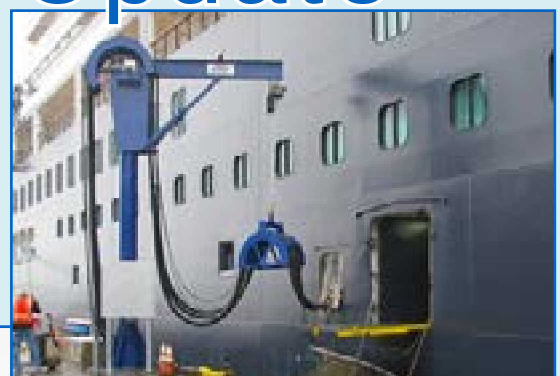
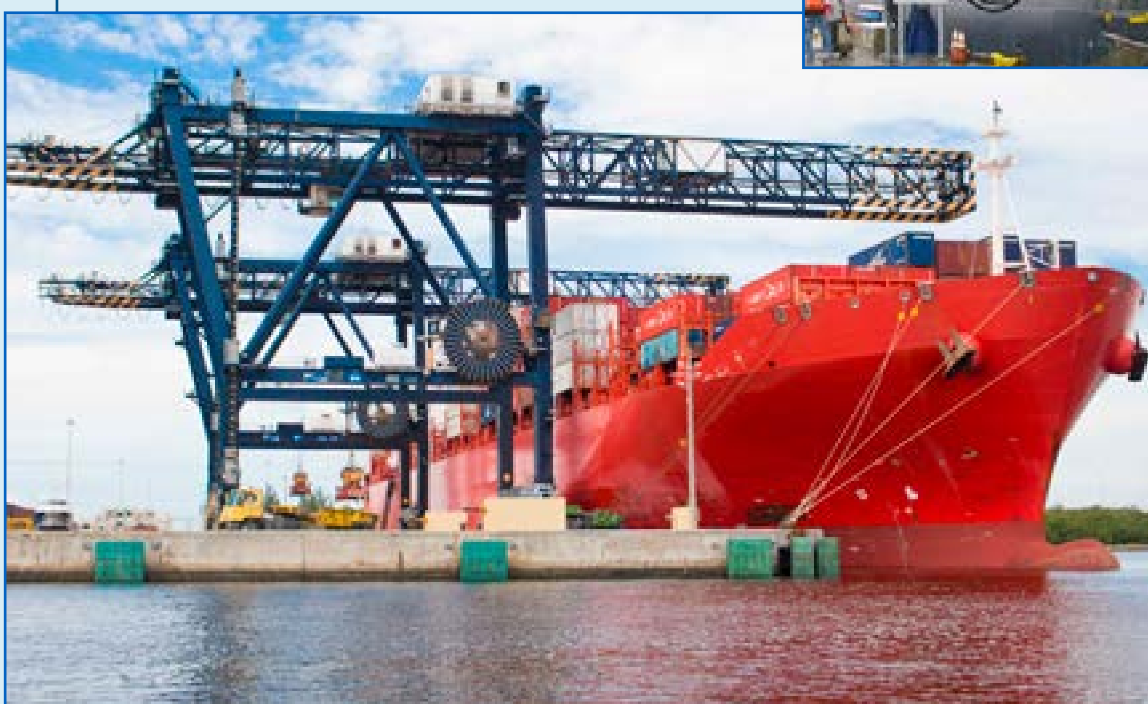
Shore Power Technology Assessment at U.S. Ports

2022 Update





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Shore Power Technology Assessment at U.S. Ports 2022 Update

Transportation and Climate Division
Office of Transportation and Air Quality
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NOTICE

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GLOSSARY

A Amperes
AMP Alternative Maritime Power
At-berth When the vessel is stationary at the dock
Auxiliary engines Onboard vessel engines that provide power for ancillary systems including loading/unloading, refrigeration, heating, cooling, etc.
Barge A non-powered marine vessel that can be pushed or pulled into position by tugboats
Berth A ship's assigned place at a dock
Bulk vessels Ships that transport bulk cargo such as coal, iron ore, etc.
Bunker fuel used in marine vessels
CAECS CARB Approved Emission Control Strategy
CARB California Air Resources Board
CH_4 Methane
CHC Commercial harbor craft
CO Carbon monoxide
CO_2 Carbon dioxide
CO_2eq Carbon dioxide equivalent
Cold ironing An alternate term for shore power
Container vessels Ships that transport containerized cargo
COVID-19 Coronavirus disease 2019 caused by SARS-CoV-2 virus
CPD Cable positioning device
Cruise vessels Ships that transport passengers to various ports-of-call
DERA Diesel Emissions Reduction Act
EERA Energy & Environmental Research Associates, LLC.
EGU Energy generating unit
eGRID Emissions & Generation Resource Integrated Database
EIA United States Energy Information Administration
EMSA European Maritime Safety Agency
EPA United States Environmental Protection Agency
ERG Eastern Research Group
EU European Union
Fishing vessels Commercial fishing vessels
g Grams
GGL Grid gross loss
GW Gigawatt
GWP Global Warming Potential
HC Hydrocarbons
HFO Heavy fuel oil
Hotelling Vessel operations while stationary at the dock
hrs Hours
HVSC High-voltage shore connection
Hz Hertz
IC Innovate Concepts
IEC International Electrotechnical Commission
IEEE Institute of Electrical and Electronics Engineers
iENCON Incentivized Shipboard Energy Conservation
IMO International Maritime Organization
IPCC Intergovernmental Panel on Climate Change
ISO International Organization for Standardization
kV Kilovolts

kVArh Kilovolt ampere reactive hours
kWh Kilowatt-hours
L Liter
LADWP Los Angeles Department of Water and Power
Laker A ship that operates on the North American Great Lakes
LNG Liquefied natural gas
LVSC Low-voltage shore connection
Main engines The vessel's propulsion engines
MDO Marine diesel oil
MGO Marine gas oil
MT Metric tons
MVA Mega volt-ampere
MW Megawatt
MWh Megawatt-hours
N_2O Nitrous oxide
NO_x Oxides of nitrogen
NA ECA North American Emission Control Area
NWSA Northwest Seaport Alliance
NYCEDC New York City Economic Development Corporation
NY/NJ Port of New York and New Jersey
OTAQ EPA Office of Transportation and Air Quality
Passenger vessels Ships that transport passengers
PM Particulate matter
PM_{10} Particulate matter with an aerodynamic diameter less than or equal to 10 microns
$PM_{2.5}$ Particulate matter with an aerodynamic diameter less than or equal to 2.5 microns
POLA Port of Los Angeles
POLB Port of Long Beach
Quayside Attached to the dock
Reefer vessels Ships that transport refrigerated cargo
RORO Roll-on/roll-off commercial marine vessels that enable freight trucks and vehicles to drive on and off of the vessel
ROPAX Roll-on/roll-off vessels that are also equipped to transport passengers
S Sulfur
Shore Power Shoreside electrical power which marine vessels can plug into while at-berth to power ancillary systems including onboard electrical systems, loading/unloading equipment, refrigeration, heating, and cooling. Shore power is also referred to as cold ironing, Onshore Power Supply (OPS), Shoreside Electricity (SEE), or Alternative Maritime Power (AMP).
Short ton 2,000 pounds
SO_2 Sulfur dioxide
SO_x sulfur oxides
Tanker vessels Ships that transport bulk liquids
TEU Twenty-foot equivalent unit
TIE Terminal Incident Event
Tug vessels Ships that assist larger vessels with maneuvering in port
USACE United States Army Corps of Engineers
V Volts
VIE Vessel Incident Event
Wharfinger The keeper or owner of a wharf or dock
WSF Washington State Ferries

Executive Summary

Ports are gateways of commerce and drivers of the United States (U.S.) economy. At the same time, they are places where large concentrations of diesel equipment can converge and emit significant amounts of air pollution, including particulate matter (PM), nitrogen oxides (NO_x), air toxics, and carbon dioxide (CO_2), which impacts human health and the environment. Many marine vessels use diesel engines while at berth to power auxiliary systems such as lighting, air conditioning, refrigeration, and crew berths. Shore power infrastructure has the potential to significantly reduce emissions by enabling vessels to turn off their engines, and instead plug into the local electricity grid to power auxiliary systems while at berth. The U.S. Environmental Protection Agency (EPA) developed this report to help port operators, state and local governments, and other stakeholders better understand and evaluate shore power as a potential emissions reduction strategy.

This *Shore Power Technology Assessment at U.S. Ports - 2022 Update* characterizes the technical and operational aspects of shore power systems in the U.S. and demonstrates an approach for comparing shore power and vessel emissions while at berth. This report is based on the previously published 2017 Assessment and has been updated to include:

- Information on new shore power systems in the U.S. since 2017.
- Updates to the California Air Resources Board (CARB) regulations, including new shore power requirements that expands participation.
- Updated information on vessel readiness and real-world costs.
- Practical operational lessons learned from CARB as well as port operators implementing shore power programs at the ports of New York & New Jersey, Seattle, Hueneme, and Los Angeles.

This report also includes further refinement of an approach to calculate emissions benefits from shore power, which has been incorporated into EPA's Shore Power Emissions Calculator (SPEC) updated in May 2022. The May 2022 SPEC includes updated vessel emissions factors from EPA's April 2022 Port Emissions Inventory Guidance, updated power grid emission factors from EPA's latest Emissions & Generation Resource Integrated Database, expanded options for vessel and fuel types, and improved usability.

This report, in conjunction with the calculator, can help port stakeholders – including applicants for Diesel Emissions Reduction Act, Bipartisan Infrastructure Law, and Inflation Reduction Act funding – evaluate whether shore power would be an appropriate means to reduce pollution at a port, and to estimate emissions reductions from installed systems.

High Voltage vs. Low Voltage Shore Power Systems

High-voltage [6.6 or 11 kilovolts] shore connection systems in the U.S. have similar technical specifications and meet international operation and safety standards. High-voltage shore connection systems are mainly used today by cruise, container, and refrigerated vessels.

Low-voltage [240-480 volts] domestic systems are used by smaller fishing, tug, workboat, and support vessels with lower power requirements. Technical specifications of these systems can vary considerably.

While this Assessment discusses both types of shore power systems, the focus is on high-voltage systems for large vessels since they have greater potential for significant emission reductions.

Key Findings of the Shore Power Technology Assessment- 2022 Update

- **Shore power can effectively reduce ship pollutant emissions at berth. Benefits vary from port-to-port and by vessel type.**
  - Shore power installations typically produce zero onsite emissions. In most cases, emissions from power generation facilities that supply electricity to shore power installations are lower than associated auxiliary engine emissions occurring at berth and are likely to decrease over time as renewable electricity generation increases. Emissions from power generation facilities may or may not be within the confines of the port and can often be located outside the local air shed.
  - The potential emissions reduction is dependent on several factors:
    - Vessel type, auxiliary engine age, and fuel type used at berth.
    - Power demand of vessel auxiliary system.
    - Time vessel spends at berth.
    - Electricity generation fuel mix.
  - EPA's Shore Power Emissions Calculator (SPEC) can be an effective tool to assess emissions benefits of shore power.
  - While shore power can reduce or eliminate auxiliary engine emissions at berth, shore power does not address emissions from boilers or other vessel sources that must be operational while the vessel is at berth. Vessels also continue to emit while in the process of connecting to and disconnecting from shore power.
  - The assessment also describes alternatives to shore power that may reduce emissions at berth.

- **Application of shore power in the United States is expanding to more places and vessel types.**
  - Commercial shore power has grown significantly since the last report. This 2022 Update identifies expansion projects at several ports with pre-existing shore power installations and three planned projects at the ports of Galveston and Miami for cruise ships and Philadelphia for container ships. Additionally, ports have seen an increase in the number of vessels that are equipped with shore power.

- There are currently ten ports using high voltage systems serving cruise, container and refrigerated ("reefer") vessels, and many more ports that use low voltage systems, serving tugs, fishing, and offshore support vessels.
- Most U.S. shore power systems for commercial marine vessels entered into service in the past decade.
- CARB's 2020 At-Berth Regulation continues to drive expansion of shore power at six ports in California by including more vessel types and visits in the program over time, and in the near future will include additional locations in California.
- International shore power standards for high-voltage systems are in place to make it easier for ports to select the proper equipment and to ensure shore-power capable ships can successfully use the systems at ports around the world.
- In addition to the deployment of shore power technology in the commercial sector, shore power has been successfully used by the U.S. Navy for decades and is included in the Navy's Incentivized Shipboard Energy Conservation program.
- Shore power can be most effective when applied at ports with a high percentage of frequently returning vessels.

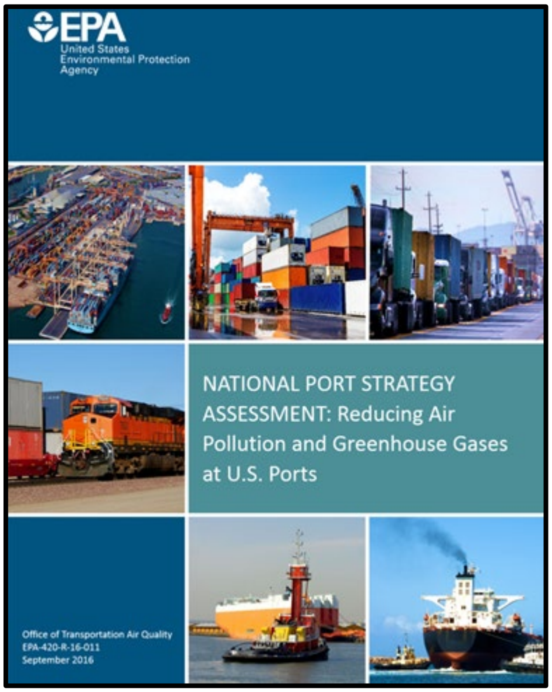
- **Barriers to shore power include infrastructure and electricity costs.**
  - Shore power can require significant investments in landside infrastructure and vessel modifications.
    - Many ports still do not have the appropriate infrastructure to connect to vessels with shore power components and upgraded connections to the electrical grid are often required.
    - Ships must be retrofitted with vessel-side infrastructure to connect to shore power systems, which can be costly and require thoughtful planning about component placement.
  - The relative cost of using shore power instead of a vessel's onboard fuel sources is more attractive when fuel costs are greater than electricity costs.

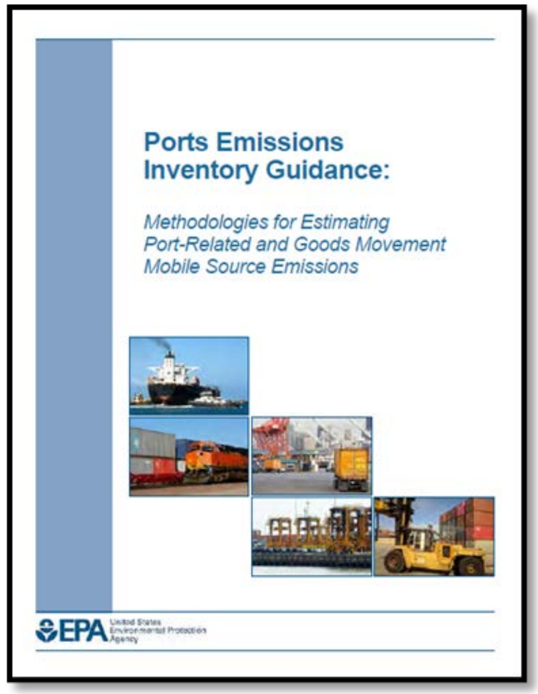
- **Lessons learned** from CARB and the port operators in New York & New Jersey, Seattle, Hueneme and Los Angeles include:

  - The **importance of early and frequent interaction and planning between the port, regulatory agencies, and utilities –** to address demands of the commercial waterfront as well as local power needs.
  - **Need for system designs to be flexible** in designating locations of dockside shore power connection vaults and cables to ensure vessels of all sizes and types can connect.
  - **System design should account for future demand** that could include other terminals and nearby berths or electrification of other types of port equipment.
  - **Reliability and availability** of shore power components and power supply to ensure successful shore power operations. Adhering to **on-time vessel scheduling**, so vessels can consistently and quickly plug in and not delay other vessels and port operations.
  - Having a **ship pre-approval system** to quickly plug in for repeat ships.
  - **Public funding sources are critical** for shore power infrastructure development.

- Shore power has helped **deliver emissions reductions for the local community**, and local residents notice when the system is not working.

This *Shore Power Technology Assessment at U.S. Ports* – 2022 *Update* is one of several technical resources to support diesel emissions reductions at ports around the country as part of EPA's Ports Initiative,[1] including the National Port Strategy Assessment,[2] Port Emissions Inventory Guidance,[3] and Best Clean Air Practices for Port Operations.[4]





1 EPA, Ports Initiative, https://www.epa.gov/ports-initiative, accessed August 16, 2022.
2 EPA National Port Strategy Assessment: Reducing Air Pollution and Greenhouse Gases at U.S. Ports. https://www.epa.gov/ports-initiative/national-port-strategy-assessment-reducing-air-pollution-and-greenhouse-gases-us , accessed August 16, 2022.
3 EPA, Port and Goods Movement Emission Inventories, https://www.epa.gov/ports-initiative/port-and-goods-movement-emission-inventories, accessed August 16, 2022.
4 EPA, Best Clean Air Practices for Port Operations, https://www.epa.gov/ports-initiative/best-clean-air-practices-port-operations, accessed August 16, 2022.

1 INTRODUCTION

The original Shore Power Technology Assessment was published in March 2017; it characterized the technical and operational aspects of shore power systems in the United States, demonstrated an approach for comparing shore power and vessel emissions while at-berth, and summarized the experience of 16 ports operating shore power systems.

This updated version of the Shore Power Ports Assessment has several enhancements:

1. Information on new shore power systems in the U.S. since 2017. (See highlighted items in Tables 2, 3 and 4)
2. Updates to the CARB regulatory section, including discussion of new shore power requirements that expands participation in the program. (See Section 3.10)
3. Updated information on vessel readiness and real-world costs. (See Section 3, including highlighted items in Table 3)
4. Practical operational lessons learned from CARB as well as port operators implementing shore power programs at the ports of New York and New Jersey, Seattle, Hueneme, and Los Angeles. (See Section 4)
5. Further refinement of the approach to calculate at-berth ship emissions and emissions from shore power, which has been incorporated into the accompanying May 2022 version of EPA's Shore Power Emissions Calculator. (See Section 5)

The report is comprised of six sections:
Section 1 provides an overview of this Shore Power Technology Assessment.
Section 2 presents background information on shore power and its potential emissions reduction benefits for at-berth (i.e., hoteling) vessels.
Section 3 evaluates the characteristics of existing shore power systems in the United States.
Section 4 summarizes lessons learned from CARB and the ports of New York and New Jersey, Seattle, Hueneme, and Los Angeles.
Section 5 presents a recommended approach for comparing shore power and vessel emissions while at-berth.
Section 6 presents study findings and concluding remarks.

The report includes two appendices:

Appendix A summarizes information on shore power programs at ports equipped for these systems (updated to include new publicly available information, including associated environmental benefits and costs).

Appendix B contains the user guide for the Shore Power Emissions Calculator.

This report and accompanying calculator were developed as part of EPA's Ports Initiative which supports efforts to improve efficiency, enhance energy security, save costs, and reduce harmful health impacts by advancing next-generation, cleaner technologies and practices at ports. Tools such as the Shore Power Calculator (SPEC) can be used to estimate how harmful air pollutants could be reduced at U.S. ports using shore power systems, benefiting air quality, human health, the economy, and the environment. These estimates can help port stakeholders – including applicants for Diesel Emissions Reduction Act, Bipartisan Infrastructure Law, and Inflation Reduction Act funding – evaluate potential shore power projects for grant applications, and for reporting emission reductions from grant projects. As many marine vessels operate around ports near communities of color and low-income families, emission reductions from these vessels could directly benefit those communities experiencing disproportionate exposures to this pollution.

2 BACKGROUND

Ports are the main gateway for U.S. trade and are essential to the overall U.S. economy, as well as the local economies of many cities and regions nationwide. In recent years, there has been a growing focus on the transportation infrastructure needed to support efficient movement of goods and people through ports. EPA's Ports Initiative recognizes the economic and environmental significance of the U.S. port industry sector and is working to explore and identify ways to evaluate and incentivize technologies and strategies to reduce diesel emissions at ports. One way to reduce emissions at ports is using shore power technology, which allows ships to "plug into" electrical power sources on shore. Turning off a ship's diesel auxiliary engines while at-berth would significantly reduce vessel emissions, but these reductions must be compared to the emissions generated by the landside electrical grid.

The potential for emissions savings will depend on vessel fuel and engine characteristics and the landside electricity generation mix (e.g., coal, oil, gas, nuclear, wind, solar, hydroelectric, geothermal, biomass). The relative share of fuel sources for electric generating units typically changes over time, varying by season, day of week, and even hour-to-hour, depending on regional electricity demand. To the extent that the electricity grid becomes cleaner and more efficient over time, the potential emissions reductions should grow relative to diesel auxiliary engines. However, the cost of shore power electric generation and delivery, for both the vessels and the port terminal, can be substantial.

Figure 1: Electrical substation (left) and high voltage shore power vessel connection system (right)
Source: Port of San Diego

Shore power installations in the U.S. have been increasing in the past decade, in terms of landside installations at existing port locations as well as new port locations. High-voltage shore power systems in the United States have similar technical specifications and meet international operation and safety standards. High-voltage systems are mainly used by cruise, container, and refrigerated vessels. The characteristics of low-voltage systems used by smaller fishing, tug, workboat and supply vessels with lower power requirements can vary considerably. The focus of this report is on high-voltage systems since they have greater potential for significant emission reductions. Low-voltage systems were not fully investigated at ports but previously available information from ports has been included in this report as these systems can also provide emissions benefits. In addition, the time vessels spend at-berth, which affects how much shore power the vessel could use, varies from port-to-port and by vessel type. Cruise ships and roll-on/roll-off (RORO) vessels are generally attached to a landside dock (referred to as hoteling) for shorter periods of time than container and bulk cargo vessels.

The emissions reduction benefits of shore power have been evaluated by multiple organizations and researchers. For example, the California Air Resources Board (CARB) has amended their At-Berth Regulation which is projected to further reduce air emissions from diesel auxiliary engines on container ships, passenger ships, and refrigerated cargo ships while at-berth ("hoteling"). The prior At-Berth regulation was estimated to reduce 80% of localized criteria pollutant emissions from Cruise, Container and Refrigerated, vessels at-berth, and the current At-Berth Regulation is expected to further reduce emissions from an additional 2,300+ vessel visits when fully phased in 2027 by expanding to include vehicle carriers (RORO) and tankers, and new ports and terminals.[5] CARB estimates a 55% decrease in cancer risk by 2031 due to air quality improvements by using shore power instead of auxiliary engines at berth, providing health benefits of $2.32 billion at a cost of $2.23 billion.

Other studies have long demonstrated significant benefits from shore power. A study by ENVIRON (2004)[6] estimated that shore power would reduce at-berth emissions of NO_x and particulate matter (PM) by more than 99% and 83–97%, respectively, for vessels calling on the Port of Long Beach, California. A report by Yorke Engineering (2007)[7] estimated that shore power could reduce at-berth emissions of NO_x, carbon monoxide (CO), hydrocarbons (HC), PM, and sulfur oxides (SO_x) by approximately 80% for cruise vessels and nearly 97% for refrigerated vessels ("reefers") that called on the Port of San Diego, California, in 2007.

A 2013 analysis by Corbett and Comer[8] estimated the potential emissions reductions from shore power for at-berth cruise vessels at the Port of Charleston, South Carolina. They found that shore power would greatly reduce air pollution from these ships: NO_x emissions could be reduced by 98%, $PM_{2.5}$ by 66%, SO_2 by 73% and CO_2 by 26%. Emission reductions were estimated to be greater in 2019 as the local electric power provider reduces the share of coal in its electricity generation portfolio.[9]

More recently, Friends of the Earth commissioned studies by ERG in 2019 and 2020, which estimated significant potential reductions at the ports of Charleston and Savannah.[10] They estimated NO_x reductions of 98% for both ports; $PM_{2.5}$ reductions of 77% and 53%, respectively; and sulfur dioxide (SO_2) reductions of 69% and 55%, respectively. Shore power CO_2 reductions were estimated at 49% and 32% at the ports of Charleston and Savannah, respectively.

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5 CARB. Control Measure for Ocean Going Vessels at Berth. August 26,2020. https://ww2.arb.ca.gov/sites/default/files/2020-08/External%20At-Berth%20Fact%20Sheet%20August%202020%20ADA_0.pdf

6 ENVIRON. Cold ironing cost effectiveness study: Volume I report. Los Angeles, 2004.

7 Yorke Engineering. Port of San Diego: Cold ironing study. Prepared for the Port of San Diego. 2007.

8 Corbett, J. J., & Comer, B. *Clearing the air: Would shoreside power reduce air pollution emissions from cruise ships calling on the Port of Charleston, SC?* Pittsford, NY: Energy and Environmental Research Associates.2013.

9 The 2013 electricity grid mix was assumed to be 48% coal, 28% natural gas, 19% nuclear, 3% hydro, and 2% biomass. The 2019 grid mix was assumed to be 33% coal, 33% natural gas, and 34% mostly nuclear and hydro.

10 Charleston: https://foe.org/resources/port-of-charleston-shore-power-analysis/ October 27, 2020.
Savannah: https://foe.org/wp-content/uploads/2019/03/Port-of-Savannah-Shore-Power-Analysis-Rev.-1-11-Feb-2019.pdf February 11, 2019.

Additional studies have focused on ports outside the United States. Hall estimated that shore power would have reduced emissions from at-berth vessels in the United Kingdom in 2005 as follows: NO_x (92%), CO (76%), SO_2 (46%), and CO_2 (25%), assuming power was drawn from the United Kingdom's national electric grid (Hall, 2010; Chang and Wang, 2012a). Chang and Wang (2012b) estimated that shore power would reduce CO_2 and PM emissions by 57% and 39%, respectively, in the Port of Kaohsiung, Taiwan. Sciberras et al. estimated that shore power could reduce CO_2 emissions by up to 42%, using a RORO port in Spain as a case study.

In Europe, under Directive 2014/94/EU, the European Commission mandated the installation of shore power in all ports in the European Union (EU) "unless there is no demand and the costs are disproportionate to the benefits, including environmental benefits." Proposed regulations in the EU (COM/2021/562 final)[11] state that from January 1, 2030, container and passenger vessels calling at EU member states must connect to shore power while at-berth. These rules apply unless the vessel is at-berth for fewer than two hours, calls at port for safety of life at sea reasons, or uses approved zero-emission technologies.[12]

It should be noted, particularly with respect to the older U.S ports studies, that the North American Emission Control Area (NA ECA) had not yet been established at the time the older studies were performed. The NA ECA began in 2012 and resulted in the use of cleaner, low-sulfur fuels in commercial marine vessels, and technologies that reduce NO_x emissions from engines on newer-built vessels within 200 nautical miles (nm) of the U.S. coast. Under the NA ECA, fuel sulfur (S) content was limited to 1.00% S and was further limited to 0.10% S on January 1, 2015. Currently, "IMO 2020"[13] set sulfur levels in the fuel oil used on board ships operating around the world, outside of designated emission control areas, at 0.50% S, a significant reduction from the previous limit of 3.5% S. Additionally, marine auxiliary engines installed on U.S. vessels built on or after January 1, 2016, and operating within the ECA are subject to stringent Tier III NO_x standards. These standards reduce NO_x emissions by 80% compared with Tier I standards. Even with the ECA in effect, shore power is still expected to substantially reduce air pollutant emissions—including NO_x and PM—at U.S. ports because of the potential to produce electricity at emissions rates even lower than those from cleaner, diesel-powered marine auxiliary engines.

Under the right circumstances when a vessel is connected to shore power, overall pollutant emissions can be significantly reduced when utilizing power from the regional electricity grid, depending on the mix of energy sources.

The studies presented in Appendix A suggest that shore power may be an effective strategy to reduce in-port and near-port emissions of air pollution, improving air quality for communities located near or adjacent to ports, many of which are non-attainment areas for criteria air pollutants.[14] CARB analysis indicates that there may also be fuel cost savings of approximately

[11] European Union Law https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:52021PC0562. July 14, 2021.

[12] Per Annex III of the proposed regulations, zero-emission technologies include fuel cells, onboard electricity storage, and onboard electricity production from wind and solar energy.

[13] IMO 2020 Global Fuel Standard, January, 2020 https://www.imo.org/en/MediaCentre/HotTopics/Pages/Sulphur-2020.aspx

[14] A map of counties designated "nonattainment" for the Clean Air Act's National Ambient Air Quality Standards can be found on EPA's Green Book website: https://www.epa.gov/green-book. Accessed April 11, 2022

1% associated with shore power use compared to marine bunker fuels,[15] though reports from industry and U.S. ports indicate that this may not always be the case in practice. Regardless, cost effectiveness is highly dependent on fuel prices, but air pollution reduction and its health benefits for the surrounding communities need to be considered in these calculations.

Improved air quality can also provide economic benefits by improving human health and reducing environmental damages, resulting in reduced medical costs and environmental remediation expenses. The studies referenced in Appendix A show that many ports adopting shore power have seen significant reductions in criteria pollutant emissions from ships at berth depending on fleet/engine fuel mix and the time frame reported. Shore power can also reduce noise levels at ports when auxiliary engines are turned off. Using shore power also allows maintenance crews to repair and maintain auxiliary equipment that might otherwise be inaccessible if the engines were running. As noted below in conversations with ports, shore power has helped ports deliver emissions reductions for the local community, and those residents notice when the system is not working.

[15] CARB. At-Berth Draft Cost Analysis – Appendix B SRIA. August 2019. https://ww2.arb.ca.gov/resources/documents/berth-draft-cost-analysis-appendixb-sria-august-2019

3 U.S. SHORE POWER CHARACTERISTICS

This section identifies and describes existing and planned U.S. shore power facilities. These systems are owned and managed either by the ports or by individual terminal tenants.

3.1 Capacity

U.S. commercial shore power systems fall into two main categories:

- High-voltage shore connection (HVSC):
  - 6,600 or 11,000 volts (V).
  - Currently servicing large cruise, container, and reefer vessels.
  - Systems to service RORO vessels may commence by 2025 at San Pedro Bay ports.[16]
- Low-voltage shore connection (LVSC) 220–480 volts (V).
  - Typically service smaller vessels such as fishing, tug, workboat, ferries, and service vessels.

In the U.S. there are currently 10 ports serving cruise, container and refrigerated ("reefer") vessels, with a mix of single vessel type shore power capable ports and several ports that can serve multiple vessel types; overall number of shore power capable ports is expected to rise. Commercial shore power has grown significantly since the last report. All six California ports have expanded their existing shore power systems to meet current regulations. For example, Port of San Diego[17] is doubling its shore power capability for cruise ships, which is expected to be available in late 2022. There are many expansion projects outside of California as noted in Table 1. For example, the Port of Tacoma is expanding shore power to container vessels and the Port of Seattle is expanding shore power to electrify its waterfront at Pier 66 culminating with shore power at the Bell Street Pier Cruise Terminal[18] by 2024. There are also planned projects at the ports of Galveston and Miami for cruise ships and Philadelphia for container ships. Port Everglades is also exploring shore power.[19] Additionally, several ports have seen an increase in the number of unique vessels that are equipped with shore power.

The focus of this assessment is on HVSC systems since they have greater potential for significant emission reductions. Tables 2, 3 and Appendix A show examples of LVSC installations, however, these are only a small fraction of the installations around the United States.

Table 1 summarizes existing U.S. ports with HVSC systems installations by capacity and the vessel type(s) served. Figure 2 shows the locations of existing U.S. ports with HVSC installations and the associated EPA Emissions & Generation Resource Integrated Database

[16] CARB, Control Measure for Ocean-Going Vessels at Berth, August 26, 2020. https://ww2.arb.ca.gov/resources/fact-sheets/control-measure-ocean-going-vessels-berth

[17] Port of San Diego Awards Contract to Double Cruise Ship Shore Power, January 12, 2022, https://www.portofsandiego.org/press-releases/general-press-releases/port-san-diego-awards-contract-double-cruise-ship-shore-power

[18] Port of Seattle, Pier 66 Shore Power Project, https://www.portseattle.org/projects/pier-66bell-street-pier-shore-power

[19] Port Everglades Explores Shore Power with Florida Power & Light Agreement, Mar. 15, 2022, https://www.porteverglades.net/articles/post/port-everglades-explores-shore-power-with-fpl-agreement/,

(eGRID) subregions. Figure 2 also notes additional ports with planned HVSC shore power installations, which are further outlined in Section 4.6.

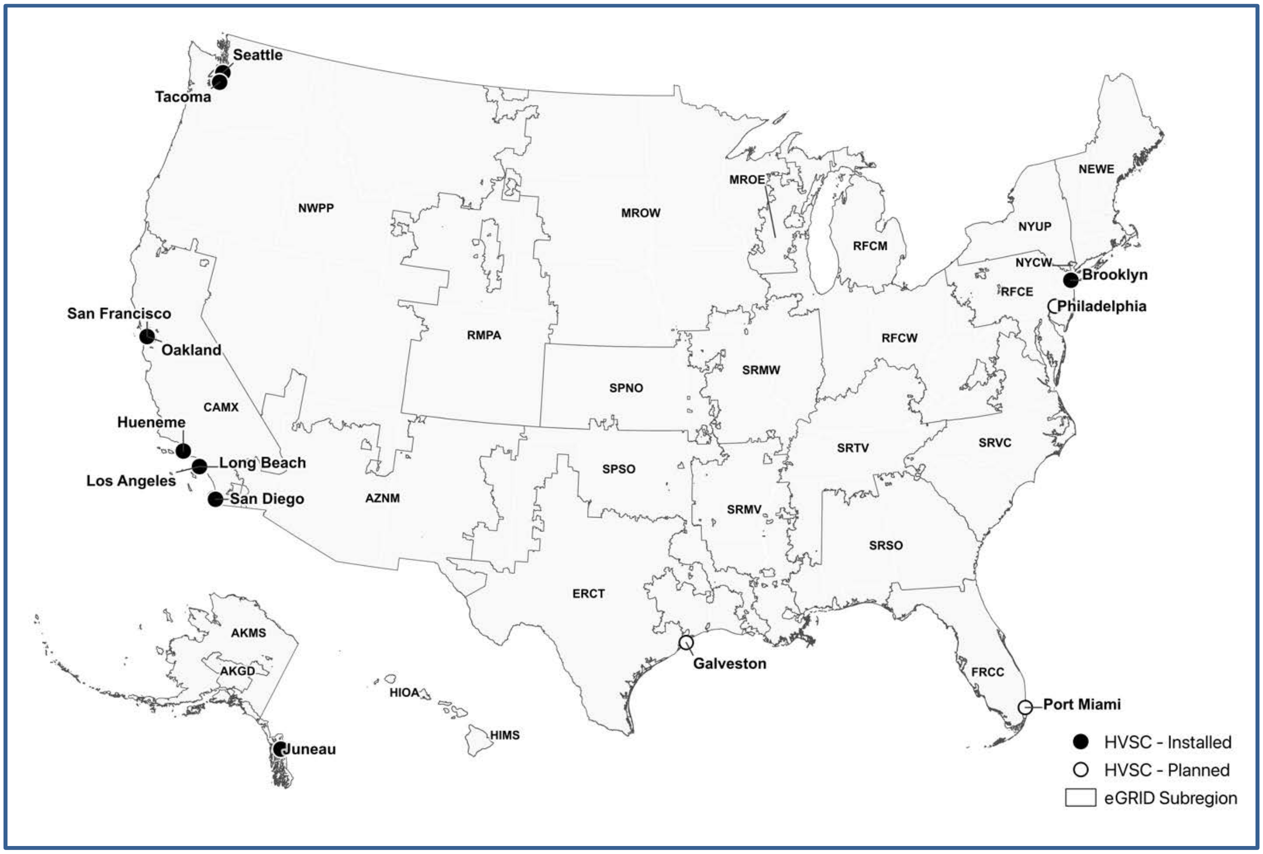

Figure 2: U. S. ports with existing and planned high-voltage shore power connections (HVSC) along with EPA eGRID subregions.

3.2 <u>Design</u>

Shore power systems can be dock-mounted, containerized, or barge-mounted. Dock-mounted systems require power metering and transformer equipment to be mounted on the dock and have a cable-positioning device to help vessels connect to the system at-berth. An example schematic is shown in Figure 3. Barge-mounted systems require little or no dockside space. These systems are self-contained power plants that typically use alternative fuels or technologies such as liquefied natural gas (LNG) and fuel cells.

A shore power system is typically made of 3 main subsystems:
1. Electrical substation
2. Interface system
3. Ship's electrical equipment on board

The Electrical substation converts the electricity from the grid, or from a local dedicated generator using clean or low carbon fuel, into the right voltage and frequency for the vessels.

These systems require electrical protection devices, transformer, frequency converter, power meters and safety control systems.

The Interface or cable management system is a system typically installed on shore (containerized or dock mounted, sometimes barge-mounted), or on ship, that stores, deploys and recovers safely the cables and connectors necessary for the shore power connection. The Cable Management System (CMS) cables then plug in to a receptacle with sockets or inlets.

Ship's Electrical Equipment is the additional electrical equipment (switchboard, control systems, transformers, power monitoring and control systems) that a ship needs to install in the engine room and near the connection point on deck to receive shore power. This equipment can be easily fitted in the hull for a new built, however, to retrofit existing vessels, one often needs to find extra space.

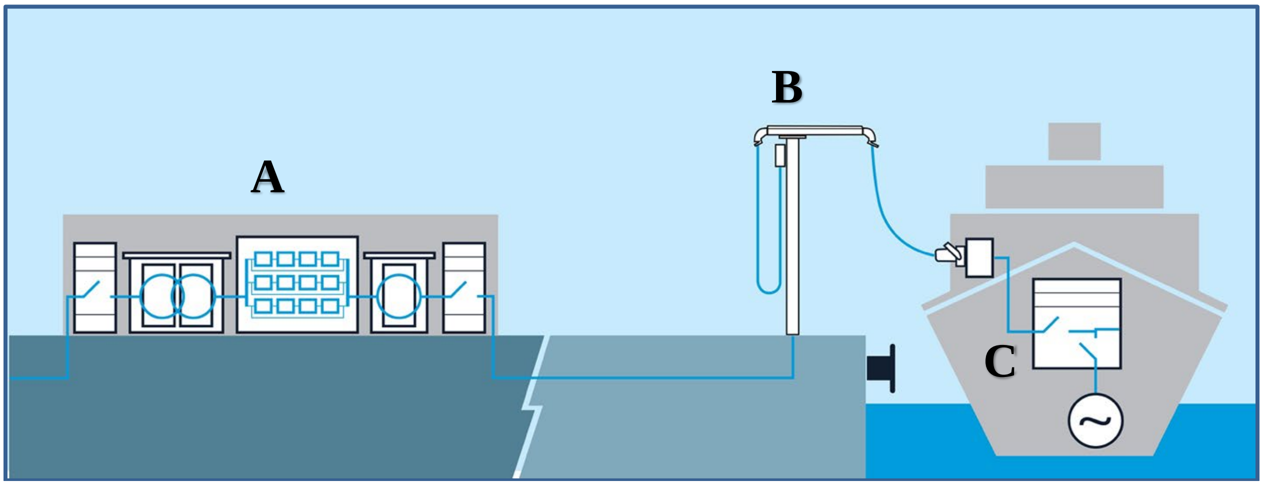

Figure 3: Schematic showing example shore power infrastructure, including the electrical substation (A), cable interface (B), and ship's electrical equipment (C). (Source: Cavotec)

3.3 Standards

The international standard on shore power (IEC/ISO/IEEE 80005) has been developed to ensure worldwide compatibility and safe connection between ports and vessels. All High Voltage Shore Connection (HVSC) installations should meet IEC/ISO/IEEE 80005-1:2019/ AMD 1:2022 industry standards,[20] which cancels and replaces the IEC/ISO/IEEE 80005-1:2012 standard. The IEC/ISO/IEEE 80005-1:2019/AMD 1:2022 standard applies to systems requiring 1 mega volt-ampere (MVA[21]) of power or more. The newer standard provides significant technical modifications for safety improvements with respect to:

- Grounding requirements.
- Procedures for alternative testing.
- Sets a minimum current of 50 milliamps for safety circuits and a maximum time for automatic breaker opening of 200 milliseconds.

[20] ISO. IEEE 80008-1:2019/ AMD 1:2022. Utility Connections in Port – Part 1: High Voltage Shore Connection (HVSC) Systems – General Requirements – Amendment 1. February 2022. https://www.iso.org/standard/82252.html

[21] 1 MVA is equivalent to 1 megawatt [MW] at a power factor of one.

- Requires use of metallic shielding.
- Requires that cruise ships be connected with four cables.[22]
- Specifies that an on-ship transformer is optional and provides further details on fixed and movable onshore supply points.

Further additions are forthcoming to the standard to address requirements for vehicle carriers which are different from RORO.[23] Details of the amendment are not available at time of this publication.

The most recent standard for Low Voltage Shore Connection (LVSC) systems (for shore-to-ship connections, transformers, and associated equipment for vessels requiring up to 1 MVA - IEC/ISO/IEEE 80005-3:2014)[24] was released in December 2014. LVSC systems below 250 amperes (A) or 125 A per cable and not exceeding 300 V to ground are not covered by this standard. Although some ports outside the U.S. have LVSC systems that adhere to the IEC/ISO/IEEE 80005-3:2014 standard (e.g., the Port of Bergen, Norway), no U.S. shore power systems are known to currently meet this standard.

3.4 Readiness of the Vessel Fleet

Worldwide there are approximately 4,500 commercial vessels with a gross tonnage greater than 5,000 tons that are currently equipped for shore power.[25] Analysis of the global fleet by the British Ports Association indicates that approximately 15% of container vessels are shore power equipped along with around 27% of cruise ships.[26] This number continues to increase and can vary significantly by vessel type and region.

The first cruise ship installation in the U.S. was for the Port of Juneau, Alaska, in 2001 and the first U.S. container ship terminal was installed in 2004 for Berth 100 at the West Basin Terminal of the Port of Los Angeles, California. Early adoption of shore power for cruise ships and container ships at Pacific ports, driven by environmental and energy availability needs and regulatory compliance, increased the rate of shore power among these vessels. For example, 48% of cruise ships visiting the Victoria Cruise Terminal in Victoria, British Columbia, in 2018 were equipped with shore power connections. This number is projected to be 85% by 2030 and 95% by 2040.[27]

In California, the Port of Los Angeles, 651 of 958 container ship calls (68%) connected to the ports shore power systems, or employed shore power equivalent methods in 2021, up from 54%

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22 ISO. IEEE 80008-1:2019: AMD 1:2022. Utility Connections in Port – Part 1: High Voltage Shore Connection (HVSC) Systems https://www.iso.org/standard/82252.html

23 IEEE SA Draft International Standard – Utility Connections in Port, February 23, 2022, https://standards.ieee.org/ieee/80005-1b/10844/

24 IEC/PAS 80005-3:2014 Utility connections in port - Part 3: Low Voltage Shore Connection (LVSC) Systems - General requirements https://www.iso.org/standard/64718.html

25 World Fleet Register. January 2021, https://www.clarksons.net/WFR/

26 British Ports Association. Reducing Emissions from Shipping in Ports: Examining the Barriers to Shore Power. https://www.britishports.org.uk/content/uploads/2021/10/bpa_shore_power_paper_may_20201.pdf Accessed August 16, 2022.

27 Greater Victoria Harbour Authority. Shore Power Project. https://gvha.ca/deep-water-terminal/shore-power-project/

in 2014.[28] At the Port of Oakland, 77% of calls in 2021 were by shore power commissioned vessels, and 70% of calls drew shore power.[29] CARB analysis estimates that the upcoming At-Berth Regulation may lead to up to 763 additional vessels to be equipped for shore power.

Rates of shore power readiness are much lower for tankers. The first tanker terminal with shore power was constructed in 2009 at the Port of Long Beach, California, for BP to handle crude oil from Alaska. To date, the Alaskan Navigator and its sister ship, the Alaska Navigator, were both equipped to connect to shore power and have been using shore power at the Long Beach facility for over a decade. However, retrofitting these two ships to accommodate for shore power was less challenging than a typical tanker due to already having diesel-electric engines, which were already well-equipped for high-voltage systems and had a trained crew. Use of shore power on tankers have different challenges than for other ship types. For example, tankers have boilers which are used for steam-driven cargo pumps and replacing these pumps may be impractical. Tankers also use the exhaust from their boilers to generate inert gas to reduce the oxygen content in the vessel's storage tanks to suppress accumulation of flammable gases.[30] CARB's berth analysis for the At-Berth Regulation, anticipates that the majority of tankers may opt for alternative control measures rather than retrofitting for shore power.[31]

For Bulk and General Cargo vessels CARB's At-Berth Regulation does not currently impose shore power or alternative control measures, as their dockside emissions are relatively small and they tend to line-haul at multiple locations along the berth during a single visit, such that investments to build or retrofit bulkers and cargo ships with shore power may not be cost-effective. However, in 2022, CARB staff will perform an interim evaluation and determine the feasibility of potential control technologies for use with bulk and general cargo vessels.

There is also a geographic element in assessing vessel fleet readiness for shore power. With California and China ports[32] requiring the use of shore power, many shore power–ready vessels are currently operating in the Pacific. Analysis of public vessel connection data for cruise ships calling on the ports of Juneau and Los Angeles, which are both shore power equipped, shows that nearly one quarter (77 out of 323) of the global shore power equipped cruise ships visit these two ports. Similarly, vessel connection data for container ships calling on the ports of Los Angeles[33] and Oakland[34] indicate that around 15.2 % (819 out of 5,371) of the global shore power equipped container ships visit these two ports. These counts do not represent a complete inventory of all vessels equipped with shore power, but instead provide a lower bound value for cruise and container ship shore power readiness.

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28 Port of LA AMP Operator Summary 2014, https://kentico.portoflosangeles.org/getmedia/7564269e-4780-47a2-86ee-3da75231e27c/2014_AMP_Counts_POLA Accessed 12/16/2022.

29 Port of Oakland Shore Power Summary All 2021. Accessed 12/16/2022. https://www.oaklandseaport.com/development-programs/shore-power/

30 Eric Tupper, Introduction to Naval Architecture (5th edition), 2013.

31 CARB Staff Analysis of Potential Emission Reduction Strategies by Port/Terminal/Berth for Crude and Product Tanker Vessels, May 2019, https://ww2.arb.ca.gov/sites/default/files/2020-04/tankeranalysis_ADA.pdf

32 Natural Resources Defense Council. China Taking Further Steps to Clean up Shipping Pollution, January 2019. https://www.nrdc.org/experts/barbara-finamore/china-taking-further-steps-clean-shipping-pollution

33 Vessel connection data for the Port of Los Angeles were obtained through a public records request

34 Port of Oakland commissioned vessels available at https://1drv.ms/x/s!AvlUF4vuwRKbs2F4s_J1d-Sq3qbv?e=BCdhe1 Port of Los Angeles vessel calls obtained via public records request. Accessed April 11, 2022.

In China, shore power is available at all container terminal berths at the Port of Shenzhen,[35] which offers subsidies for construction of shore power berths (30%), fully subsidizing demand charges, and fully subsidizing electricity prices to align with the rate demanded by the government which also factors in the price of oil.[36] The Port of Shanghai has entered into an "EcoPartnership" with the Port of Los Angeles to facilitate sharing shore power information, and have created a Green Shipping Corridor between the two ports.[37] China has mandated that China-flagged public service vessels, inland river vessels, and river-sea vessels built on or after January 1, 2019, be equipped with a shore power system. China also mandated that additional China-flagged vessels built on or after January 1, 2020, including coastal container ships, cruise ships and ferries, passenger ships over 3,000 metric tons, and dry bulk carriers over 50,000 metric tons be equipped with shore power systems.[38]

It should also be noted that shore power applications are expanding in Europe. EU regulation 2014/94/EU requires European ports to provide shore power by 2025.[39] As more European ports offer shore power, there are likely to be more shore power–ready vessels in the Atlantic.
At present, shore power has not been extensively adopted globally. However, the International Maritime Organization (IMO), transportation and environment advocacy groups, and port certification groups have been encouraging ports throughout the world to adopt shore power systems. A list of 68 shore power-equipped ports around the world has been compiled by the World Ports Climate Action Program[40] (Figure 4).

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35 DaChan Bay Terminals, DaChan Baty Terminals Becomes the First Container Terminals in South China with all Berths Providing Shore Power, December 6, 2019, https://www.dcbterminals.com/en/news/press-release/22/6/dachan-bay-terminals-becomes-the-first-container-terminals-in-south-china-with-all-berths-providing-shore-power.html

36 Shenzhen Government on line, 2018 http://www.sz.gov.cn/zfgb/2018/gb1068/201809/t20180903_14059441.htm Note that information was obtained from an archived version of this link, translated using Google Translate. https://web.archive.org/web/20191214162115/http://www.sz.gov.cn/zfgb/2018/gb1068/201809/t20180903_14059441.htm

37 Maritime Executive, Los Angeles and Shanghai Plan World's First Green Shipping Corridor, January 31, 2022, https://maritime-executive.com/article/los-angeles-and-shanghai-plan-world-s-first-green-shipping-corridor

38 Seatrade Maritime News, China Mandating Shore Side Power for New Vessels on Domestic Trades, December 13, 2018. https://www.seatrade-maritime.com/asia/china-mandating-shore-side-power-new-vessels-domestic-trades

39 European Parliament. More Efficient and Cleaner Maritime Transport. P9_TA (2021)0131, April 2021.

40 World Ports Sustainability Report 2020. https://sustainableworldports.org/wp-content/uploads/WORLD-PORTS-SUSTAINABILITY-REPORT-2020-FIN.pdf

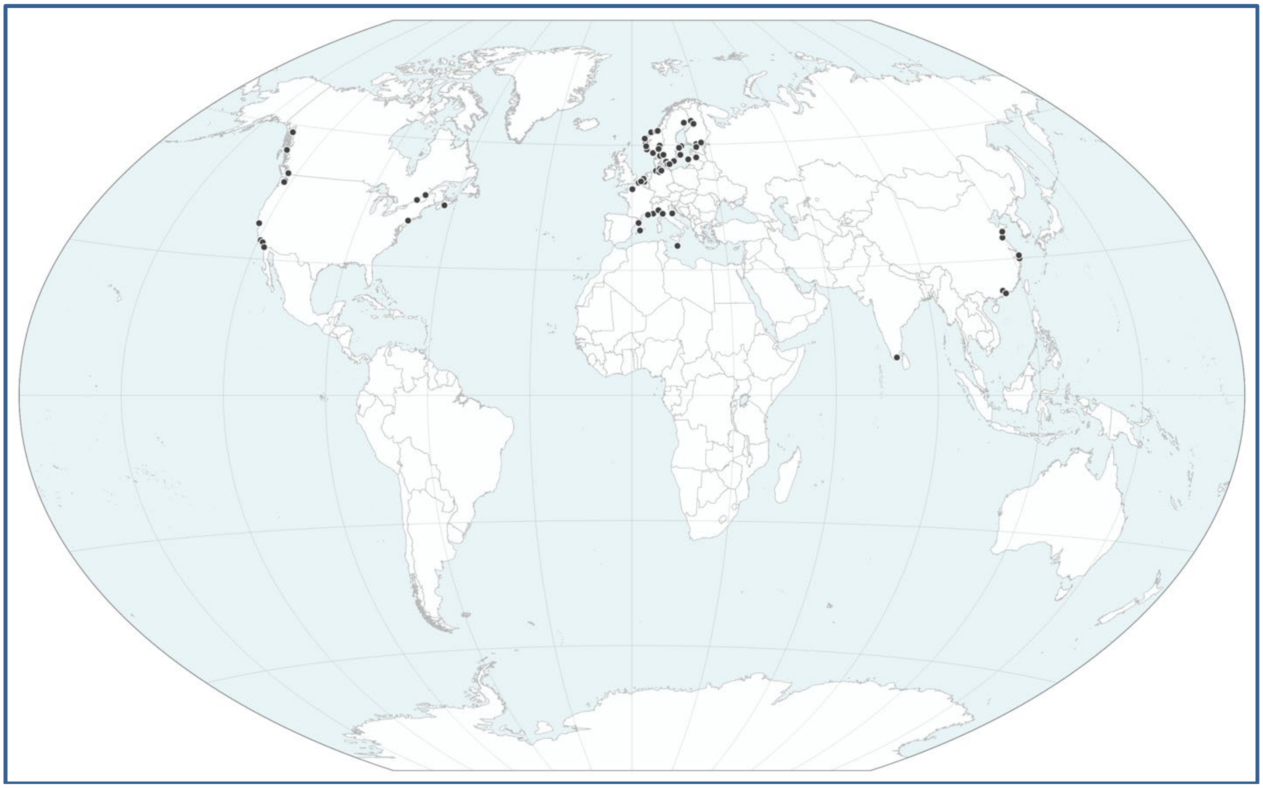

Figure 4: Global shore power installations. Data compiled by World Ports Climate Action Program

3.5 <u>Technical Specifications</u>

Table 1 summarizes the technical specifications for shore power systems installed at 22 U.S. port locations, including 11 installations that were partially funded by EPA's Diesel Emissions Reduction Act (DERA) Program that are referenced in Table 1. These specifications were compiled from several different sources, outlined in the Table 1 footnotes; blanks indicate technical specifications we were unable to determine. The table shows that high-voltage shore power currently serves cruise, container, tanker, and reefer vessels, whereas low-voltage systems serve fishing, tug and support vessels. As of the year 2022 all U.S. systems use 60 hertz (Hz) frequency. High-voltage systems use 6.6 kV, 11 kV, or both; low-voltage systems typically use 220–480 V. Average usage is reported in various ways, including watt-hours, electricity cost, or days of usage.

The European Maritime Safety Agency (EMSA) has published additional technical guidance on equipment, technology, planning, installation, operations, and safety of shore power systems for European ports. This two-part guide by EMSA titled "Shore-Side Electricity, Guidance to Port Authorities and Administrations" [41] is intended to aide all ports and stakeholders.

[41] EMSA Shore Side Electricity, https://emsa.europa.eu/electrification/sse.html. August 12, 2022.

Table 1: Technical specifications for shore power systems installed and planned at U.S. ports.

(Values in **bold** show updated data from the 2017 Shore Power Technology Assessment at U.S. Ports)[42]

	Port Name	Vessel Types	First Year of Installation	Maximum Capacity (MW)	Average Annual Usage	Voltage (kV)	Manufacturer
High Voltage	Juneau[43]	Cruise	2001	11.00	4,107 MWh	6.6 and 11	Local Utility
	Seattle[44,45*]	Cruise **Cruise** **Ferries (WSF Terminal)**	2004 **2024 Planned** **2025 Onwards**	**20**	4,091MWh (2019)‡	6.6 and 11	Watts Marine
	San Francisco[46,47*]	Cruise	2010	12.00	3,872 MWh (2019)‡	6.6 and 11	Watts Marine
	Brooklyn[48,49*]	Cruise	2015	20	596 MWh (2019)‡	6.6 and 11	Watts Marine
	Los Angeles[50]	Cruise, Container	2004	40.00	19,560 MWh[51]	6.6	Cavotec
	Long Beach[52]	Cruise Container Tanker	2011 2009 2000	16.00	10,182MWh (2019)‡	6.6 and 11	Cavotec; Watts Marine
	San Diego[53]	Cruise, Reefer	2010	12.00	3,308 MWh (2019)‡	6.6 and 11	Watts Marine
	Oakland[54]	Container	2012-2013	8	32,087MWh (2020)[55]	6.6	Cavotec
	Hueneme[56,57*]	Reefer	2014	3 MW	4,420 MWh[58]	6.6	Cavotec
	Tacoma[59*60,61*]	Container, RORO **Container**	2009 **2022 Planned**			6.6	Wood Harbinger

42 EPA, Shore Power Technology Assessment at U.S. Ports, 2017 https://www.epa.gov/ports-initiative/shore-power-technology-assessment-us-ports
43 Alaska Electric Light and Power Co. Princess Cruise Ship Shore Power Project 2001 Juneau, Alaska. https://renewablejuneau.org/wp-content/uploads/2019/02/JuneauShoresidePowerProject.pdf
44 Port of Seattle, Waterfront Electrification- Shore Power at Pier 66. https://www.portseattle.org/sites/default/files/2018-12/waterfront-electrification-P66.pdf
45 FY20 DERA National Grant, Port of Seattle. Cruise Ship Shore Power Project
46 ENVIRON (2015).
47 FY09 DERA National Grant, Port of San Francisco. Design and install shore-to-ship electrical connection system for cruise ships
48 WPSP, WPCAP Power2Sship dynamic Google Earth Map https://sustainableworldports.org/wpcap/wg-3/wpcap-power2ship-dynamic-google-earth-map/. Accessed December 16, 2022.
49 FY09 DERA National Grant, Port Authority of New York and New Jersey. Install shore power at the Brooklyn Cruise Terminal
50 Port of LA, Alternative Maritime Power (AMP) https://www.portoflosangeles.org/environment/air-quality/alternative-maritime-power-(amp). Accessed December 16, 2022.
51 $4.2 million in utilities at an average electricity cost of $0.215/kWh (Port of Los Angeles, 2014).
52 Port of Long Beach Shore to Ship Power – Design Standards, https://thehelm.polb.com/download/20/shore-power-cold-ironing-resources/6624/cold-ironing-shore-to-ship-standards-100605.pdf
53 Port of San Diego, Terminals January 12, 2022 https://www.portofsandiego.org/press-releases/general-press-releases/port-san-diego-awards-contract-double-cruise-ship-shore-power
54 Personal Communication: Chris Peterson, Wharfinger, Port of Oakland.
55 Table 2-12. Port of Oakland 2020 Seaport Air Emissions Inventory. https://www.portofoakland.com/files/PDF/Port%20Oakland%202020%20Emissions%20Inventory%20Final%20Report.pdf
56 P2S Inc., Port of Hueneme, Shore Power Infrastructure, https://www.p2sinc.com/projects/port-of-hueneme-shore-power-infrastructure. Accessed December 16, 2022.
57 FY13 DERA National Grant, Port of Hueneme. Install shore-side power to ocean going vessels.
58 CARB At Berth Emission Estimates https://ww2.arb.ca.gov/resources/documents/berth-emission-estimates
59 Wood Harbinger, TOTE Vessel Shore Power – Port of Tacoma. https://www.woodharbinger.com/projects/tote-vessel-shore-power/. Accessed December 16, 2022.
60 FY19 DERA National Grant, Northwest Seaport Alliance. Husky Terminal Shore Power Project.
61 FY09 ARRA National Grant, Port of Tacoma. Retrofit two ocean-going vessels; add certified ship-side technology.

	Port Name	Vessel Types	First Year of Installation	Maximum Capacity (MW)	Average Annual Usage	Voltage (kV)	Manufacturer
High Voltage	**Port Miami[62],[63]***	**Cruise**	**2023, Planned**				
	Galveston[64]	**Cruise**	**2023, Planned**				
	Philadelphia[65]	**Container**	**Planned**				
Low Voltage	Seattle[66]	Fishing		0.096	up to 180 days	0.480	
	Boston[67,68*]	Fishing	2011	0.045	up to 300 days 132.7 MWh		Cooper| Crouse-Hinds
	New Bedford[69,70*]	Fishing and **Offshore support**	2011	0.0264	up to 330 days ~12,450 MWh	0.220	Local Utility
	Philadelphia[71]	Tug					
	Baltimore	Tug		0.250	daily	0.480	
	Los Angeles / Long Beach[72]*	Tug	2009	0.3402	340.2 kWh daily		
	Fourchon[73]	**Offshore support vessels**	**2020**			**0.440**	
	Port Lake Charles[74]	**Tug**	**2021**		**1,490 MWh**	**0.440**	
	Swinomish Indian Tribal Community, WA[75]*	**Fishing**	**2013**		**2,000 – 3,000 MWh**	**0.440 0.220 0.110**	

‡ Data provided by Watts Marine

* Denotes installations partially funded by EPA's Diesel Emissions Reduction Act (DERA) Program

62 Miami-Dade County, Miami-Dade County Major Daniella Levine Cava Announces Commitment with Carnival Cruise Line for Shore Power Pilot at Port Miami. March 19, 2021. https://www.miamidade.gov/releases/2021-03-19-portmiami-shore-power.asp

63 FY21 DERA National Grant, Miami-Dade County's Seaport Department. Port Miami Shore Power Pilot Program.

64 Port of Galveston, Port Going Green with Major Environmental Programs. July 22, 2021. https://www.portofgalveston.com/CivicAlerts.aspx?AID=180

65 Philadelphia Regional Port Authority, Port Development Plan March 2017, https://www.philaport.com/wp-content/uploads/2017/03/Philadelphia-Port-Development-300Mill-UPDATE.pdf.

66 Personal Communication: Ellen Watson, Port of Seattle.

67 Massport, Massport Receives $100,000 Stimulus Grant to Extend Shore Power at Boston Fish Pier and Cut Vessel Emissions. March 18, 2009. https://www.massport.com/massport/media/newsroom/massport-receives-100-000-stimulus-grant-to-extend-shore-power-at-boston-fish-pier-and-cut-vessel-emissions/

68 FY08 DERA National Grant, Massachusetts Port Authority, Electrification of Fish Pier Vessel Berths in South Boston, Massachusetts.

69 Personal Communication: Edward Anthes-Washburn, Port of New Bedford. Reduction in diesel consumption of ~310,000 gallons annually (Appendix A). 1 gallon = ~40.15 kWh.

70 FY09 DERA National Grant, Harbor Development Commission. Port of New Bedford Shore-side Power Electrification Project.

71 ICF. *Tug/towboat emission reduction feasibility study: Draft final report.* Prepared for U.S. Environmental Protection Agency 2009.

72 FY09 DERA National Grant, City of Los Angeles Harbor Department. Flex-Grid System for Alternative Maritime Power Project.

73 Darryl Richard, Entergy Newsroom, Plugging into Entergy's Shore Power Program. Feb 1, 2021. https://www.entergynewsroom.com/article/plugging-into-entergy-s-shore-power-program-t-d-world-magazine/

74 Port of Lake Charles, Port Partners with Crowley Maine, Entergy Louisiana to Reduce Local Emissions through Shore Power August 23,2021, https://portlc.com/news/port-partners-with-crowley-marine-entergy-louisiana-to-reduce-local-emissions-through-shore-power/. Usage estimated based on reported annual savings of 500 tonnes CO_2 and eGRID grid emissions factor for Port Lake Charles region (740.36 lb/MWh).

75 FY13 DERA National Grant, The Swinomish Indian Tribal Community. The Swinomish Marine Engine Repower and Fish Plant Shore Power Project.

3.6 Usage and Price

Table 2 summarizes vessel activity at high-voltage shore power terminals and the price for connecting to shore power. Low-voltage activity and pricing is shown in Table 3. Recent publicly available information was evaluated to assess activity levels, but complete information was not available for all ports, indicated by blank cells. To quantify cruise activity at the ports of Juneau, Brooklyn, Seattle, and San Diego cruise schedules were cross referenced with lists of shore power-equipped cruise vessels and port-published statistics. The number of shore power connections at the Port of San Francisco was estimated using CARB-documented calculations. Calls at Los Angeles, Long Beach, and Oakland were estimated based on the most recently published vessel call data from the ports. Service prices for connecting to shore power were obtained from various sources shown in the footnotes.

Table 2: Vessel activity and service price at high-voltage shore power facilities in the United States.

(Values in **bold** show updated data from the 2017 Shore Power Technology Assessment at U.S. Ports)[76]

Capacity	Port Name	Vessel Types Using Shore Power	# Shore Power Berths	# Unique Shore Power Vessels	Annual Shore Power Calls	Total Calls on Shore Power–Capable Berths (year)	Service Price
High Voltage	Juneau	Cruise	2	49	213	**584 (2019)**[77]	**P: $0.0592/kWh OP: $0.0555/kWh**[78]
	Seattle	Cruise	2[79]	**10 (2019)**	**85 (2019)**	**148 (2019)**	**P: $0.0867/kWh OP: $0.0572/kWh**[80]
	San Francisco[81]	Cruise	1	20	49	**81 (2017)**	Peak Summer Rate $58.304/meter-day + $17.39/kW demand + $0.1333/kWh energy[82]
	Brooklyn	Cruise	1	2	**34**[83]	**35 (2019)**	$0.12/kWh ($0.26/kWh to deliver)

76 EPA, Shore Power Technology Assessment at U.S. Ports, 2017 https://www.epa.gov/ports-initiative/shore-power-technology-assessment-us-ports.

77 City and Borough of Juneau, CBJ Dock Electrification Fact Sheet, https://juneau.org/wp-content/uploads/2019/12/2019-11-23-JCOS-CBJ-Dock-Electrification-Backgrounder-Fact-Sheet-1-2-19.pdf, Juneau has also discussed plans to electrify a starboard-side berth to increase connection options.

78 For Juneau electricity rates from Alaska Electric Light & Power Co., see https://www.aelp.com/Customer-Service/Rates-Billing/Current-Rates. P denotes peak energy rates; OP denotes off-peak energy rates. Additional peak demand charges of $13.85/kW and off-peak demand charges of $8.82/kW also apply. Cruise terminal rates were assumed to fall under the large commercial service category and may not reflect negotiated rates.

79 Seattle is building a new shore power connection at Pier 66.

80 For Port of Seattle electricity rates from Seattle City Light, see https://www.seattle.gov/city-light/business-solutions/business-billing-and-account-information/business-rates#seattlebusinesses. P denotes peak energy rates; OP denotes off-peak energy rates. Additional peak demand charges of $3.85/kW and off-peak demand charges of $0.27/kW also apply. Cruise terminal rates were assumed to fall under the High Demand General Service category for facilities with a maximum monthly demand equal to or greater than 10,000 kW in the City of Seattle.

81 CARB, CARB Staff Analysis of Potential Emission Reduction Strategies by Port/Terminal/Berth for Passenger Vessels, May 2019. https://ww2.arb.ca.gov/sites/default/files/2020-04/cruiseanalysis_ADA.pdf

82 PG&E Electric Schedule E-20. Service to customers with maximum demands of 1,000 kW or more. https://www.pge.com/tariffs/assets/pdf/tariffbook/ELEC_SCHEDS_E-20.pdf, Accessed August 12, 2022.

83 Thirty-four cruise calls scheduled for 2022. The Queen Mary 2 and the Caribbean Princess, Enchanted Princess, and Coral Princess are currently listed as able to plug into shore power. https://www.nytimes.com/2019/12/26/nyregion/cruise-ship-exhaust-shore-power-nyc.html.

Capacity	Port Name	Vessel Types Using Shore Power	# Shore Power Berths	# Unique Shore Power Vessels	Annual Shore Power Calls	Total Calls on Shore Power–Capable Berths (year)	Service Price
High Voltage	Los Angeles	Container	**79[84]**	**231**	**629**	**927 (2020)**	**AMP: $150 service charge + $1.43/kW facilities charge + $0.07511/kWh energy charge (additional charges may be applied—see the source)[85]** **AMP-B: AMP + $10,000 minimum monthly charge (additional charges may be—see the source; no facilities charge)**
		Cruise	**2**	**20**	**47**	**92**	
	Long Beach	Cruise	1		81	2018* (2013)	Varies; each terminal equipped with shore power has its own account and rate structure with Southern California Edison
		Container	15		125		
		Tanker	1		16		
	San Diego	Cruise	2[86]	4	16	87 (2012)	
	Oakland	Container	**19**	**518 commissioned** [87]	**591**	**848* (2021)**	$267 /hour[88] + **$31/hour maintenance rate**
	Hueneme	Reefer	3			391*	
	Tacoma[89]	Container	**3**	**45**		**47* (2019)**	**$83.25 per month + $0.11944/kWh[90]**

* Denotes total port-wide vessel calls, not specific to shore power–equipped berths or terminal.

84 Seventy-nine total AMP vaults as of 2020. https://www.portoflosangeles.org/environment/air-quality/alternative-maritime-power-(amp)

85 Port of LA AMP Special Commercial industrial rates. https://www.ladwp.com/ladwp/faces/ladwp/aboutus/a-financesandreports/a-fr-electricrates/a-fr-er-spcommindrates?_adf.ctrl-state=ysue09j9n_4&_afrLoop=35682275737481&_afrWindowMode=0&_afrWindowId=jzrb4g76g_18#%40%3F_afrWindowId%3Djzrb4g76g_18%26_afrLoop%3D35682275737481%26_afrWindowMode%3D0%26_adf.ctrl-state%3Djzrb4g76g_42

86 Second berth anticipated to be completed in 2022. https://www.portofsandiego.org/press-releases/general-press-releases/port-san-diego-awards-contract-double-cruise-ship-shore-power

87 Oakland List of Shore Power Vessels https://1drv.ms/x/s!AvlUF4vuwRKbs2F4s_J1d-Sq3qbv?e=BCdhe1. Accessed April 11, 2022.

88 Port of Oakland, Shore Power. June 2021. https://www.oaklandseaport.com/development-programs/shore-power/

89 West Coast Collaborative, DERA 2019: Northwest Seaport Alliance – Husky Terminal Shore Power Project. https://westcoastcollaborative.org/files/grants/2019/dera2019-northwest-seaport-alliance-husky-terminal-shorepower-project.pdf https://www.nwseaportalliance.com/environment/clean-air/investing-cleaner-air

90 Tacoma Power Schedule SP Shore Power Service, April 1, 2022, https://www.mytpu.org/wp-content/uploads/SP_2022.pdf

Table 3: Vessel activity and service price at low-voltage shore power facilities in the U.S.

(Values in **bold** show updated data from the 2017 Shore Power Technology Assessment at U.S. Ports)

Capacity	Port Name	Vessel Types Using Shore Power	# Shore Power Berths	# Unique Shore Power Vessels	Annual Shore Power Calls	Total Calls on Shore Power–Capable Berths (year)	Service Price
Low Voltage	Seattle	Fishing	300				**$0.080/kWh**[91]
	Boston[92]	Fishing	18	13			**$0.045/kWh**[93]
	New Bedford[94]	Fishing and Service	50				**$0.059/kWh**[95]
	Philadelphia	Tug					
	Baltimore	Tug	3	3	Daily		
	Los Angeles / Long Beach	Tug	1	2	Daily		
	Port Fourchon	**Offshore Workboat/ Platform support vessels**	**12**				
	Port Lake Charles	**Tug**					
	Swinomish Indian Tribal Community, WA	**Fishing**	**36**				

91 Shore power hookups at Fisherman's Wharf were assumed to fall under the Medium Standard General Service category for the city of Seattle, covering customers with a maximum monthly demand equal to or greater than 50 kW, but less than 1,000 kW. Demand charges of $4.01/kW also apply. Note that this is the publicly offered rate and the port may have negotiated an alternate rate.

92 Massport, Massport Receives $100,000 Stimulus Grant to Extend Shore Power at Boston Fish Pier and Cut Vessel Emissions. March 18, 2009. https://www.massport.com/massport/media/newsroom/massport-receives-100-000-stimulus-grant-to-extend-shore-power-at-boston-fish-pier-and-cut-vessel-emissions/

93 Assumed to fall under "Rate B2 – General" for customers demanding greater than 10 kW but less than 200 kW. Rate given is for June–September; demand charges of $10.59/kW apply along with monthly customer charge of $18.00. See source for additional charges. https://www.eversource.com/content/docs/default-source/rates-tariffs/ema-greater-boston-rates.pdf?sfvrsn=c27ef362_54

94 Massachusetts Clean Energy Center, New Bedford Maine Commercial Terminal. https://www.masscec.com/our-focus/offshore-wind/new-bedford-marine-commerce-terminal-nbmct

95 Massachusetts does not allow for organizations passing through the cost of electricity to impose additional tariffs for services rendered on top of the price of electricity. Vessels using shore power at the Port of New Bedford pay market electricity rates, metered and monitored by the Port of New Bedford. Rate was assumed to fall under the General Annual (G1) category for non-residential customers with load not exceeding 100 kW. Demand charges of $5.38/kW occur over 10 kW along with monthly customer charges, transmission charges, and others. https://www.eversource.com/content/docs/default-source/rates-tariffs/ema-south-shore-rates.pdf?sfvrsn=cd7ef362_40

3.7 Time At-Berth

The U.S. Department of Transportation's Bureau of Transportation Statistics (BTS) provides time at-berth for container tanker, and RORO vessels[96] at the ports of Long Beach, New York and New Jersey, Seattle and Tacoma, and Los Angeles (Table 4). Cruise time at berth was derived from port emission inventories, where available. RORO vessels consistently spend the least amount of time at-berth. At Long Beach, container vessel at-berth times increased as vessel size (i.e., capacity) increased.[97] Similarly, time at-berth for container vessels at the Port of New York and New Jersey increased from 20 hours for a 1,000 twenty-foot equivalent unit (TEU) vessel, to 60 hours for a 13,000 TEU vessel.[98] Cruise and container at-berth times at the ports of Seattle and Tacoma are consistent with those observed at the Port of New York and New Jersey.[99]

Table 4: Average time at berth (hrs) by port and vessel type for select U.S. ports in 2020.

Vessel Type	POLB	NY/NJ	Seattle	Tacoma	POLA
Container	54.3	31.6	32.0	43.1	61.8
Tanker	36.1	38.1	NA	NA	37.7
RORO	21.5	21.4	NA	18.1	21.5
Cruise	32.1[100]	16[101]	8-10[102]	NA	36.7[103]

Dwell time data, by vessel type, averaged over the top 25 U.S. ports are available from the Bureau of Transportation Statistics.[104] The data were reported in hours for 2020, the most recent year of complete data available. Note: the year 2020 was not a typical year for cruise and other vessels due to the COVID-19 world-wide pandemic. Table 5 presents these data.

Table 5: Average time at-berth by vessel type at top 25 U.S. ports.

Vessel type	Average time at-berth (hrs.)
Container	28.1
Crude Oil Tanker	41.4
RORO	23

96 BTS Vessel Dwell Times, https://data.bts.gov/stories/s/Vessel-Dwell-Times/4kd6-2t87. Accessed April 11, 2022.
97 Port of Long Beach Air Emissions Inventory 2020, October 2021. https://polb.com/download/14/emissions-inventory/12958/2020-air-emissions-inventory.pdf
98 Port Authority of NY&NJ,2020 Multi-Facility Emissions Inventory, December 2021. https://www.panynj.gov/content/dam/port/our-port/clean-vessel-incentive-program/FINAL%20PANYNJ%202020%20Multi%20Facility%20EI%20Report.pdf
99 Starcrest. (2013). 2011 Puget Sound maritime air emissions inventory (May 2013 update). Prepared for Puget Sound Maritime Air Forum.
100 Port of Long Beach Air Emissions Inventory 2020, October 2021. https://polb.com/download/14/emissions-inventory/12958/2020-air-emissions-inventory.pdf
101 Port Authority of NY&NJ,2020 Multi-Facility Emissions Inventory, December 2021. https://www.panynj.gov/content/dam/port/our-port/clean-vessel-incentive-program/FINAL%20PANYNJ%202020%20Multi%20Facility%20EI%20Report.pdf
102 Port of Seattle, Questions about Cruise Ship Emissions at Berth, https://www.portseattle.org/blog/questions-about-cruise-ship-emissions-berth. July 12, 2021.
103 Port of LA Air Emissions Inventory, Version 2, 2021. https://www.portoflosangeles.org/environment/air-quality/air-emissions-inventory
104 BTS Vessel Dwell Times, https://data.bts.gov/stories/s/Vessel-Dwell-Times/4kd6-2t87

3.8 Costs and Benefits

This study does not contain a comprehensive analysis of the costs and benefits of shore power. However, certain observations from various studies performed by CARB and for particular ports are noteworthy. A summary of published studies examining various aspects of the economic and environmental costs and benefits of shore power is included as Appendix A. Section 4 presents new port case studies that include useful information on costs. Benefit-cost ratios will vary by port, based on the cost differential of bunker fuels and local electricity prices, including demand charges and connection fees. Expansion of shore power to new ports, and greater shore power availability at ports currently offering shore power, increases the benefit to vessels without increasing costs to vessels that already utilize shore power. Improvements to the grid, including low pollution generation sources and increased resilience, further benefit shore power and other electrification efforts at ports.

The 2020 CARB "Control Measure for Ocean-Going Vessels At Berth" cite that these regulations will improve health benefits for California communities impacted by port operations. Specifically, by 2032, total costs for all entities to implement the rule will exceed $2.23 billion, while health benefits in that time add up to $2.32 billion from avoided adverse health outcomes.[105]

Vaishnav et al. (2016) determined that for the U.S., nationwide shore power has the potential to produce a net benefit to society of up to $33 million annually considering both costs and health benefits. Gillingham and Huang (2020) used a general equilibrium model of the U.S. energy system to estimate the net benefits of using shore power. Their analysis found that shore power fuel costs, which are generally higher than equivalent marine fuel costs, are largely offset by significant social benefits stemming from improved local air quality and reduced carbon emissions, suggesting the cost-benefit ratio is approximately neutral.

Estimates from the International Council on Clean Transportation[106] for vessels using shore power at the Port of Shenzhen found marginal abatement costs of $2,300 per tonne of CO_2 and up to $56,000 per metric ton of NO_x and $290,000 per metric ton of SO_x abated. Analysis by CARB accompanying the At-Berth Regulation found that more than 2.4 million people, of which approximately 1.5 million live in disadvantaged communities, would have their potential cancer risk reduced.

At current bunker prices, the marine industry contends shippers are less likely to opt for shore power than marine gas oil (MGO) use due to the high up-front vessel commissioning costs (annual certification that the vessel is able to properly connect to the system), cost of purchasing electricity while in port, connection fees, and the availability of other, lower cost emission reduction options such as capture and control systems that scrub exhaust gases to reduce engine emissions. However, currently there is only one capture and control system that is approved only for OGV containers by CARB.[107] Maersk specifically claims that shore power is not a cost-

[105] CARB, Control Measure for Ocean-Going Vessels At Berth, 2020. https://ww2.arb.ca.gov/our-work/programs/ocean-going-vessels-berth-regulation/resources

[106] ICCT, Costs and Benefits of Shore Power at the Port of Shenzhen. December 2015. https://theicct.org/sites/default/files/publications/ICCT-WCtr_ShorePower_201512a.pdf

[107] CARB At Berth Regulation Executive Orders: https://ww2.arb.ca.gov/berth-regulation-executive-orders

effective emissions reduction strategy for vessels calling at U.S. ports for short periods of time.[108] However, if marine fuel prices rise relative to electricity prices, then shore power may become more favorable. Note that the break-even point can vary by vessel and port depending upon the price of fuel paid by the vessel, and electricity rates, peak demand charges, and connection fees which can vary significantly between ports.

3.9 United States Navy Shore Power Operations

The U.S. Navy has used shore power on their large ocean-going vessels for decades (where available) and shore power is included in their Incentivized Shipboard Energy Conservation (iENCON) program.[109] The iENCON program mainly focuses on energy reductions while vessels are underway, but also includes energy savings at-berth. Water and electricity usage are monitored and reported while in port and the shore power performance of each vessel is used as part of the evaluation process for the Secretary of the Navy's Energy Award.

The U.S. Navy's Ship Energy Conservation Awards help promote energy conservation within the Department of the Navy. All ships are encouraged to participate, and innovative and efficient energy management practices are rewarded. Energy savings from "cold ironing" (an alternate term for shore power) are specifically identified as a primary criterion, alongside overall energy savings, innovation, and awareness and training.

The Port of San Francisco 2013 Emissions Inventory[110] lists five U.S. Navy vessels using shore power while docked at Pier 70 for maintenance. The average at-berth electric load for these vessels was between 497 kW and 790 kW, with at berth times ranging from eight to 192 hours. Total naval energy use at San Francisco's Pier 70 was approximately 284,000 kWh in 2013.

There are some significant differences between the U.S. Navy and commercial ports use of shore power. Naval vessel power demand at berth is often a smaller fraction of total installed power than commercial marine vessels. Naval vessels are also typically at-berth for longer periods (weeks or months) than many commercial vessels (one to three days). Longer berthing times and auxiliary demands proportional to total installed power make shore power cost effective from a fuel consumption standpoint. Similar to commercial vessels, the additional cost of installing shore power equipment on naval vessels is offset by the difference in cost between electricity and bunker fuels while at-berth.

3.10 CARB's Shore Power Regulations

Shore power is installed at approximately 65 berths at ports in California. CARB has developed the At-Berth Regulation to regulate shore power usage in the State of California.[111] Existing At-Berth Regulations apply to around 4,000 vessel calls from container, reefer, and cruise vessels at the ports of Los Angeles, Long Beach, Oakland, San Francisco, San Diego, and Hueneme. The

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[108] American Shipper. (2014). *Shore power disruptor?*
[109] U.S. Navy. (2015). *iENCON: Incentivized shipboard energy conservation.*
[110] ENVIRON. (2015a). *Port of San Francisco seaport air emissions inventory 2013*. Prepared for the Port of San Francisco.
[111] Information in this section is derived in part from communications with representatives from CARB. We thank them for their input.

Regulation would expand the existing requirements to include vehicle carriers (e.g., RORO) and tanker vessels, reducing emissions from a further 2,300 or more vessel calls. The estimated benefits of the At-Berth Regulation include decreased health risk to port-adjacent populations by virtue of reduced emissions from shore power connected vessels.[112] The Regulation is estimated to cost $2.23 billion, and the benefits of avoided adverse health effects are valued at $2.32 billion. CARB suggests that the costs are reasonable when considered over individual units of freight, at $1.14 per TEU, $4.65 per cruise passenger, $7.66 per automobile, and less than $0.01 per gallon of finished oil product.

3.10.1 CARB Regulation: Ocean-Going Vessels and Shore Power

CARB approved the "Airborne Toxic Control Measure for Auxiliary Diesel Engines Operated on Ocean-Going Vessels At-Berth in a California Port" Regulation, or At-Berth Regulation, in December 2007. Since 2014, at-berth emissions from container, reefer, and cruise vessels have been subject to the At-Berth Regulation. CARB estimates that the existing regulation results in an 80% reduction of criteria pollutant emissions from around 4,000 individual vessels in 2020.[113]

CARB has updated the existing At-Berth Regulation with a set of new Regulations[114] that expand the scope of the past regulation to increase the public health and environmental benefits by including additional vessel types and increasing the number of shore power calls at California ports. The new Regulation expands requirements to include tankers and RORO vessels.

Many of California's ports are located in or near at-risk communities that directly benefit from emissions reductions associated with the use of shore power. The Regulation shifts the burden of regulatory compliance from the vessel operator to a shared responsibility between the vessel and terminal operators. Furthermore, the At-Berth Regulation contributes to meeting California's greenhouse gas emissions reduction targets.

Under the Regulation, vessel operators are required to plug into shore power on 100% of calls to a terminal or use an approved alternative control measure (CARB Approved Emission Control Strategy, or CAECS), such as bonnet capture and control systems, to achieve emissions reductions equivalent to those obtained from plugging into shore power. In order to be approved, emission control strategies must be demonstrated to achieve emission rates of less than 2.8 g/kWh for NO_x, 0.03 g/kWh for $PM_{2.5}$, and 0.1 g/kWh for reactive organic gases[115]. Furthermore, alternative emission control strategies must be grid-neutral based on the year of approval, meaning the strategy shall not emit more GHG emissions than if powered by the California grid. For tankers with steam-driven pumps not using shore power, a CAECS must be demonstrated to achieve emission rates less than 0.4 g/kWh for NO_x, 0.03 g/kWh for $PM_{2.5}$, and 0.02 g/kWh for reactive organic gases from tanker auxiliary boilers. CARB projects that CAECS

[112] CARB, Control Measure for Ocean-Going Vessels At-Berth, August 26, 2020. https://ww2.arb.ca.gov/resources/fact-sheets/control-measure-ocean-going-vessels-berth

[113] CARB, Control Measure for Ocean-Going Vessels At-Berth, August 26, 2020. https://ww2.arb.ca.gov/resources/fact-sheets/control-measure-ocean-going-vessels-berth

[114] Full text for the Final Regulation Order and supporting information for the At-Berth Regulation are available at: https://ww2.arb.ca.gov/rulemaking/2019/ogvatberth 2019.

[115] Reactive Organic Gases (ROG) means Total Organic Gases (TOG) minus ARB's "exempt" compounds (e.g., methane, ethane, CFCs, etc.). Fact Sheet: Development of Organic Emission Estimates for California's Emission Inventory and Air Quality Models https://www.arb.ca.gov/ei/speciate/factsheets_model_ei_speciation_tog_8_00.pdf

systems will be the primary compliance pathway for tankers due to safety and operational constraints associated with retrofitting vessels, and because tanker auxiliary boilers and the steam pumps they drive cannot be operated using shore power without extensive retrofitting and replacement with electric-powered boilers.

The compliance start dates under the new Regulations vary by vessel type, with rules affecting container, cruise, and refrigerated cargo vessels going into effect on January 1, 2023. Compliance for RORO vessels will follow starting on January 1, 2025. Compliance start dates for tankers are differentiated between vessels calling at the San Pedro Bay Ports (i.e., the ports of Los Angeles and Long Beach), for which the new rules go into effect on January 1, 2025, and all remaining ports, for which the new rules go into effect on January 1, 2027.

The At-Berth Regulation also includes a provision to allow for Innovative Concepts (IC) for emission abatement equivalent to the CAECS standards. The IC provision was requested by industry and allows for regulated entities to use CARB-approved strategies to offset emissions from vessels at-berth for up to five years. IC strategies are open-ended in scope and may include land-based measures that are unrelated to vessel activity, such as locomotive engine upgrades or other abatement strategies. Emissions reductions from IC must be demonstrated to be equivalent to or greater than emissions reductions from shore power and be verifiable and enforceable. Applications for ICs were due on December 1, 2021, and new applications for IC strategies will not be considered after that date under the current rule.

Terminal Incident Events (TIEs) are exceptions provided to terminal operators that allow for a limited number of calls where the vessel does not use shore power, or another control measure, as required. Vessel Incident Events (VIEs) are exceptions provided to vessel fleets that allow for a limited number of calls where the vessel operator does not use shore power or another approved control measure during the call. The number of TIEs and VIEs available to each fleet will be granted by CARB at the start of each year. TIEs and VIEs must be reported by the terminal or vessel operators, respectively. The number of TIEs and VIEs granted by CARB is based on a percentage of the fleet vessel visits, to be determined based on the 2021 fleet baseline. The number of TIEs granted will be capped at 15% for the first two years of the Regulation (2023–2024), falling to 5% thereafter. The number of VIEs granted will be set at 5% of the fleet from the outset of the regulation, as it applies to different vessel types, with VIEs being granted at a rate of 5% per year for tankers calling at the San Pedro Bay Ports and ROROs calling at all ports in 2025. VIEs will be granted for tankers calling at other ports starting in 2027, corresponding to the year in which the regulation goes into effect for those vessels at those ports (San Pedro Bay Ports January 1, 2025, and all other ports January 1, 2027.)

At time of this publication CARB is further evaluating their proposal to clarify the amendments with respect to the penetration of zero-emission and cleaner combustion technologies, while minimizing the economic impact on CHC owners and operators, especially to small businesses and fleets. CARB is seeking public comment with a “Second Notice of Public Availability of Modified Text and Availability of Additional Documents and Information”[116]

[116] CARB’s Second Notice of Public Availability of Modified Text and Availability of Additional Documents and Information on CHC posted October 10, 2022: https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2021/chc2021/2nd15daynotice.pdf

4 CASE STUDIES AND LESSONS LEARNED

This section presents the results of conversations with CARB and selected ports regarding their ongoing shore power operations, including best practices from California Air Resources Board and lessons learned from; two ports in California, the ports of Los Angeles and Hueneme; one port in the Pacific Northwest, the Port of Seattle; and the Port of New York & New Jersey in the Northeast. These ports were chosen for its geographic diversity and its size and types of vessels visiting its port.

CARB Best Practices

- Ports should standardize processes for: commissioning of ships for shore power, plug-in approval systems and electric rates.
- Some ports can use Advanced Qualified Unlading Approval (AQUA) Lane[117] – a key item in the pre-approval system to aid in quicker shore power plug-in which saves a lot of time for repeat ships.
- Communication with port and vessel for proper ship alignment before it arrives.
- Clear instructions and training in relevant languages for shore power personnel to ensure safe and efficient shore power connections.
- Planning for and adding additional connections at terminal.

4.1 Port of Los Angeles

The Port of Los Angeles is located at the southern waterfront of the City of Los Angeles, sharing San Pedro Bay with the Port of Long Beach. In 2019 the port was visited by over 1,800 vessels (all types).[118] Most of this traffic was container ships, but it is also a major terminal for cruise ships and automobile carriers.[119] Vessels calling at the Port of Los Angeles are subject to the CARB's At-Berth Regulations for shore power. The Port of Los Angeles refers to shore power as Alternative Maritime Power, or AMP. The port has been operating shore power since 2004 and showed compliance levels of 79% for container and reefer ships in 2020.[120]

[117] CTPAT, Advanced Qualified Unlading Approval Lane, January 7, 2022, https://www.cbp.gov/sites/default/files/assets/documents/2022-May/Aqua%20lane%20FINAL%20PBRB%20approved%201%2019%2022%20%28002%29.pdf

[118] Port of LA Annual Facts and Figures Card, 2021, https://www.portoflosangeles.org/business/statistics/facts-and-figures

[119] Port of Los Angeles. (2014). Comprehensive annual financial report for the fiscal year ended June 30, 2014.

[120] Information in this section is derived in part from communications with representatives from the Port of Los Angeles. We thank them for their input.

Port of Los Angeles Lessons Learned

- Interaction between the port and regulatory agencies is critical for the development of policies that consider the demands of the commercial waterfront and are actionable and enforceable.
- The final shore power system design needs to provide flexibility in the location of the shore power connection cables to ensure that vessels of all sizes can connect.
- The capacity assumptions used in planning the shore power system need to account for future demands, not only the current vessel fleet, but other pending decarbonization initiatives.
- Tankers are anticipated to utilize capture and control devices in lieu of plugging into shore power due to feasibility of electrification of boilers and pumps and issues of safety.

4.1.1 Challenges and Opportunities

When shore power was initially developed at the Port of Los Angeles, the relationship between shipping lines and terminals was more distinct, with specific lines generally calling at specific terminals. This allowed for planning the layout of the shore power systems to meet the needs of a relatively well-defined and consistent set of vessels at each terminal. Over time, changes in alliances among the shipping lines have led to vessels calling at alternate terminals, and so the shore power systems that were initially planned are now sometimes misaligned with the layout of the new vessels now calling at those terminals.

Adding new shore power connection boxes to the terminal docks (also referred to as terminal aprons) is costly and not typically welcomed by terminal tenants. Mobile connectors with cable reels could allow for greater flexibility in connections, as the system may be moved along the

Figure 5: Mobile shore power cable reel (left) and vessel connection (right) at the Port of Los Angeles
Source: Port of Los Angeles

bull rail (i.e., guard rail at the edge of the dock) as needed. Such systems cost approximately $250,000 and require ample clearance along the rail. In cases where there is adequate clearance, tenants may purchase a small shore power "box" and mount it along the rail at a convenient location, then tie back into the main connection. This approach has its challenges, however, as cable management and safety concerns arise when crews are working overtop the shore power cables.

At first, cruise terminals at the Port of Los Angeles were designed with 6.6 kV shore power systems. However, cruise vessels calling at the port were typically equipped with 11 kV systems, which was more common among larger cruise vessels, so the shore power systems required upgrades to accommodate vessels with either 6.6 kV or 11 kV systems. In order to accommodate both voltage systems, the transformer serving the shore power systems was upgraded to provide constant voltage. The transformer upgrade process lasted around 18 months, starting in 2019, during which time the shore power system was unavailable to cruise vessels calling at the port.

Another challenge for the port is the vehicle carrier/RORO vessel shore power systems, the international plug standard has not yet been established and it is unclear whether the standard will adopt 6.6 kV systems, which are more common in the United States, or 11 kV systems, which are more common in Europe.

Port of Los Angeles engineering personnel planned extensively for the initial development of the shore power systems. Large private and port investments were supported by California Proposition 1B funding for the initial shore power installations. Port staff were involved with developing the international IEEE/IEC/ISO 80005 standards for shore power, as well as the regulatory process at the IMO and with other ports around the world to unify the process and ensure that the port was up to date and engaged with the international requirements.

4.1.2 Planning

The Port of Los Angeles is preparing for the CARB At-Berth Regulation update, expanding the number of vessel types covered to include tankers and RORO vessels. Planning for RORO systems is ongoing, though early indications are that 6.6 kV shore power systems are most likely to be used at RORO terminals as these vessels also call at other terminals around the world that serve container vessels.

Tanker operators expressed concerns regarding the safety of retrofitting shore power to their vessels, though those concerns do not extend to new builds. Therefore, tankers calling at the Port of Los Angeles are most likely to use capture and control systems to achieve emissions reductions equivalent to shore power. Alternative capture and control technologies generally operate by extending a bonnet on a boom arm that reaches up and over the stack to capture exhaust emissions. Currently the port has a single barge-based system that uses a tug to position the barge next to the vessel (Figure 6). The system is currently only certified by CARB to treat container vessels. This barge-based system is currently shared between the Port of Los Angeles and the Port of Long Beach.

Figure 6: Barge-based capture and control system operating at the Port of Los Angeles (Source: Port of Los Angeles)

4.1.3 Infrastructure and Utility

Shore power electricity at the Port of Los Angeles is provided by the Los Angeles Department of Water and Power (LADWP), subject to "Special Commercial/Industrial Rates." The shore power systems at the Port of Los Angeles are served by a 34.5 kV substation. Shore power loads are metered separately from other loads, and metering occurs on the primary side of the transformer, or on the secondary side of the transformer compensating for transformer losses, which can be significant.

The LADWP has the discretion to interrupt service to the shore power system with 30 minutes' notice. Interruptions are unlimited in frequency and duration when the operating reserves on the system are inadequate to maintain system energy supply. In previous summers the Port has paused shore power capabilities to vessels due to the State of California Emergency Proclamation for extreme heatwaves and wildfires.

Shore power at the Port of Los Angeles is divided into two rate schedules, AMP and AMP-B, which are both billed monthly to the port. The port then passes the LADWP bill to the respective terminal operator who then bills the individual shipping lines for the portion of the total used by their vessels. AMP-B applies to vessels with maximum demand not less than 7 MW per month and the AMP schedule applies to all other vessels. The top-level breakdown for the two rate schedules is shown in Table 6. The rate structures differ between the two billing schedules, and not all rate categories apply to both AMP and AMP-B. Charges are comprised of monthly service charges, energy charges, and adjustments. AMP service is billed with a monthly service charge and a per kW facilities charge, in addition to energy charges and adjustments. AMP-B service has a monthly service charge and a minimum monthly charge of $10,000 and no facilities charge, in addition to energy charges and adjustments.

Shore power charges at the Port of Los Angeles are also subject to adjustment factors published by LADWP,[121] as well as reactive energy charges for metered ($/kVArh)[122] and unmetered as dollars per kilowatt-hour($/kWh) service. Reactive energy charges range from $0.00014/kWh to $0.00027/kWh for unmetered service and $0.00042/kVArh to $0.00513/kVArh for power factors ranging from 0.95 to zero, respectively. As shown in Table 7, rates are consistent for AMP and AMP-B service, with the exception of facilities charges and minimum monthly charges. For the comparison, "Large Commercial and Multi-Family Service (34.5 kV)" for 2021 is also shown in Table 8, with reactive energy charges and adjustment factors available from LADWP (see footnote 51 and 79).

Table 6: AMP and AMP-B rates for shore power from LADWP.

Rate Category	AMP	AMP-B	Large Commercial and Multi-Family Service
Monthly Service Charge	$150.00	$150.00	$75.00
Minimum monthly charge	-	$10,000.00	-
Facilities Charge ($/kW)	$1.43	-	$4.56
Energy Charge ($/kWh)	$0.07511	$0.07511	$0.03798
High/Low Peak ($/kWh)	-	-	$0.05464
High Peak Demand Charge ($/kW)	-	-	$4.30
Energy Cost Adjustment ($/kWh)	$0.05690	$0.05690	-
Electric Subsidy Adjustment ($/kW)	$0.46	$0.46	-
Reliability Cost Adjustment ($/kWh)	$0.003	$0.003	-

4.1.4 Commissioning and Labor

Vessels are required to be commissioned by the port before they can plug in to the AMP system. The commissioning process[123] requires the vessel to be IEC/ISO/IEEE 80005-1 compliant, or to have been previously accepted for use of the port's AMP system. The commissioning process involves visually inspecting the system following a checklist, as well as verifying the operating functionality of the connection and cable management systems. Commissioning also requires testing the correct functionality of control equipment and protection devices on the ship and on shore.

121 Details of AMP service from LADWP may be found by visiting www.ladwp.com and searching for "AMP" in the search box, then selecting "Special Commercial / Industrial Rates" from the search results.

122 kVArh: kilo-volt ampere reactive hours. Reactive power is power that flows back to the grid during passive phases.

123 Port of Los Angeles System Safety Verification High Voltage Shore Connection (HVSC) https://kentico.portoflosangeles.org/getmedia/b05ac7c1-5c7c-4b2d-9f72-a165d6416e17/AMP_System_Safey_Verification

4.2 Port of Hueneme

The Port of Hueneme is located in Ventura County in Southern California, approximately 60 miles northwest of the ports of Los Angeles and Long Beach.[124] The port provides intermodal connections with total trade valued at $8.75 billion in 2020. Top import and export commodities include refrigerated produce, motor vehicles and parts, textiles and textile products, and heavy machinery.[125] The port started providing shore power to visiting vessels in 2014.

Port of Hueneme Lessons Learned

- Interaction between the port and regulatory agencies is critical for the development of policies that consider the demands of the commercial waterfront and are actionable and enforceable.
- Smaller ports experience significant limitations and challenges obtaining funding for feasibility studies and planning, as well as for shore power infrastructure.
- Shore power has helped the port deliver emissions reductions for the local community, which is noticed when vessels do not connect.
- Engaging in early, often, and open dialogue with the utility is critical to ensure that the needs of the shore power system are met without detriment to the local community.
- Stocking critical spare parts and engaging in regular routine maintenance has helped the port to avoid long delays and parts shortages, allowing them to keep the shore power system operational.
- Providing high voltage system technical training to operators is critical for maintaining shore power operations.

4.2.1 Challenges and Opportunities

The Port of Hueneme installed shore power in compliance with the CARB At-Berth Regulations, adopting an early version of Cavotec's shore power system. Representatives from the Port of Hueneme reported challenges sourcing parts to service their system and identified a lack of competition in the shore power equipment industry as a contributing factor for the difficulty maintaining the system. Port representatives reported that parts of their system, which is an earlier version than those currently offered, are insufficiently equipped for the marine environment and the rigors of a working waterfront. Vaults and boxes accumulate moisture, requiring regular outlet maintenance. The port has adopted the practice of keeping spare parts for critical components in storage and is experimenting with 3-D printing of its own parts, to alleviate issues with sourcing and parts availability. The Port of Hueneme has entered into a quarterly maintenance contract with Cavotec and is now experiencing fewer moisture issues with the regular maintenance schedule.

The Port of Hueneme is also in the process of electrifying cargo handling equipment, and other systems under regulations separate from the At-Berth Regulation. However, the shore power system and associated infrastructure at the port is subject to a State mandated tariff that requires

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[124] Information in this section is derived in part from communications with representatives from the Port of Hueneme. We thank them for their input.

[125] Port of Hueneme. (2015). Port of Hueneme: Vessel Schedule. Retrieved from http://www.portofhueneme.org/vesselschedule/

that the infrastructure be used only for OGV shore power. As such, the planned developments for additional electrification would not be able to tie into the shore power infrastructure, complicating the electrification process and requiring the installation of additional electrical infrastructure with different plug and voltage standards. Each of these separate sets of infrastructure require coordination with the utility and corresponding electrical service requests.

> "*Environmental sustainability is a top priority for the Port and this largest emissions reduction project in county history represents our commitment to being a good neighbor by being a strong environmental steward," said Port Commission President Dr. Manuel Lopez. "Over the lifetime of this project (30 years), annual emissions from refrigerated cargo vessels also known as "reefer vessels" will be significantly reduced." Anticipated reductions include a 92% reduction in PM, 98% reduction in NO_x, and a 55% reduction in greenhouse*

Representatives from the port reported that the shore power system is the single largest emissions reduction project in Ventura County history. In addition to helping reduce emissions while cargo throughput has increased, the shore power system has delivered emissions reductions of diesel particulate matter which is of greatest concern to the local community. Port representatives report that neighbors notice when the shore power system is non-operational and vessels are emitting at-berth, compared to times when vessels are plugged in with no emissions coming from the vessel stacks and engine noise is reduced. The community is strongly in support of the shore power system at the port.

4.2.2 Planning

The Port of Hueneme is in the process of preparing for the newest version of CARB's At-Berth Regulation Port representatives stressed the importance of communication between the port and rulemaking and enforcement groups at regulatory agencies. Alignment between practitioners and rule-makers helps to ensure that regulations consider the nuances and complexities of the commercial maritime environment and system operations, as details of terminal operations vary port by port, berth by berth. Port representatives also stressed the importance of integrating flexibility in the promulgated rules, while providing clarity and reducing compliance reporting and enforcement burdens that are poorly suited to on-dock realities such as time requirements which could jeopardize safety.

The port is currently engineering a new shore power system for their north terminal which is dominated by vehicle carrier/RORO vessel calls. The port has encountered significant challenges associated with this project during their planning for the At-Berth Regulation.

First, when initiating discussions with the local utility (Southern California Edison), it appeared that the utility was not prepared for the increased power demand needed to comply with CARB's At-Berth Regulation. The utility indicated that while they may be able to accommodate the increased demands of the north terminal within the current system, during periods of high demand there may be brownouts for the community. The potential for adverse effects on the local community could negatively impact how the port is perceived and highlighted the importance of early, frequent, and open communication between the port and the utility regarding the shore power system. In this case, it was recommended that during the rulemaking process discussions between regulators and the local power suppliers should be included to develop the rule, so everyone is aware of the required infrastructure and the timing, load scale and frequency of power demand to meet shore power system needs.

Second, funding for the additional shore power infrastructure, and the necessary feasibility studies, remains a significant need for the port. At the south terminal, the port had approximately $4 million dollars available in their budget, but the total cost of the project was $15 million, leaving the port to find alternative funding sources to make up the difference. Funding for the shore power system at the south terminal was ultimately funded through four sources: South Coast Air Quality Management District, Ventura County Air Pollution Control District, EPA's Diesel Emissions Reduction Act (DERA) funding, and federal Congestion Mitigation and Air Quality Improvement funding. However, the north terminal serves RORO vessels, for which shore power is a largely unproven technology, making it a challenge for the port to successfully apply for grants. In addition to infrastructure funding, the port sees significant funding needs for engineering, assessment, and planning studies to determine the feasibility and electrical demand of the new and upgraded system. Port representatives also cited challenges in meeting tight deadlines to submit their plans to regulatory authorities.

Third, port representatives cited uncertainty on the vessel side as a complicating factor for developing their shore power systems, specifically regarding the need for alternative compliance pathways for RORO vessels, such as bonnets and other CARB Approved Emissions Control Systems (CAECSs). Furthermore, for those vehicle carrier/RORO vessels installing shore power systems, the international plug standard has not yet been established. It is unclear whether the standard will adopt the 6.6 kV systems, which are more common in the United States, or 11 kV systems, which are more common in Europe. The international standard for HVSC installations (IEC/ISO/IEEE 80005-1:2019/AMD 1:2022) covers both 6.6 kV and 11 kV systems.

The three factors cited above—uncertainty regarding availability of the service from the utility, significant need for infrastructure and scoping study funding, and uncertainty around vessel-side demand—has created concerns over the increasing cost of adopting and integrating shore power systems and corresponding concerns regarding port competitiveness, both regionally and nationally.

4.2.3 Infrastructure and Utility

The Port of Hueneme installed six shore power outlets in 2014 at three berths at a cost of $14 million to serve vessels regulated under the CARB At-Berth Regulations. The configuration allowed the port to concurrently plug in two vessels at any two of the three electrified berths.[126] Upgrades to the electrical infrastructure included new 16.9 kV service switchgear, 2,000 feet of duct banks, two shore power substations, and six shore power outlet boxes each providing 3 MVA, 6.6 kV connection points.

[126]VSTAR, Port of Hueneme Flips Switch on Shore Power. https://archive.vcstar.com/business/port-of-hueneme-flips-switch-on-shore-power-system-for-ships-ep-458928732-351411851.html/

The port, in partnership with Tesla, has also installed five battery packs to purchase and store lower-cost, off-peak electricity for daytime use by vessels connected to shore power.[127] Statements from the CEO of the Port of Hueneme[128] reveal that infrastructure upgrades will be required to support port electrification, including the shore power system, and upgrade the substations from 16.9 to 66 kV systems, as the existing system is nearing capacity.

The port reports average shore power electricity costs around $0.20/kWh, with rates set by Southern California Edison for large businesses.[129] Hourly charges are variable based on time of day and ambient temperatures, and demand charges are on the order of $14.67/kW of maximum monthly demand. Port representatives reported that vessel operators are not seeing a cost savings using shore power.

4.2.4 Commissioning and Labor

Vessels that call at the Port of Hueneme and request shore power for the first time undergo a commissioning process with the port. This process involves a detailed review of the vessel shore power system specifications and compatibility, and safety checks. If vessels have not plugged in at Port of Hueneme, but have plugged in elsewhere in California, then the port considers them to be commissioned and allows them to connect after a review of the vessel shore power system specifications.

Port representatives identified specialized training as key for the proper functioning of the shore power system. The port does not have dedicated high voltage electrical engineers for the shore power system due to staffing constraints, and responsibility for connection falls to the terminal operators and longshoremen. As such, the port cannot guarantee which labor will be provided for connections. If the operators are not well trained and experienced operating the shore power equipment, then specialized technical assistance is required. Shoreside operators rely on equipment manufacturer technicians to train the shoreside technicians, and when complex challenges are encountered related to the infrastructure of the supporting substation equipment operators will often request help from port technical staff.

4.3 Port of New York & New Jersey

The Port of Brooklyn cruise terminal opened in 2006 and is located in the Red Hook area on the Buttermilk Channel between the borough of Brooklyn and Governs Island. In 2018 it had approximately 28 ship calls handling 143,000 passengers. The New York City Economic Development Corporation (NYCEDC) announced the opening of the shore power system at the Brooklyn Cruise Terminal in November of 2016. Ports America has been operating the terminal since 2017.[130]

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[127] Port of Hueneme Kristin Decas Testimony April 15, 2021. https://transportation.house.gov/imo/media/doc/Decas%20Testimony.pdf

[128] Port of Hueneme. Puts Final Touches on Shore Power Project: https://www.portofhueneme.org/port-puts-final-touches-on-shore-power-project/. May 2016.

[129] Special tariff schedules for the Port of Hueneme are not available. See for example: https://library.sce.com/content/dam/sce-doclib/public/regulatory/tariff/electric/schedules/general-service-&-industrial-rates/ELECTRIC_SCHEDULES_TOU-8-RTP.pdf

[130] Information in this section is derived in part from communications with representatives from NYCEDC and Ports America. We thank them for their input.

Port of New York & New Jersey Lessons Learned

- The shore power design should provide sufficient flexibility in the location of the shore power connection cables to ensure that all vessels can connect.
- Shore power has helped the port deliver emissions reductions for the local community, and local residents notice when the system is not working.
- Engaging in early, often, and open dialogue with the utility is critical to ensure the needs of the shore power system are met without impact to the local power needs.
- Tidal and wind/weather events can affect the ability of the ship to safely connect to shore power.
- Adhering to on-time cruise vessel schedules are a critical factor in determining whether a vessel will plug in. If the vessel is behind schedule, then it generally doesn't connect to shore power.

4.3.1 Challenges and Opportunities

The shore power system at the Brooklyn Cruise Terminal was installed per Watts Marine's (formerly Cochran Marine) design and completed in 2015. The cable positioning device (CPD) has an extendable boom and can be remotely monitored. The shore power system at Brooklyn was designed to accommodate the Queen Mary 2, operated by Cunard, which is part of the Carnival Corporation. In addition to the Queen Mary 2, Princess Cruises, which is also part of the Carnival Corporation, now calls at the Brooklyn Cruise Terminal as well. The system is fixed in place on the apron. The terminal apron at the Brooklyn Cruise Terminal is 25 feet wide, and initial thoughts were that the apron was too narrow for a mobile system, however, the port now believes that future systems may be flexible enough to fit on the apron and accommodate other vessels with shore power connection points in different locations. Additionally, there were safety concerns regarding loading and unloading operations on the small apron in close proximity to the shore power cables.

The system has been adapted to service more than one cruise ship since Princess Cruises started calling at the terminal, though vessels still only connect approximately 50% of the time. Connection issues arise due to a range of factors, including tidal-related challenges that make aligning shore and vessel systems difficult, delays due to late vessel arrivals and short connection times, and connectivity to the local grid. If the local grid is stressed, such as during high electrical demand, then the shore power system is typically unavailable. These issues—including local grid reliability, vessel arrival times and schedules, tidal and wind conditions, and vessel-side operations—has led to concerns from ship captains regarding the reliability of the shore power system and potential disruptions to vessel operations while at berth. On-time vessel arrivals were cited as the most important factor ensuring successful use of the shore power system.

The connection time at the Brooklyn Cruise Terminal is around 90 minutes, while disconnecting takes approximately an hour. A typical call at the terminal lasts around eight to nine hours. The connecting and disconnecting process is performed by trained technicians from Watts Marine. Representatives from NYCEDC and Ports America noted that if the vessel arrives late, then the shore power system is typically not connected due to time constraints and the need to follow proper procedures for connecting and disconnecting, which cannot be rushed in order to accommodate shorter turnaround times needed to ensure the vessel departs on time.

4.3.2 Planning

In addition to the Brooklyn Cruise Terminal, NYCEDC manages operations at the Manhattan Cruise Terminal, located on the Hudson River on Manhattan's West Side. NYCEDC is planning upgrades to terminal and dock facilities at the Manhattan Cruise Terminal, with no confirmed plans to add shore power at that facility.

Per communications with representatives from NYCEDC and Ports America, the electrical grid on Manhattan's West Side is complex and challenging for utility planners. The planned Manhattan Terminal will have three berths. Given the complexities of the local grid, the project costs to provide shore power to are estimated to be very high. The terminal footprints and the working area at the Manhattan Terminal are also more constrained than at the Brooklyn Terminal, further complicating shore power installation. Additionally, when developing the shore power system at the Brooklyn Cruise Terminal, the port worked closely with the Carnival Corporation, which owns Cunard and Princess Cruises, providing confidence in the number of calls by vessels equipped to connect to shore power. Analysis of vessels calling at the Manhattan Cruise Terminal by NYCEDC and port staff shows high variability in the frequency of calls by shore power capable vessels.

At the Brooklyn Cruise Terminal, around 43% of calls (9 calls) connected to the shore power system in 2018. In 2022, there are 31 scheduled calls at the Brooklyn Cruise Terminal.[131] The Queen Mary 2, which is shore power capable, is scheduled to call 16 times, and the Enchanted Princess, which is also shore power capable is scheduled to call eight times. The Caribbean Princess is scheduled to call six times and the Sky Princess once in 2022.

The Brooklyn Cruise Terminal is working with Watts Marine to expand the range of connection points on the pier to provide greater flexibility for vessel connections. Representatives from the terminal have also discussed moving from a fixed connection system to a movable system, providing greater flexibility for connection. The cost of a movable system reportedly would be about one million dollars.

4.3.3 Infrastructure and Utility

When the shore power system at the Brooklyn Cruise Terminal was planned, the landside infrastructure also needed to be upgraded in advance to accommodate the additional electrical load from the system.

The shore power system at the Brooklyn Cruise Terminal is tied into the local grid operated by Consolidated Edison. Three feeder lines serve the local grid from Consolidated Edison generation facilities. Port representatives noted that due to the demands of the shore power system, if one or more of the feeder lines go down, or other electrical issues arise on the local

[131] NY Cruise Schedule: https://www.nycruise.com/schedule/. Accessed April 11, 2022.

grid, then the shore power system is typically the first to be taken offline. The port also noted that in some cases, they do not find out until the day of vessel arrival that the shore power system is unavailable. Power availability from the grid was seen as one of the most significant factors in fully utilizing the cruise terminal's shore power system.

Vessels calling at the Brooklyn Cruise Terminal pay a fixed rate of 12.5 cents/kWh for electricity while at-berth. This rate is jointly subsidized by the City and State of New York, which covers the balance of the full applicable tariff rate from the New York Power Authority. This rate does not include demand charges, which are also covered by the City.

4.3.4 Commissioning and Labor

The shore power system at the Brooklyn Cruise Terminal is commissioned at the start of each cruise season and decommissioned at the end of the season, in addition to regular planned and unscheduled maintenance of the equipment. Commissioning and decommissioning are performed by trained technicians from Watts Marine, who also facilitate the regular shore power connections at the terminal. The commissioning and decommissioning processes are described by the port as routine operations to test the systems to ensure proper working order, with the exercises taking approximately two days each.

4.4 Port of Seattle

Shore power has been in use for cruise vessels at the Port of Seattle since 2004, when it was first installed for Holland America at Terminal 30.[132] When cruise operations moved to the two-berth Smith Cove Cruise Terminal at Terminal 91 in 2009, shore power was installed at both berths. With this installation, Port of Seattle became the first cruise port in the world with two shore power berths. In 2019, 85 of 95 shore power–equipped vessel calls connected to shore power at Terminal 91, providing a connection rate of 89%. Shore power use in 2019 reduced an estimated 3,000 tonnes of CO_2e. While COVID-19 led to the cancellation of the 2020 cruise season, cruise ships returned to Seattle for a partial cruise season in 2021 with 82 total cruise calls. 30 of 31 (97%) shore power-equipped vessel calls connected at Terminal 91 in 2021, reducing an estimated 1,800 tonnes of CO_2e.[133]

Marine cargo ship calls at regional terminals are managed by the Northwest Seaport Alliance (NWSA). The NWSA is installing shore power at two berths as part of a project to modernize Terminal 5 in Seattle. The shore power system at Terminal 5 is being partially funded by a special appropriation from the State of Washington.[134]

[132] This section is based on literature review and conversations with representatives from the Port of Seattle and Watts Marine. We thank them for their input.

[133] Puget Sound Maritime Air Emissions Inventory - Deep Dive: Cruise Shore Power https://www.portseattle.org/programs/puget-sound-maritime-air-emissions-inventory. Accessed August 15, 2022.

[134] The Northwest Seaport Alliance. Investing in Cleaner Air. https://www.nwseaportalliance.com/environment/clean-air/investing-cleaner-air. Accessed August 15, 2022.

Port of Seattle Lessons Learned

- Shore power infrastructure costs are high and public funding is critical in helping the port implement shore power.
- Connections with the utility are complex, and utility-imposed demand charges significantly increase the cost to vessels to operate using shore power at dock.
- Conversations with vessel operators indicate that they are not yet seeing cost savings when using shore power.
- Public funding sources are critical for shore power infrastructure development.
- The shore power system design should provide flexibility in the location of the shore power connection cables to allow all vessels that are shore power ready to connect
- The shore power system design should also account for future demands that include other appropriate terminals and decarbonization initiatives.

4.4.1 Challenges and Opportunities

The biggest challenge identified by representatives from the Port of Seattle is the limited availability of shore power connections on vessels calling at the port. At present, just over 50% of cruise vessels calling at the port are equipped with a connection. Under the Northwest Ports Clean Air Strategy[135], the port has a goal of installing shore power at 100% of major cruise and container berths, with 100% of cruise ships equipped with and able to connect to shore power by 2030.

Representatives from the Port also identified challenges implementing shore power for vessel types other than cruise ships. While the port is seeing increasing numbers of shore power-equipped vessels in the cargo sector, implementing shore power for the bulk sector—particularly grain ships—remains challenging. The port sees relatively few calls from grain ships, and though they may berth for extended periods, many of these vessels are not recurring visitors, so the economic investment associated with shore power may not exist from the vessel owner's perspective if shore power is not available at other ports along its route.

The Port of Seattle also identified the high cost of shore power infrastructure as a barrier to adoption. Shore power projects are typically very expensive, on the order of tens of millions of dollars. Representatives from the port identified available grant funding as essential to meet the Northwest Ports Clean Air Strategy goals. Furthermore, the large electrical loads required for shore power present a significant challenge to the local utility, which has to design and upgrade systems for maximum loads, and often faces feeder capacity and load balancing issues. Utility infrastructure upgrades add considerable costs and complexity to shore power projects. Additionally, the demand charges associated with shore power systems can change the financial case for vessels, particularly cruise ships, such that shore power is not necessarily a lower-cost option compared to running auxiliary engines on bunker fuels.

[135] 2020 Northwest Ports Clean Air Strategy: https://www.nwseaportalliance.com/environment/clean-air/northwest-ports-clean-air-strategy

Coordinated planning on shore power projects is also critical, especially as Port of Seattle and other users of the waterfront plan for electrification and decarbonization of the maritime sector. As Port of Seattle is in the process of adding shore power to a third cruise berth at Pier 66 along the downtown Seattle waterfront, Washington State Ferries (WSF), which operates the largest ferry system in the United States, is also undertaking an effort to electrify their fleet with plug-in hybrid-electric vessels and corresponding terminal enhancements.[136] By design, these vessels will not utilize standard diesel auxiliary engines but instead rely on landside electrical power while at-berth to provide electricity while docked and charge the batteries used for propulsion.

WSF plans to replace 16 aging vessels with new vessels, and to retrofit 6 existing vessels. According to WSF, "shore charging" will require electrical charging infrastructure at the terminals to support the new plug-in vessels. The shore charging power supply will involve a rapid charging system connecting the ferry terminal wingwall with the vessel's onboard battery system. Development of the rapid charging system is challenging due to the time constraints involved with ferry operations, which make frequent terminal calls but have very short turnaround times and may require shoreside energy storage systems to alleviate strain on the local grid when vessels plug in, as well as provide rapid direct current charging.

The WSF ferry terminal is located adjacent to Pier 66. The Port, WSF, and the local utility is coordinating with all stakeholders to ensure there is sufficient electric capacity for multiple high demand uses from maritime electrification. The Port expects challenges to arise in other locations around the Port and waterfront as electric technologies become increasingly available in maritime applications. To help alleviate these challenges, the Port initiated a holistic waterfront planning effort in collaboration with the local utility, Seattle City Light, to jointly plan for future loads that are aligned with the Port's decarbonization goals.

4.4.2 Planning

The Port of Seattle has faced similar planning challenges to other ports regarding the flexibility of fixed shore power CPDs. Fixed gangways and CPDs do not allow for flexibility to accommodate the full variety of vessels that could connect to the shore power systems. Watts Marine has outfitted a manlift that can be moved along the pier to facilitate shore power connections. One of the challenges of this solution, however, is the cable required for shore power is heavy and bulky making it a challenge to manage.

The Port of Seattle plans to expand its waterfront electrification program by adding shore power at the Pier 66 Bell Street Cruise Terminal, which serves Norwegian Cruise Line and Oceania Cruises' service to Alaska. Project cost estimates total approximately $30 million.[137] The Pier 66 project is funded in part by grant funding from EPA's DERA program, the state of Washington Department of Ecology, the TransAlta Centralia Coal Transition Board, cost sharing from the port, and additional leveraged funds. The addition of shore power will require onsite and offsite work to add a dual voltage (6.6 kV and 11 kV) 20 MW system for the single berth at Pier 66 and other cruise and container ship facilities. Offsite work will include upgrading the connections to

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136 Washington State Ferries System Electrification Plan. December 2020. https://wsdot.wa.gov/sites/default/files/2021-11/WSF-SystemElectrificationPlan-December2020.pdf

137 Port of Seattle, Waterfront Electrification- Shore Power Pier 66 https://www.portseattle.org/sites/default/files/2018-12/waterfront-electrification-P66.pdf https://www.portseattle.org/projects/pier-66bell-street-pier-shore-power

the utility for 20 MW supply and lay new conduit and cabling to feed the shore power system. The port is in the permitting process to lay a submarine cable from Pier 46 to Pier 66. Delivering power via a submarine cable avoids construction from trenching city streets along Seattle's central waterfront, which would substantially delay implementation and increase costs. Onsite work will include new conduits, cables, and transformers and switchgears that feed into the CPD at the bull rail. Cruise ships such as those expected to call at Pier 66 tend to have large power requirements, up to 14 MW. Furthermore, the port is in discussion with Washington State Ferries, which would require an estimated 10 MW of power, to co-develop electrification at Pier 66 to serve both cruise ships and ferries.

4.4.3 Infrastructure and Utility

The primary switchgear at Terminal 91 which includes metering equipment and relay protection devices, is fed by Seattle City Light at 27.5 kV. The primary switchgear then feeds into a transformer and a secondary switchgear that delivers either 6.6 kV or 11 kV depending on the vessel needs.

Electricity is provided by Seattle City Light and metered as High Demand General Service (10,000+ kW maximum monthly demand). Rates provided by Seattle City Light include peak and off-peak service and demand charges,[138] as shown in Table 7. The grid mix supplying Seattle City Light is 93% renewable, including hydroelectricity, wind power, and biogas.

Table 7: High Demand (10,000 kW+) electric service rates for the city of Seattle from Seattle City Light.

Measurement	Rate Category	High Demand Rate
Service Charge (Per kWh)	Peak	$0.0867
	Off-Peak	$0.0572
Demand Charge (Per kW)	Peak	$3.85
	Off-Peak	$0.27
Minimum bill per meter day		$93.33

In addition to shore power for cruise, low-voltage shore power connections are common for fishing vessels and tugs around the Port of Seattle. All fishing vessels can connect to low-voltage systems, and port representatives report that if fishing vessels are at-berth for four or more days, then they almost always connect. At Terminal 91, standard power pits carry 480 V, 400 A service, with two 480 V, 800 A services also available. Vessel operators of newer and larger fishing vessels have identified the need for a higher amperage connection of 600A. The port works closely with the vessel operators to supply low-voltage shore power, with vessel operators informing the port of their power needs and the port electricians adapting the available service to those needs.

138 Seattle Government, Seattle City Light, Business Rates. https://www.seattle.gov/city-light/business-solutions/business-billing-and-account-information/business-rates#seattlebusinesses. Accessed April 11, 2022.

In October 2020, the Port of Seattle Commissioners authorized funding for low-voltage shore power improvements for Dock-E at Harbor Island Marina.[139] The existing infrastructure no longer meets the power requirements of the tug and marine construction/salvage companies that are currently tenants, and the existing transformer presents a safety issue. The total estimated project cost for the improvements is $450,000 to upgrade the existing 200 A and 30 A service at Dock-E to three-phase 480 V service. The upgrades completed in 2021. The project removed the existing transformer from the dock and relocated new electrical equipment landside. The upgrade also included a new transformer providing 600 A, three-phase 480 V power to serve six shore power pedestals with combination three-phase 480 V and single-phase 120 V power.

4.4.4 Commissioning and Labor

Vessels connecting to shore power at the Port of Seattle are typically "home port" cruise vessels with established berthing schedules. Shore power-capable, home port vessels are then commissioned by the port to ensure safety, security, and compatibility between the vessel and the landside shore power system. Once the vessel is commissioned it is given an agreement to connect to the shore power system.

Once shore power equipment has been commissioned at the port, electricians from Watts Marine provide operations and maintenance support. Watts electricians work with the ships' crews to support the connection to shoreside infrastructure and are responsible for commissioning and decommissioning the system at the beginning and end of the cruise season.

The Watts Marine system at the port is semi-automated and remotely monitored. While the connection process itself is not automated, once it is connected, remote operators are able to monitor the system and gather information regarding connection and disconnection times, kWh consumed, and associated emissions reductions.

Watts contracts with union electricians that have experience with medium and high-voltage systems. Watts requires additional in-house training and certification of electricians before they can operate the system. Most of the cable management and system operation is done from a human-machine interface that mitigates risk to operators.

4.5 Decarbonization of the Grid

Shore power use can have a net positive impact on air quality if the landside emissions from the electric generating units (EGUs) providing power to the shore power system are lower than the associated auxiliary engine emissions occurring at berth. Generally, the coastal electric grid is cleaner due to increased use of renewables (Table 8), except for certain areas such as Alaska, Hawaii, Michigan, and the Mississippi Valley, where emissions for specific pollutants are higher.

139 Additional details may be found in Attachments 6f for the October 13, 2020, Commission Meeting at: https://meetings.portseattle.org

Table 8: Comparison of regional eGRID emission factors.

eGRID Subregion Name[140]	Regional Emission Factors g/kWh)			
	NOx	SO_2	CO_2eq	$PM_{2.5}$
ASCC Alaska Grid	2.48	0.50	474.00	0.093
ASCC Miscellaneous	3.50	0.31	239.03	0.355
WECC California	0.21	0.02	226.20	0.014
ERCT All	0.25	0.38	424.60	0.021
FRCC All	0.16	0.13	424.63	0.029
HICC Miscellaneous	3.46	1.80	507.60	0.420
HICC Oahu	1.59	3.63	763.21	0.262
NPCC New England	0.18	0.06	239.30	0.021
WECC Northwest	0.26	0.17	291.82	0.017
NPCC Upstate NY	0.06	0.04	115.16	0.008
RFC East	0.15	0.22	326.58	0.022
RFC Michigan	0.36	0.59	599.28	0.029
RFC West	0.37	0.42	532.53	0.048
SERC Mississippi Valley	0.28	0.44	389.35	0.020
SERC South	0.22	0.13	468.77	0.016
SERC Virginia/Carolina	0.20	0.12	339.07	0.023
Marine Engine Emission Factors				
Higher than NO_X Tier III	2			
Higher than MGO (0.10%S)	7.7	0.424	705	0.174
Higher than MDO (0.50%S)	7.7	2.121	705	0.299

Table 8 compares the EGU emission factors by region with those for auxiliary engines, on a kWh basis.

Comparing eGRID Regional Emission Factors to Marine Engine Emission Factors, in most cases the grid emission factors are significantly lower except in a few instances highlighted in table above. Aggregated emissions per kWh for landside power generation are generally declining over time due to more use of natural gas, expansion of wind, solar, hydroelectric power, and use of biofuels. The expansion of renewable power is occurring while combustion of fossil fuels such as coal represent a smaller fraction of the total U.S. electricity generation mix (Figure 7).[141]

140 See Figure 5 for Subregion locations.
141 EIA Projects Renewables Share of U.S. Electricity Generation Mix Will Double by 2050 (2021). https://www.eia.gov/todayinenergy/detail.php?id=46676

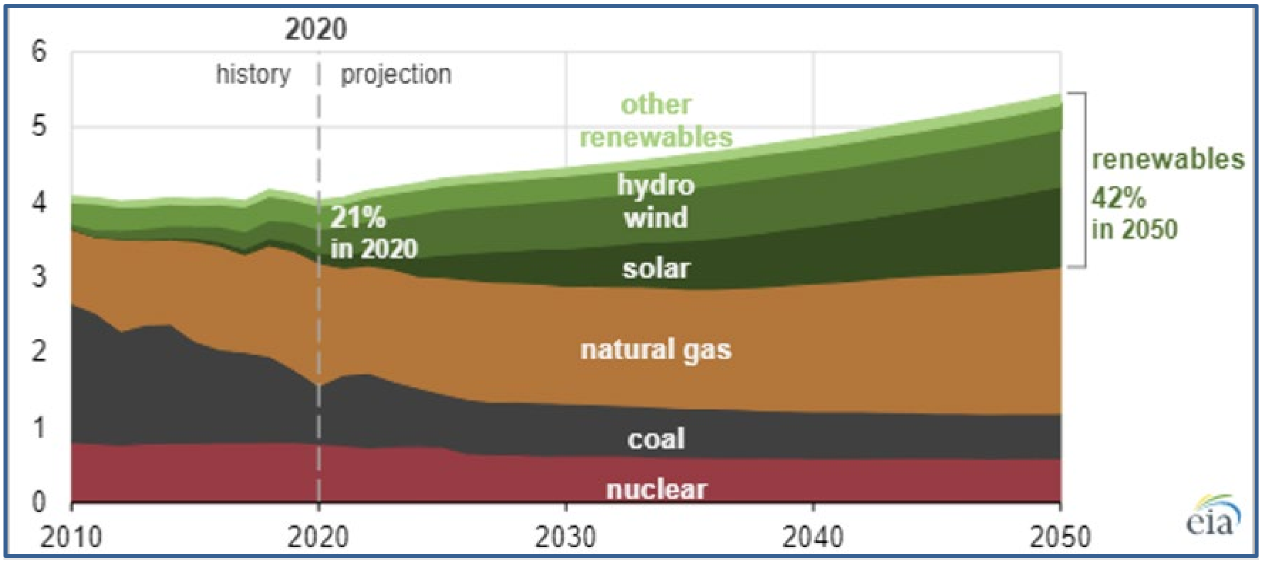

Figure 7: Historical and projected U.S. electricity generation.

Renewables account for 79.3% of U.S. electricity generating capacity that came online in 2022 (including planned capacity) (see Figure 8).[142] Of the anticipated 44.4 gigawatts (GW) of new electrical capacity, solar accounts for 17.8 GW, mostly in Texas, California, and North Carolina. Wind power accounts for 11.2 GW, which is planned for Texas and offshore of Virginia. To address the issue of intermittent power generation intrinsic to solar and wind power, investments in battery storage continue to increase (6.2 GW). Increasing battery storage allows for energy to be saved during daylight hours or when wind is generating power. This energy can then be available during evening hours or when winds are light or too fast to safely generate power. One of the largest solar battery storage units was developed at Manatee Energy Storage Center in Florida with 409 MW of capacity completed in 2021.[143]

As long as emissions from the energy source used to support shore power is cleaner than emissions from the diesel auxiliary engines used by marine vessels while dockside, then shore power will provide a positive air quality impact. The expansion of renewables helps ensure shore power will continue to provide a cleaner option.

142 U.S. Energy Information Administration. August 3, 2022. The U.S. power grid added 15 GW of generating capacity in the first half of 2022. https://www.eia.gov/todayinenergy/detail.php?id=53299

143 U.S. Energy Information Administration. January 11. 2021, Renewables account for most new U.S. electricity generating capacity in 2021. https://www.eia.gov/todayinenergy/detail.php?id=46416

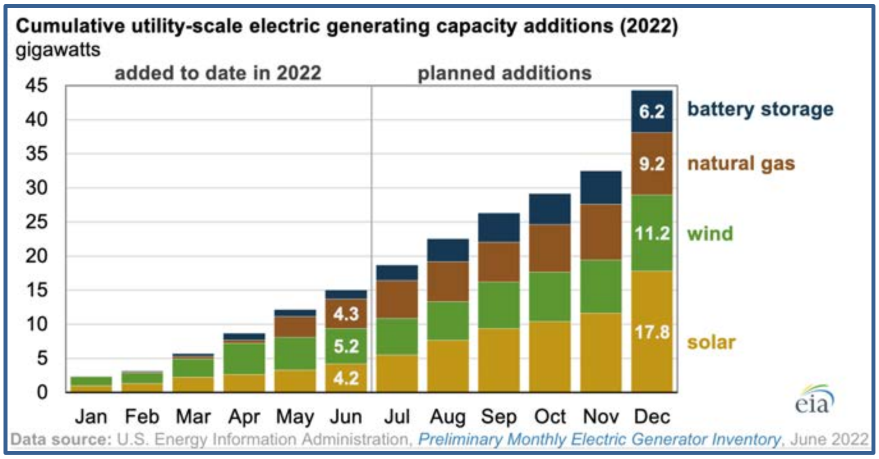

Figure 8: Planned additional utility-scale electricity generating capacity in 2022 (GW).

4.6 Future Shore Power Technologies and Projects

Recent advances in shore power utilize alternative fuels and technologies, resulting in low- or zero-emission systems. For instance, Sandia National Laboratories has been working with Young Brothers' Shipping at the Port of Honolulu, Hawaii, to develop a hydrogen fuel cell-based shore power system. The prototype unit, which is the size of a twenty-foot container, will consist of four 30 kW fuel cells totaling 120 kW of available shore power, able to operate independent of the grid.

Crowley Maritime[144] has designed an 82-foot, all-electric powered harbor tugboat the "eWolf" which will use shore power at its berth at the Port of San Diego starting in 2023. The unique power-charging station can leverage different alternative, cleaner sources of energy as available and feasible while providing enough energy capability to support the harbor vessel's full daily operations. Crowley is working with SDG&E and the Port to create the necessary infrastructure required. The charging system is designed to ensure optimal efficiency while leveraging 3 MWh of energy storage for quick charging, avoiding peak demand times and electrical loads that will allow users to use the most efficient and sustainable energy available. Shoreside connection to the shipboard electrical system can be done with a semiautomated davit system to further support safety of the crew while adjusting for changing tides and weather conditions. Crowley's goal is to a create a repeatable and scalable charging systems for installation in other Ports to support all future harbor craft.

Foss Maritime has been operating two hybrid tug vessels, the *Carolyn Dorothy* and the *Campbell Foss* at the Port of Long Beach. The hybrid tugs take advantage of a combination of batteries, generators, and main engines to achieve improved fuel economy, especially while operating at low loads. This hybrid system is an EPA verified system which reduces PM emissions by 25%, NO_x by 30%, and CO_2 by 30% during operation. Battery storage on the *Campbell Foss* provides 240 kWh of energy and can be charged using a bi-directional 14 kW converter. At berth loads for the *Campbell Foss* are about 50 kW (Foss, 2011).

[144] Information acquired from Greg Glover of Crowley Maritime.

LNG is also being considered as a fuel source for shore power. For example, the Port of Hamburg, Germany, has completed technical trials of an LNG hybrid barge designed to provide alternative power to cruise vessels. The barge, developed by Becker Marine Systems, uses gas motors powered by LNG to provide up to 7.5 MW of power. Technical trials were successful, and commissioning of the barge began in May 2015.

European ferries are often larger and operated on longer routes than their U.S. counterparts. As such, loading times tend to be longer and auxiliary engine demands greater. In the Netherlands, Stena Line, which operates a ferry terminal at Hoek van Holland, Rotterdam, installed two shore power berths and commissioned four ferries—two RORO and two ROPAX—to operate on shore power in 2012.[145] Stena Line's vessels that are plugging into shore power at Hoek van Holland have electrical systems that operate at 60 Hz. In order to connect to the local grid, which operates at 50 Hz, Stena Line employed an 11 kV static frequency conversion shore power system from ABB Ltd. that allows the vessel and local electrical grids to connect. Also in Europe, Cavotec developed and implemented an automated mooring and shore power system at the Lavik and Oppedal passenger ferry berths in western Norway.[146] The automated mooring and shore power system will serve two battery-powered ferries operated by Norled between the two terminals, which each make around eight calls per day.

There is also a Canadian project in the Vancouver area. The Seaspan Ferries Corporation has implemented a shore power system at their Swartz Bay Ferry Terminal, which provides a daily commercial truck and trailer service between the mainland and Vancouver Island. Transport Canada provided an $89,500 grant toward total project costs of $179,300. The shore power system is anticipated to reduce greenhouse gas emissions by 120 tons annually at the terminal.[147]

China's Ministry of Transport had announced in 2016, that seven terminals will begin trial implementations of shore power, including cruise, bulk, and container terminals.[148] Three vessels were used to test the emissions reductions and operational challenges of shore power, including a 10,000 TEU COSCO Shipping container vessel. Chinese authorities anticipated 99% reductions in NO_x emissions, and 3–17% reductions in PM compared to vessels burning conventional heavy fuel oil (HFO). In 2018, the China Ministry of Transport released an action plan for establishing a national domestic emission control area (DECA) that mandated certain ships use shore power while at berth starting in 2021. In addition to the DECA, China has voluntarily encouraged its ports to use shore power by providing governmental funding to subsidize shore power infrastructure.[149]

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145 ABB, Success Story, Turnkey Shore-to-Ship Power Connection at Stena Line B.V. Ferry Terminal in Hoek van Holland, the Netherlands, https://library.e.abb.com/public/69e4dc9bd3afc54ac1257a2900310ac0/Case%20study%20ferries%20-%20Stena%20Hoek%20van%20Holland%20NL.pdf

146 Cavotec, Cavotec Moormaster/Automatic Plug-in System, Sept 21, 2016.https://press.cavotec.com/videos/cavotec-moormaster-slash-automatic-plug-in-system-25224

147 Ship and Bunker, Canadian Ferry Terminal to Get Shore Power. March 7, 2013. http://shipandbunker.com/news/am/341961-canadian-ferry-terminal-to-get-shore-power

148 Ship and Bunker, China Announces Seven Terminals to Trial Shore Power, July 13, 2016. https://shipandbunker.com/news/apac/613843-china-announces-seven-terminals-to-trial-shore-power

149 NRDC China Taking Further Steps to Clean Up Shipping Pollution, January 10, 2019, https://www.nrdc.org/experts/barbara-finamore/china-taking-further-steps-clean-shipping-pollution

In California, CARB's At-Berth Regulations will require the expansion of shore power as an option at its existing terminals, to include vessel types not covered under the existing rule. The regulation will also expand to tanker terminals in Northern California at the ports of Carquinez, Richmond, Rodeo, and Stockton with shore power being explored at certain terminals.

Analysis by CARB staff[150] indicates that significant infrastructure upgrades are necessary for tankers calling at California ports, including development of both land-based and barge-based capture and control systems. CARB analysis indicates that the primary compliance pathway with the At-Berth Regulation for tankers will be to use capture and control technologies, with shore power as an option, when feasible. Compliance pathways for tanker terminals are still being evaluated, with updated plans to be submitted in 2024. CARB has published each port and terminal plan on their website.[151]

CARB analysis of the additional needs under the At-Berth Regulation for container and reefer vessels shows that five new shore power vaults plus one additional capture and control system will be necessary to meet increased demand. Two additional vaults are estimated to be required at container terminals at the Port of Los Angeles, along with one additional capture and control system shared with the Port of Long Beach. Three additional vaults will be required at container and reefer berths at the Port of Oakland to meet projected needs under the At-Berth Regulation.

For cruise vessels, additional demand for shore power due to the At-berth Regulation may potentially lead to one additional shore power berth in San Francisco, with all other ports projected to be able to meet demand. The Port of San Diego previously announced plans to double the shore power capacity at its B Street and Broadway Pier cruise terminals,[152] at a cost of $4.6 million, to allow two cruise vessels to connect to shore power outlets concurrently.

Vehicle carriers/RORO vessels are also included in the At-Berth Regulation. Per CARB's analysis, the needs of vehicle carrier/RORO vessels under the Regulation can be met using the existing infrastructure or using barge- or land-based capture and control systems.

In Florida, Port Miami has announced plans for shore power,[153] which would be the second high-voltage system on the U.S. East Coast and the first in the Southeast. The mayor of Miami announced that Carnival Cruise Line and Miami-Dade County have agreed to a shore power pilot program at Port Miami. The agreement includes a commitment by Carnival to use shore power for up to four vessels calling at the port's new cruise terminal starting Fall 2023. Additionally, Miami-Dade County signed a joint statement with six cruise companies and Florida Power and Light to bring shore power to the port. EPA's DERA program partially funded the first phase of the project with a $2 million grant.

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150 Berth analyses by CARB staff are available at: https://ww2.arb.ca.gov/new-berth-regulation-development

151 CARB Terminal and Port Plan Submissions, https://ww2.arb.ca.gov/terminal-and-port-plan-submissions

152 Port of San Diego Environment, Port of San Diego to Double Shore Power at Cruise Terminals, April 26, 2021 http://www.latecruisenews.com/2021/04/26/port-of-san-diego-to-double-shore-power-at-cruise-terminals/

153 Miami-Dade County, Miami-Dade County Mayor Daniella Levine Cava Announces Commitment with Carnival Cruise Line for Shore Power Pilot at Port Miami, March 19, 2021. https://www.miamidade.gov/releases/2021-03-19-portmiami-shore-power.asp

In July 2021 the Port of Galveston, Texas, announced that it is partnering with Royal Caribbean International cruises to determine the feasibility of providing shore power to Oasis-class vessels at the new cruise terminal being built at Pier 10, set to open in 2023.[154]

In March 2022 Port Everglades has entered into an agreement with Florida Power & Light (FPL) to explore shore power at all its eight cruise ship berths. The agreement gives FPL to begin the design services required to construct a new electrical sub-station and power distribution facilities at the Port. [155]

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[154] Port of Galveston, Port Reports Progress on Green Marine Programs, April 6, 2022. https://www.portofgalveston.com/CivicAlerts.aspx?AID=211

[155] Port Everglades, Port Everglades explores Shore Power, March 15, 2022. https://green-marine.org/stayinformed/news/port-everglades-explores-shore-power/

5 Recommended Approach for Comparing Shore Power and Vessel Emissions

The Shore Power Emissions Calculator (SPEC) developed for this study accounts for vessel characteristics, marine fuel characteristics, shipside and shoreside emissions control technologies, and shoreside electricity generation fuel mix, among others. While many of the calculator's input assumptions will be relatively certain (e.g., the number of port calls expected over a given timeframe, the average at berth time), others may be less certain. In these instances, the SPEC provides estimates for certain parameters (e.g., auxiliary engine power and load, shoreside electric power emissions).

EPA's updated May 2022 Shore Power Emissions Calculator is located on EPA's website: https://www.epa.gov/ports-initiative/shore-power-technology-assessment-us-ports

This section describes the inputs, data and assumptions, equations, and outputs that are used by the Calculator to estimate emissions reductions resulting from shore power system use.

5.1 Inputs

The approach for calculating emissions reductions from shore power compared to operating auxiliary engines includes the following inputs:

- Vessel inputs:
  - Auxiliary engine at-berth load (kW), or:
  - Installed main engine power (kW) and auxiliary engine fraction of installed main engine power (%).
  - Auxiliary engine load factor at-berth (%).
  - Auxiliary engine emission factors (g/kWh).
- Activity inputs:
  - Vessel port calls per year.
  - At-berth hours per port call.
- Shore power inputs:
  - Electricity generation by regional fuel mix that is contributing to the shore power system (MWh).
  - Shore power emission factors (i.e., quotient of total emissions and total electricity generation, for SO_2, NO_x, PM_{10}, $PM_{2.5}$, CO, CO_2).

5.2 Data and Assumptions

Users of the companion May 2022 Shore Power Emissions Calculator developed for this study are required to provide values for each of the inputs identified above (User Guide provided in Appendix B). Some assumptions may need to be made depending on data availability and the uncertainty associated with different parameters. In some cases, it may be appropriate to use a range of estimates. Users should keep in mind that the value of each assumption may change depending on the timeframe being evaluated. If the analysis is retrospective, users can use actual recorded data for some equation inputs (e.g., vessel calls for a particular year). However, some inputs (e.g., vessel emission factors) will still need to be estimated. If the analysis is prospective, users will need to make assumptions for all inputs based on trends in previous data for the study area or from published literature. Calculator users may also specify improvements in vessel efficiency for Energy Efficient Design Index vessels, such as lower emission factors for greenhouse gases. This section discusses sources of reliable data and reasonable assumptions for each calculation input.

5.2.1 Vessel Inputs

When analyzing vessels for potential emissions reductions from shore power, if a user knows the specific vessels that have called or will call on the port, the user can usually find the vessel's name and IMO number.[156] The vessel name can also be used to look up the vessel's installed main engine power online. Many companies list vessel specifications, including installed main engine power, on their websites. The IMO number can be used to look up a vessel's installed main engine power through Lloyd's PC Register of Ships or other (subscription-based) vessel registry databases. Additionally, there are websites where one can search for vessel characteristics, such as installed main engine power, by name or IMO number. For example, ships that operate on the Great Lakes have their installed main engine power available through Greenwood's Guide to Great Lakes Shipping.[157]

5.2.1.1 Auxiliary engine hotel load at-berth

Vessels operate their auxiliary engines when at-berth to generate electric power needed to run ancillary equipment and provide heating, cooling, refrigeration, and more. These engines are not usually operated at full capacity. The percentage of full capacity that the auxiliary engine is operated at is called the "load factor" and, in conjunction with the auxiliary engine size, it can be used to estimate at-berth engine load in kW. If at-berth load is not known, EPA provides default ocean-going vessel auxiliary engine operating loads by mode in Appendix E Table E.1 of the 2022 Ports Emissions Inventory Guidance, shown in Table 9.

Table 9: Hoteling load by vessel type and size.

Ship Type	Subtype	Hoteling (kW)
Bulk Carrier	Small	280
Bulk Carrier	Handysize	280
Bulk Carrier	Handymax	370
Bulk Carrier	Panamax	600
Bulk Carrier	Capesize	600
Bulk Carrier	Capesize Largest	600
Chemical Tanker	Smallest	160
Chemical Tanker	Small	490
Chemical Tanker	Handysize	490
Chemical Tanker	Handymax	1,170
Container Ship	1,000 TEU	340
Container Ship	2,000 TEU	600
Container Ship	3,000 TEU	700

[156] USACE maintains Entrance and Clearance vessel data for most major ports: https://www.iwr.usace.army.mil/About/Technical-Centers/WCSC-Waterborne-Commerce-Statistics-Center-2/WCSC-Foreign-Data/

[157] Greenwood's Guide to Great Lakes Shipping is an annual report published by Harbor House Publishers. It is available for order online at: http://www.greenwoodsguide.com/

Ship Type	Subtype	Hoteling (kW)
Container Ship	5,000 TEU	940
Container Ship	8,000 TEU	970
Container Ship	12,000 TEU	1,000
Container Ship	14,500 TEU	1,200
Container Ship	Largest	1,320
Cruise	2,000 Ton	450
Cruise	10,000 Ton	450
Cruise	60,000 Ton	3,500
Cruise	100,000 Ton	11,480
Cruise	Largest	11,480
Ferry/Passenger (C3)	2,000 Ton	186
Ferry/Passenger (C3)	Largest	524
Ferry/Roll-on/Passenger (C3)	2,000 Ton	105
Ferry/Roll-on/Passenger (C3)	Largest	710
Fishing (C3)	All C3 Fishing	200
General Cargo	5,000 DWT	120
General Cargo	10,000 DWT	330
General Cargo	Largest	970
Liquified Gas Tanker	50,000 DWT	240
Liquified Gas Tanker	100,000 DWT	240
Liquified Gas Tanker	200,000 DWT	1,710
Liquified Gas Tanker	Largest	1,710
Miscellaneous (C3)	All C3 Misc.	190
Offshore Support/Drillship	All Offshore Support/Drillship	320
Oil Tanker	Smallest	250
Oil Tanker	Small	375
Oil Tanker	Handysize	625
Oil Tanker	Handymax	750
Oil Tanker	Panamax	750
Oil Tanker	Aframax	1,000
Oil Tanker	Suezmax	1,250
Oil Tanker	VLCC	1,500
Other Service	All Other Service	220
Other Tanker	All Other Tanker	500
Reefer	All Reefer	1,080
RORO	5,000 Ton	800
RORO	Largest	1,200
Vehicle Carrier	4,000 Vehicles	800
Vehicle Carrier	Largest	800
Yacht	C2/C3 Yacht	130

5.2.1.2 Auxiliary engine emission factors

Auxiliary engine emission factors are critically important to estimating the amount of air emissions from hoteling when ships are operating their onboard auxiliary engines. EPA (2022)[158] provides emission factors for auxiliary engines. These emission factors, summarized in Table 10, vary by fuel type and engine Tier level for a medium speed engine (250-1200 revolutions per minute). For most cases in North America, MDO (0.1% S) should be assumed.

[158] EPA (2022) Ports Emissions Inventory Guidance: Methodologies for Estimating Port-Related and Goods Movement Mobile Source Emissions Report EPA-420-B-22-011. April 2022. (https://www.epa.gov/state-and-local-transportation/port-emissions-inventory-guidance.)

Note that auxiliary engine emission factors for LNG vessels are derived from the Fourth IMO Greenhouse Gas Study (IMO, 2020)[159]. Tier 0 applies to NO_x emissions from vessels built in 1999 or earlier, Tier I applies to vessels built from 2000–2010, and Tier II applies to vessels built from 2011–2015. Tier III, the most stringent NO_x control, applies to vessels built in 2016 or later.

Table 10: Auxiliary engine emission factors for medium-speed engines (g/kWh), as found in EPA (2022) and IMO (2020).

Tier	Fuel	NO_x	SO_2	CO_2	CH_4	$PM_{2.5}$	N_2O	CO_2eq
Tier 0	MGO (0.10% S)	13.8	0.424	696	0.01	0.166	0.03	705
Tier I	MGO (0.10% S)	12.2	0.424	696	0.01	0.166	0.03	705
Tier II	MGO (0.10% S)	10.5	0.424	696	0.01	0.166	0.03	705
Tier III	MGO (0.10% S)	2.6	0.424	696	0.01	0.166	0.03	705
Tier 0	MDO (0.50% S)	13.8	2.12	696	0.01	0.294	0.03	705
Tier I	MDO (0.50% S)	12.2	2.12	696	0.01	0.294	0.03	705
Tier II	MDO (0.50% S)	10.5	2.12	696	0.01	0.294	0.03	705
Tier III	MDO (0.50% S)	2.6	2.12	696	0.01	0.294	0.03	705
Tier 0	HFO (3.50% S)	14.7	12.0	707	0.01	1.42	0.03	717
Tier I	HFO (3.50% S)	13.0	12.0	707	0.01	1.42	0.03	717
Tier II	HFO (3.50% S)	11.2	12.0	707	0.01	1.42	0.03	717
Tier III	HFO (3.50% S)	2.8	12.0	707	0.01	1.42	0.03	717
Otto-MS	LNG	1.30	0.00526	457	5.500	0.0300	0.03	603

Vessels operating within the NA ECA were required to operate on fuel with a maximum S content of 0.1% as of January 1, 2015, per MARPOL Annex VI Regulation 14. Additionally, under MARPOL Annex VI Regulation 13, Tier II engine standards require an approximate 20% reduction in NO_x emissions compared to Tier I NO_x standards for diesel engines installed on vessels built on or after January 1, 2011. Moreover, Tier III standards require an 80% reduction from Tier I NO_x standards for vessels built on or after January 1, 2016 and operating within an ECA. Thus, if the vessels calling on the ports being studied are newer builds, their emission factors for NO_x, assuming they operate on 0.1% S MDO fuel, would be as follows:

- 11.1 g/kWh NO_x for vessels built on or after 1/1/2011 (Tier II)
- 2.78 g/kWh NO_x for vessels built on or after 1/1/2016 and operating in an ECA (Tier III) (Note: This is based on the "keel laid" date. However, there were some Tier II vessels brought in service after 2016 which were pre-built with a keel laid date of 2015.)

[159] LNG emission factors for SO_2 and CH_4 are from the Fourth IMO Greenhouse Gas Study, retrieved from: https://docs.imo.org

5.2.2 Activity Inputs

Activity inputs include the number of vessel port calls per year and the average hoteling hours per port call.

5.2.2.1 Vessel port calls per year

Historical data on vessel port calls per year can serve as the basis for Emissions Calculator inputs. Users should obtain, at a minimum, estimated annual port calls by vessel type (e.g., container, passenger, reefer). Some larger ports will have these data on hand. Additionally, USACE maintains a publicly available database of entrances and clearances for foreign vessel traffic for major U.S. ports.[160] However, many domestic port calls, which typically make up only a small percent of total calls, will be absent from this database. In some cases, researchers may use Automatic Identification System positional data to identify vessels and port calls. Publicly available data for the United States are available from the Marine Cadastre.[161] The best way to estimate annual vessel port calls will vary depending on the port being analyzed.

5.2.2.2 Hoteling hours per port call

Average hoteling hours per port call by vessel type are important to estimate power demand for at-berth vessels. CARB used wharfinger data, based on observed at-berth times, in its analysis to reduce the uncertainty associated with this input[162]. Average hoteling hours may also be obtained from emissions inventories for the port being analyzed or for a similar port. Finally, Automatic Identification System[163] data, available from the Marine Cadastre and private companies, can be used to track vessel movements estimate hoteling times. For instance, when a vessel arrives at a port terminal, its speed will reduce to near zero at the berth, and when the vessel leaves the terminal, its speed will become non-zero. The difference in the two-time stamps for arrival and departure equals the hoteling time. This approach does not account for the time it takes to connect the vessel to shore power while it is at-berth. However, users may be able to estimate the connection time and subtract it from the shore power hoteling time (CARB assumes a connection/disconnection time of three hours).

5.2.3 Shore Power Inputs

EPA Emissions & Generation Resource Integrated Database (eGRID[164]) is a comprehensive database detailing the environmental characteristics of electricity generated in the United States. Characteristics include total annual air emissions, as well as emissions rates, net generation, and generation type system fuel mix. These data are provided at the generation facility level and are aggregated up to the state, subregional, regional, and national levels. Table 11 shows how the

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160 USACE U.S. Waterway Entrances and Clearances data can be found at https://www.iwr.usace.army.mil/About/Technical-Centers/WCSC-Waterborne-Commerce-Statistics-Center-2/WCSC-Foreign-Data/

161 MarineCadastre Vessel Traffic Data. Available at: https://marinecadastre.gov/ais/

162 CARB. (2007). Technical support document: Initial statement of reasons for the proposed rulemaking: Regulations to reduce emissions from diesel auxiliary engines on ocean-going vessels while at-berth at a California port. Sacramento, CA: California Air Resources Board. Retrieved from http://www.arb.ca.gov/regact/2007/shorepwr07/shorepwr07.htm.

163 U.S. Coast Guard Navigation Center, Automatic Identification System Overview http://www.navcen.uscg.gov/?pageName=aismain

164 eGRID can be used to estimate regional electricity generation fuel mix, and emissions and historical data can be used to predict future regional fuel mix and emissions. eGRID can be accessed at: https://www.epa.gov/egrid

emission rates vary for eGRID subregions shown in Figure 9.

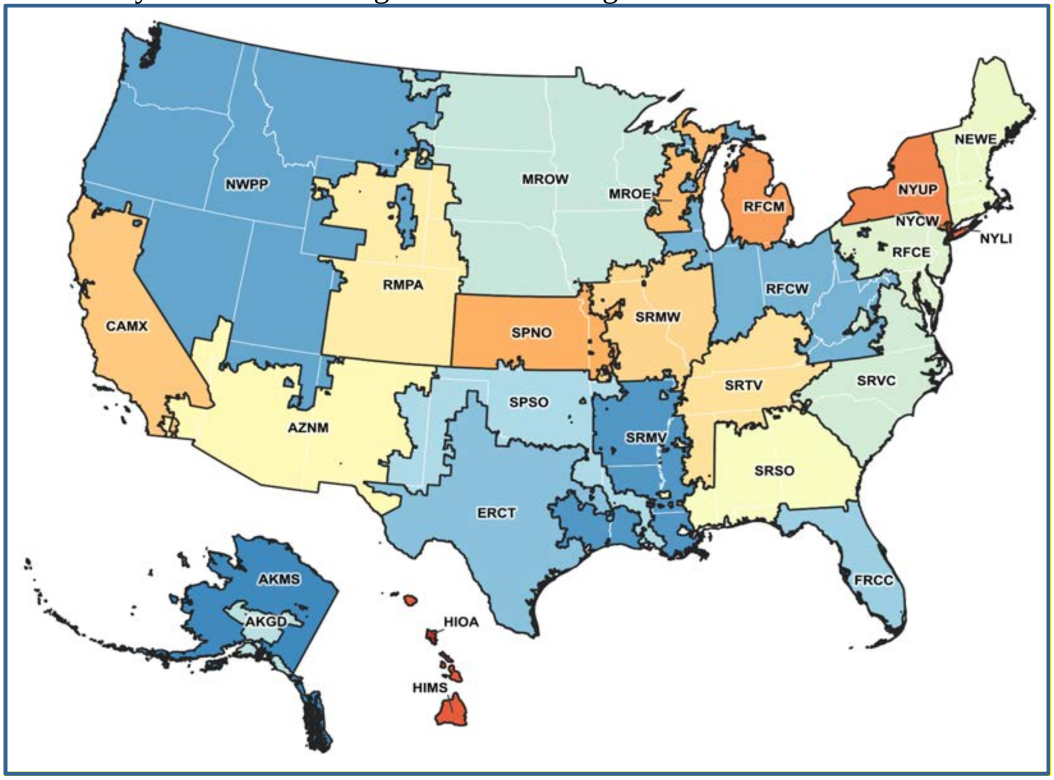

Figure 9: EPA eGRID subregions in 2019. Colors are used to delineate regions.

Figure 9 shows the eGRID 2019 subregions. These subregions are identified and defined by EPA as a compromise between North American Electric Reliability Corporation (NERC) regions, which are generally large, and the balancing authorities, which are generally small. EPA defined the eGRID subregions limit the import and export of electricity, thus establishing an area where aggregated emissions most closely match the grid generation and emissions from individual facilities in the subregion. The geographic boundaries shown in Figure 9 are approximate, derived from electrical grid attributes.

eGRID estimates for carbon dioxide-equivalent emissions (CO_2eq) are estimated using global warming potentials (GWPs) from the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report for methane (CH_4, GWP = 25) and nitrous oxide (N_2O, GWP = 298). eGRID emission rates are estimated at the point of generation, and do not account for transmission and distribution losses. Grid gross loss (GGL) is an estimate of the energy lost in the process of supplying electricity to end users. These losses mainly occur from energy dissipated in the conductors, transformers, and other equipment used for transmission, transformation, and distribution of power[165]. Accounting for GGL is imperative when estimating landside emissions from shore power, as transmission losses mean that more electricity must be generated than is ultimately consumed by the vessel connected to the shore power system. The amount of generation (in kWh) required to meet shore power system load, is given by Equation 1, accounting for GGL.

[165] EPA eGRID How is GGL Calculated https://www.epa.gov/egrid/egrid-questions-and-answers#egrid5aa

$$Total\ Generation = \frac{Shore\ Power\ Demand}{1 - GGL} \quad \text{Equation 1}$$

Table 11: 2018 eGRID annual emissions rates (Coastal and Great Lakes subregions).

Annual region emissions rate (g/kWh)

Subregion Name	**NO_x**	**SO_2**	**CO_2**	**CH_4**	**N_2O**	**CO_2eq**	**$PM_{2.5}$**	**GGL**
ASCC Alaska Grid	2.48	0.50	471.57	0.037	0.005	474.00	0.093	0.0512
ASCC Miscellaneous	3.50	0.31	238.17	0.011	0.002	239.03	0.355	0.0512
WECC Southwest	0.33	0.12	463.73	0.035	0.005	466.09	0.036	0.0480
WECC California	0.21	0.02	225.22	0.015	0.002	226.20	0.014	0.0480
ERCOT All	0.25	0.38	422.60	0.030	0.004	424.60	0.021	0.0487
FRCC All	0.16	0.13	422.68	0.030	0.004	424.63	0.029	0.0488
HICC Miscellaneous	3.46	1.80	503.80	0.054	0.008	507.60	0.420	0.0514
HICC Oahu	1.59	3.63	757.47	0.082	0.012	763.21	0.262	0.0514
MRO East	0.40	0.40	761.13	0.077	0.011	766.41	0.017	0.0488
MRO West	0.44	0.61	562.39	0.063	0.009	566.63	0.030	0.0488
NPCC New England	0.18	0.06	236.92	0.037	0.005	239.30	0.021	0.0488
WECC Northwest	0.26	0.17	289.86	0.029	0.004	291.82	0.017	0.0480
NPCC NYC/Westchester	0.11	0.01	270.53	0.010	0.001	271.14	0.033	0.0488
NPCC Long Island	0.39	0.11	537.16	0.063	0.008	541.18	0.028	0.0488
NPCC Upstate NY	0.06	0.04	114.81	0.008	0.001	115.16	0.008	0.0488
RFC East	0.15	0.22	324.76	0.028	0.004	326.58	0.022	0.0488
RFC Michigan	0.36	0.59	595.37	0.059	0.008	599.28	0.029	0.0488
RFC West	0.37	0.42	528.93	0.053	0.008	532.53	0.048	0.0488
SPP South	0.38	0.56	529.15	0.041	0.006	531.95	0.023	0.0488
SERC Midwest	0.48	1.13	754.85	0.084	0.012	760.57	0.029	0.0488
SERC South	0.22	0.13	466.26	0.037	0.005	468.77	0.016	0.0488
SERC Virginia/Carolina	0.20	0.12	337.17	0.030	0.004	339.07	0.023	0.0488

The May 2022 version of the Calculator includes improvements over the version 1 calculator released in 2017. These include:

- Added forty-four new vessel types and engine loads, including size ranges within vessel type.
- Updated vessel emission factors consistent with current EPA guidance (2022), including engine tier and LNG emission factors.
- Added a new reference section that provides emission factor calculation formulas and input data.
- Updated eGRID emission factors.
- Added latest eGRID $PM_{2.5}$ emission factors.
- Updated CO_2eq weighting factors using IPCC Fourth Assessment Report GWPs.
- Added $PM_{2.5}$ emission estimates to the primary outputs.
- Updated user guide integrated with the calculator.
- Added custom error messages and improved error handling.

6 Conclusions

This report has characterized the technical and operational aspects of shore power systems in the United States, summarized selected studies that evaluated shore power, and updated the calculation approach for comparing shore power and vessel emissions while at-berth.

The approach presented in this report and the accompanying calculator is flexible enough to be applied to nearly any port in the United States and, indeed, around the world, provided the necessary inputs can be obtained. This report advises how users can obtain or estimate these inputs. The approach presented here can be used to estimate potential reductions of harmful air pollution emissions at U.S. ports through the use of shore power systems.

Finally, this report describes some of the experiences and lessons learned by ports that have implemented shore power systems. These experiences highlight the need for flexibility in designating locations of dockside vaults, reliability of components, grid connections and power supply, the importance of on-time vessel scheduling and coordinating with utilities and funding partners in advance.

Shore power can substantially reduce air pollutant emissions linked to deleterious human health effects, environmental damage, and climate change. Despite these benefits, the use of shore power faces a number of barriers. Depending on the relative costs of marine fuels to shoreside electricity, it may be cheaper to operate auxiliary engines rather than connect to shore power. Furthermore, fleets must make substantial necessary investments in vessel-side infrastructure to connect to shore power systems.

These barriers can be overcome by further research into ways of implementing or incentivizing the use of shore power or other advanced emissions reduction technologies, and the provision of public funds that enable ports to identify the technical feasibility of installing shore power connections, as well as assist in funding infrastructure investments. Further, global harmonized standards for shore power installations can reduce uncertainty for fleet owners and operators in deciding what vessel-side infrastructure to adopt that will enable them to connect to shore power.

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Appendix A: Summary of Studies of the Costs and Benefits of Shore Power

Port Name	***Economic Costs and Benefits***	***Environmental Costs and Benefits (if quantified)***	***Source Link***
Juneau	Princess Cruises spent approximately $5.5 million to construct the shoreside facilities and to retrofit the vessels (about $500,000 each). Princess Cruises estimates the cost of the shore power to be approximately $1,000 per vessel day more than the cost of running the onboard auxiliary engines.		http://www.lbreport.com/port/coldiron.pdf
Los Angeles	$1.21 million DERA grant to install natural gas–powered shore power system at the port (DERA 2009-2010). $23.73 million in Proposition 1B funding from the state of California for development of shore power at 10 berths. Total cost of infrastructure was ~$200 million.	The Ports of San Pedro reduced emissions by up to 75% since 2005. “The operational benefits are also clear. When ships at-berth plug in, maintenance and repairs can be done on equipment not in operation, vessels conserve fuel, and the cost of running on board systems is lower. Noise pollution from the engines is also eliminated.”	http://www.ship-technology.com/features/feature-shore-power-green-answer-costly-berthing-emissions EPA Grant: https://www.epa.gov/dera/national-dera-awarded-grants Proposition 1B: http://www.aqmd.gov/home/programs/business/business-detail?title=goods-movement-emission-reduction-projects-(prop-1b)&parent=vehicle-engine-upgrades
Seattle	$1.49 million American Reinvestment and Recovery Act (ARRA) grant in 2009 to retrofit two vessels and add shore power. $1.4 million EPA grant to install shore power infrastructure at the TOTE terminal.	Annual CO_2 emissions cut by up to 36%. Combined emissions reductions for 36 cruise vessel calls by Princess Cruises and Holland America Line in 2011 were 1,756 tons CO_2eq.	Puget Sound Maritime Air Emissions Inventory, 2012: https://www.portseattle.org/programs/puget-sound-maritime-air-emissions-inventory EPA Grant: https://www.epa.gov/dera

Port Name	*Economic Costs and Benefits*	*Environmental Costs and Benefits (if quantified)*	*Source Link*
San Diego	Smaller ships visit San Diego ports and electricity rates are higher than the Port of Los Angeles. Cost effectiveness is \$23,500/ton NO_x for cruise ships and for \$13,700/ton NO_x for Dole vessels (reefers). The largest contributor to the cost is the SDG&E (electric utility) infrastructure to power the terminals, followed by electrical infrastructure at the terminals, ship electrical modifications, and net vessel operator energy costs. \$2.4 million CARB Carl Moyer grant in 2010 for shore power at the Cruise Ship Terminal.		Port of San Diego 2012 Maritime Air Emissions Inventory Report: https://pantheonstorage.blob.core.windows.net/environment/2012-Maritime-Air-Emissions-Inventory.pdf
San Francisco	Electrical energy supply costs are a significant consideration in the feasibility of shoreside auxiliary power supply. They affect the cost-effectiveness of the emissions control measure and the operating cost to the vessel and industry on an ongoing basis. It costs the cruise industry more to use shoreside power while at port than shipboard-generated electrical power. The "break-even" point for this portion of the cost is \$0.05–0.10/kWh. The port of San Francisco was awarded a \$1 million grant from EPA to support shore power installation. \$1.9 million CARB Carl Moyer grant (year 8/9 funding) for cruise ship shoreside power installation.	Use of shore power leads to 61-81% estimated reduction in emissions according to ENVIRON's 2005 Shoreside Power Feasibility Study for Cruise Ships Berthed at Port of San Francisco. Estimated emission benefits per 10-hour ship call 1.3 tons NO_X 0.87 tons SO_X 19.7 tons CO_2	Port of San Francisco (2005) Shoreside Power Feasibility Study for Cruise Ships Berthed at Port of San Francisco Table 4-14. Funding and program details: Mayor Newsom And The Port Of San Francisco Inaugurate Cruise Ship Using Shoreside Power https://archive.epa.gov/region9/mediacenter/web/pdf/sf-port-shore-power.pdf

APPENDIX A: SUMMARY OF STUDIES OF THE COSTS AND BENEFITS OF SHORE POWER

Port Name	***Economic Costs and Benefits***	***Environmental Costs and Benefits (if quantified)***	***Source Link***
Long Beach	Average cost effectiveness of 12 selected vessels is $69,000 per ton (combined emissions, per Table 6-4 of that report, treated with equal weights), and a vessel-weighted average is $16,000/ton. $30 million in Proposition 1B funding from the state of California for shore power development at 12 berths ($2.5 million/berth).	Cold ironing is cost effective as a retrofit from a vessel operator perspective when the annual power consumption is 1,800,000 kWh or more. This number drops to 1,500,000 kWh for new builds to be cost effective.	https://polb.com/download/20/shore-power-cold-ironing-resources/6622/cold-ironing-cost-effectiveness-study-volume-i-and-ii-100710.pdf
Oakland	$12.8 million grant from Bay Area Air Quality Management District and U.S. Maritime Administration. Additional approximately $20 million awarded by CARB and Metropolitan Transportation Commission / Federal Highway Administration.	LNG emissions reductions allegedly are equal to the typical shore power methods. Port of Oakland added $5 million to the port's shore power fund to reduce "the health risk from seaport sources of diesel emissions by 85% by 2020."	https://www.greencarcongress.com/2007/08/demonstration-o.html https://www.portofoakland.com/files/PDF/Volume%20I.pdf Grants: http://www.portofoakland.com/pdf/newsroom/pressrel_319.pdf
Hueneme	CARB preliminary draft report (which cannot yet be cited for academic purposes in accordance with the request to "do not cite" in the report) notes that the ports of Hueneme and Los Angeles have lower electricity rates than the Port of San Diego. $500,000 DERA (2013) grant for Phase II Shore Power Infrastructure Project. $4.5 million from California under Proposition 1B administered by South Coast Air Quality Management District to fund shore power infrastructure at three berths.	In comparing the Port of Hueneme to Los Angeles and San Diego, CARB indicates that the average cost-effective values for Hueneme are the lowest, followed by San Diego, then Los Angeles, whose average cost-effective values are two to three times greater than those for Hueneme. Hueneme has the lowest cost-effectiveness values because it has three times the number of ships that visited often (i.e., six visits or more) than the other two ports. Conversely, Los Angeles has the highest average installations. At 2 MW load, both Hueneme and San Diego are more cost effective than container ships using shore power at Los Angeles or Long Beach.	EPA Grant: https://archive.vcstar.com/business/port-of-hueneme-awarded-500000-epa-grant-for-power-system-ep-458889712-351407161.html/

APPENDIX A: SUMMARY OF STUDIES OF THE COSTS AND BENEFITS OF SHORE POWER

Port Name	***Economic Costs and Benefits***	***Environmental Costs and Benefits (if quantified)***	***Source Link***
Boston	Mixed opinion about the use of shore power for tug and push boats. The general consensus is that shore power is not feasible for tugs and tows given their typical operating cycles. Constellation Maritime kept tugs on shore power while berthed. However, Constellation Maritime has since left the Port of Boston. $400,000 DERA (2008) grant to install an additional six shore power stations at the Boston Fish Pier.		ICF (2009) Tug/Towboat Emission Reduction Feasibility Study. Draft Final Report https://www.portcompliance.org/files/TugBoatFinalReportv3.0.1.doc EPA Grant: https://www.epa.gov/dera/national-dera-awarded-grants Electricity to Berths at Fish Pier Massachusetts Port Authority DE-97120501-2 $400,000.00 6/23/ 2011
Brooklyn	In August 2011, the Port Authority of New York and New Jersey voted to spend $12.1 million to build a shore power station. EPA granted another $2.9 million for the project, and the Empire State Development Corporation allocated $4.3 million to the project, for a total of $19.3 million. New York City Economic Development Corporation and New York Power Authority entered into an agreement to deliver electricity to vessels at a rate of $0.12/kWh. Total energy delivery costs are $0.26/kWh, and New York City Economic Development Corporation will cover the difference in costs.	Expected annual emissions reductions: 6.5 tons of PM. 95.3 tons of NO_x. 1,487 tons of greenhouse gases.	EPA grants provided under ARRA from the 2009 National Clean Diesel Funding Assistance Program
New Bedford	The port was awarded $1 million from EPA and $540,000 from the Federal Highway Administration's Congestion Mitigation and Air Quality Improvement program to install shore power at its commercial fishing piers.	~3,000 tons greenhouse gases avoided annually. Reduced diesel consumption of ~310,000 gallons annually from using shore power.	https://nbedc.org/city-of-new-bedford-gets-us1-million-for-shore-side-power-electrification-project/

APPENDIX A: SUMMARY OF STUDIES OF THE COSTS AND BENEFITS OF SHORE POWER

Port Name	***Economic Costs and Benefits***	***Environmental Costs and Benefits (if quantified)***	***Source Link***
Philadelphia	Tugboat shore power has been implemented at the Port of Philadelphia. Costs were approximately $1 million in capital costs per berth, with unknown capital costs per tug. Total costs are also affected by the price differential between electricity and bunker fuel.		ICF (2009) Tug/Towboat Emission Reduction Feasibility Study. Draft Final Report https://www.portcompliance.org/files/TugBoatFinalReportv3.0.1.doc
Tacoma	Shore power at Tacoma's TOTE terminal is estimated to reduce diesel particulate emissions by 3.4 tons annually, NO_x emissions by 24.5 tons, CO emissions by 2.1 tons, HC emissions by 0.8 tons, and CO_2 by over 1,360 tons annually. $1,488,080 DERA ARRA grant from EPA (2011), with $1,101,303 in leveraged matching funds from TOTE and partners.	Fifty jobs estimated to be created by the shore power project.	https://westcoastcollaborative.org/files/grants/2010/DERA-ARRA-PortTacomaShorepowerFactSheet.pdf
Other Resources			
CARB (2020) At-Berth Regulation	Cost: $2.23 billion Costs are approximately: • $1.14/TEU for containers and reefers. • $4.65 per cruise passenger. • $7.66 per automobile (RORO). • < $0.01 per gallon of finished oil product (tanker).	Emissions reductions > 80%. Benefits: $2.32 billion through reduced cancer risk (-55%).	https://ww2.arb.ca.gov/new-berth-regulation-development

APPENDIX B: USER GUIDE: SHORE POWER EMISSIONS CALCULATOR

(note this appendix is the guide embedded in the calculator)

The shore power emissions calculator can calculate emissions of criteria and greenhouse gas (GHG) pollutants based on vessel and fuel inputs, and the regional electricity grid mix. Shore power emissions are estimated using emission factors from the United States Environmental Protection Agency's (EPA) Emissions & Generation Resource Integrated Database (eGRID) data (1), and vessel emissions are estimated using emission factors from EPA's 2022 Port Emissions Inventory Guidance (EPA, 2022) (2).

The calculator provides two primary operating modes:

- General Calculator
- User Entry Calculator

The General Calculator is appropriate for users who will be using default values for vessel, fuel, and electricity grid parameters. The User Entry Calculator is appropriate for users who can supply inputs to specify vessel characteristics and electricity generation emission factors.

User input is required in blue cells; calculator output is shown in grey cells in the Excel® spreadsheet example. Non-user-input cells are locked, or protected, to avoid inadvertent changes. Cells can be unprotected, if necessary, by selecting the "Review" menu at the top of the window and clicking the "Unprotect Sheet" button. No password is required.

Footnotes can be found at the bottom of this document. You can access the calculator and read the full user guide on EPA's Shore Power Technology Assessment at U.S. Ports webpage.

GENERAL CALCULATOR

The General Calculator is found in the General Calculator tab and is available for users who will be using default values for estimating shore power emissions. To use the General Calculator:

1. Select the General Calculator tab in the Shore Power Emissions Calculator Workbook.

2. Select the eGRID Region containing the port of interest using the dropdown menu. eGRID regions are shown in the eGRID Region tab.

3. Select the Vessel Type using the dropdown menu. The user may select one of 53 combinations of vessel types and sub-types/sizes that are included, with more detail available in the Vessel Type tab. Vessel sizes/subtypes are described in EPA (2022), Table 3.4. The Shore Power Emissions Calculator estimates emissions based on auxiliary engine loads while hoteling.

4. Select the Fuel / Engine Tier using the dropdown menu. Available fuels include MGO (0.10% S), MDO (0.50% S), HFO (3.50% S), and LNG. Tier 0 through Tier III NO_x controls are available for 0.10% S, 0.50% S, and 3.50% S fuels. (3)

a. Engine Tier is determined based on the date that the vessel's keel was laid (described in Table B-1 of this document and included in the Engine Tier tab).
b. If the user is uncertain of engine tier, selecting Tier I is recommended based on the assumptions used in the 2017 National Emissions Inventory.
c. The naming of marine fuels and their associated sulfur contents can, and has, changed over time. If uncertain, users should select fuels based on sulfur content.

Table B-1: Engine tier by keel laid date.

Keel Laid Date	Engine Tier
1999 and earlier	Tier 0
2000–2010	Tier I
2011–2015	Tier II
2016 and later	Tier III

5. Populate the power, in kW, in the Hoteling Load (kW) field automatically based on default operating loads for the vessel type selected. See EPA (2022), Table E.1, for additional detail on assumed operating loads.

6. Enter the Number of Annual Vessel Calls that will be using shore power for each Vessel Type entered. Note that the calculator assumes a single vessel for each vessel type selected.

7. Enter the Average Hotel Hours per Vessel Call.

8. Estimate quantities of emissions in metric ton (MT). Annual Energy Consumption (kWh), Annual Vessel Power Emissions (MT), Annual Shore Power EGU Emissions (MT), Annual Difference (MT), and Annual Percent Difference outputs are populated in the gray cells. Negative differences show reductions in emissions, while positive differences show increases in emissions.

9. Estimate CO_2eq using the Global Warming Potentials (GWP) of greenhouse gas species from the IPCC Fourth Assessment Report, aligned with the EPA eGRID methodology. (GWP for CO_2 = 1, CH_4 = 25, N_2O = 298). For LNG fuels, sulfur emissions are estimated as SO_X; for all other fuels, sulfur emissions are estimated as SO_2.

Vessel power emissions are calculated in columns J through N as:

$$\begin{aligned} Emissions = {} & Vessel\ Fuel\ Emission\ Factor \\ & \times Aux.\ Engine\ Hotel\ Load \\ & \times No.\ of\ Annual\ Vessel\ Calls \\ & \times Average\ Hotel\ Hours \end{aligned}$$

and shore power EGU emissions, incorporating grid losses, are calculated in columns J through N as:

$$Emissions = Electricity\ Generation\ Emission\ Factor \times \frac{Aux.Engine\ Hotel\ Load}{1 - Grid\ Gross\ Loss} \times No.of\ Annual\ Vessel\ Calls \times Average\ Hotel\ Hours$$

Emissions of NO_x, SO_2, and $PM_{2.5}$ are given in metric tonnes rounded to three decimal places. Emissions of CO_2 and CO_2eq are given rounded to the nearest whole number.

USER ENTRY CALCULATOR

The User Entry Calculator follows a similar format to the General Calculator, with additional functionality allowing the user to specify alternate inputs for electricity generation emission factors, vessel type and vessel fuel emission factors. To use the User Entry Calculator:

1. Select the User Entry Calculator tab in the Shore Power Emissions Calculator Workbook.
    a. Select the eGRID Region containing the port of interest, or one of the two USER DEFINED regions using the dropdown menu. eGRID regions are shown in the eGRID Region tab. USER DEFINED region emission factors must be specified in rows 31 and 32 in the eGRID Region tab.

2. Select the Vessel Type using the dropdown menu. The user may select one of 53 combinations of vessel types and sub-types/sizes or up to ten USER VESSEL types, specified in the Vessel Type tab, rows 58–67. Users wishing to estimate the emissions from harbor craft using low voltage shore power may customize one or more of these unspecified USER VESSEL types for their fleet. When entering vessel power parameters, the calculator reads from column F of the Vessel Type tab, corresponding to the load when "hoteling." When entering USER VESSEL data, enter the expected power, in kW, used during hoteling, calculated as Auxiliary Engine Hotel Loading (kW). Note: the calculator only uses data for "Hoteling (kW)" (column F) from the Vessel Type tab.

3. Select the Fuel / Engine Tier using the dropdown menu. Available fuels include MGO (0.10% S), MDO (0.50% S), HFO (3.50% S), and LNG. Tier 0 through Tier III NO_x controls are available for MGO, MDO, and HFO fuels. Users may also select up to two USER FUEL–USER TIER auxiliary engine emission factors, which must be entered in rows 21 and 22 of the Vessel Fuel Emission Factors tab, in g/kWh. (4)
    a. The Engine Tier is determined based on the date that the vessel's keel was laid (described in Table 1 of this document, and in the Engine Tier tab).
    b. If the user is uncertain of engine tier, selecting Tier I is recommended based on the assumptions used in the 2017 National Emissions Inventory.
    c. Naming of marine fuels and their associated sulfur contents can, and has, changed over time. If uncertain, users should select fuels based on sulfur content.

4. The Auxiliary Engine Hoteling Load (kW) field populates automatically based on assumed operating loads for the vessel type selected, or user-entered USER VESSEL values.

5. Enter the Number of Annual Vessel Calls that will be using shore power for each Vessel

Type entered. Note that the calculator assumes a single vessel for each vessel type selected.

6. Enter the Average Hotel Hours per Vessel Call.

7. Quantities of emissions are estimated in MT. Annual Energy Consumption (kWh), Annual Vessel Power Emissions (MT), Annual Shore Power EGU Emissions (MT), Annual Difference (MT), and Annual Percent Difference outputs are populated in the gray cells. Negative differences show reductions in emissions, while positive differences show increases in emissions.

   CO_2eq is estimated using the GWPs of greenhouse gas species from the IPCC Fourth Assessment Report, aligned with the EPA eGRID methodology (GWP: carbon dioxide (CO_2): 1, methane (CH_4): 25, nitrous oxide (N_2O): 298).

   For LNG fuels, sulfur emissions are estimated as SO_x; for all other fuels, sulfur emissions are estimated as SO_2:

$$Emissions = Vessel\ Fuel\ Emission\ Factor \times Aux.Engine\ Hotel\ Load \times No.of\ Annual\ Vessel\ Calls \times Average\ Hotel\ Hours$$

   and shore EGU power emissions, incorporating grid losses, are calculated in columns P through T as:

$$Emissions = Electricity\ Generation\ Emission\ Factor \times \frac{Aux.Engine\ Hotel\ Load}{1 - Grid\ Gross\ Loss} \times No.of\ Annual\ Vessel\ Calls \times Average\ Hotel\ Hours$$

Emissions of NO_x, SO_2, and $PM_{2.5}$ are given in metric tonnes rounded to three decimal places. Emissions of CO_2 and CO_2eq are given rounded to the nearest whole number.

Footnotes:

(1) U.S. EPA Emissions and Generation Resource Integration Database https://www.epa.gov/egrid

(2) EPA (2022) Ports Emissions Inventory Guidance: Methodologies for Estimating Port-Related and Goods Movement Mobile Source Emissions Report EPA-420-B-22-011. April 2022. (https://www.epa.gov/state-and-local-transportation/port-emissions-inventory-guidance.) LNG emission factors for SO_2 and CH_4 are from the Fourth IMO Greenhouse Gas Study, retrieved from: https://docs.imo.org

(3) and (4) NO_x, SO_2, $PM_{2.5}$, CH_4, N_2O vessel emission factors are rounded to three decimal places. CO_2 and CO_2eq are rounded to the nearest whole number.

Additional Resources:

These resources contain additional vessel parameters for use in the "User Entry Calculator"

(1) CARB Update to Inventory for Ocean-Going Vessels at Berth (2019): Methodology and Results, Appendix H. ww2.arb.ca.gov/sites/default/files/barcu/regact/2019/ogvatberth2019/apph.pdf

(2) The Port of Los Angeles Annual Inventory of Air Emissions. www.portoflosangeles.org/environment/air-quality/air-emissions-inventory