimated to be 580 kW.¹³²

580 kW

¹³¹ Image Credits: Boskalis. *Southern Ocean Construction Support Vessel*. (April 2021). Photograph. Retrieved on March 11, 2024, from https://boskalis.com/media/lg0g14ti/boka_ocean.pdf

¹³² Boskalis. *Southern Ocean Construction Support Vessel Equipment Sheet*. (March 2021). from https://boskalis.com/media/lg0g14ti/boka_ocean.pdf

Appendix 2: Analysis of Port Communities in the U.S.

The following analysis was done with ARCGIS. 49,530,581 people live within 5km of ports, while 25,787,031 (or 52%) of these residents are BIPOC. This is a disproportionality as BIPOC communities make up 42.2% of the population in the US.¹³³

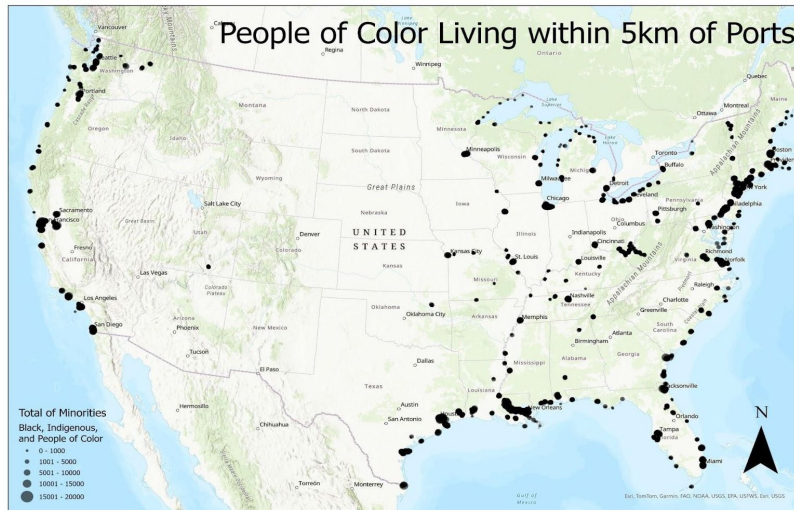


Figure 28: Minority groups living around Ports in the U.S.

¹³³ Jensen E., Jones, N., Rabe, M., Pratt, B. Medina, L., Orozco, K., Spell, L. U.S. *Population More Racially and Ethnically Diverse Than Measured in 2010*. (2021). US Census Gov, from <https://www.census.gov/library/stories/2021/08/2020-united-states-population-more-racially-ethnically-diverse-than-2010.html>