Shore Power Technology Assessment at U.S. Ports

United States Environmental Protection Agency

Office of Transportation and Air Quality
EPA-420-R-17-004
March 2017

Shore Power Technology Assessment at U.S. Ports

Transportation and Climate Division
Office of Transportation and Air Quality
U.S. Environmental Protection Agency

Prepared for EPA by
Eastern Research Group, Inc.

and

Energy & Environmental Research Associates, LLC

EPA Contract No. EP-C-11-046
Work Assignment No. 4-06

NOTICE

This technical report does not necessarily represent final EPA decisions or positions. It is intended to present technical analysis of issues using data that are currently available. The purpose in the release of such reports is to facilitate the exchange of technical information and to inform the public of technical developments.

United States
Environmental Protection
Agency

EPA-420-R-17-004
March 2017

SHORE POWER TECHNOLOGY ASSESSMENT AT U.S. PORTS – OVERVIEW

Ports are major centers for movement of goods and passengers from vessels in the United States (U.S.) and are vital to America's business competitiveness, jobs, and economic prosperity. Goods and passengers moving through ports are projected to grow as are the size of ships due to the opening of the new Panama Canal locks in 2016 and other factors. Some vessel types, such as cruise, container, and refrigeration, can require significant power while at berth. This power is typically generated by diesel auxiliary engines.

Emissions from vessels running auxiliary diesel engines at berth can be significant contributors to air pollution. As port traffic grows in certain areas, air pollution may also increase. Exposure to air pollution associated with emissions from ocean going vessels and other diesel engines at ports (including particulate matter, nitrogen oxides, ozone, and air toxics) can contribute to significant health problems—including premature mortality, increased hospital admissions for heart and lung disease, increased cancer risk, and increased respiratory symptoms – especially for children, the elderly, outdoor workers, and other sensitive populations.[1] Many ports and port-related corridors are also located in areas with a high percentage of low income and minority populations who are often disproportionately impacted by higher levels of diesel emissions.[2]

Shore power can be used by marine vessels to plug into the local electricity grid and turn off auxiliary engines while at-dock. When using shore power, auxiliary systems, such as lighting, air conditioning, and crew berths use energy from the local electrical grid. Shore power typically produces zero onsite emissions. The power generation plant that supplies electricity to shore power applications may or may not be within the confines of the port and can be located outside the local air shed. While shore power can reduce auxiliary engine emissions at berth, shore power does not address emissions from boilers or other vessel sources. The assessment also describes other alternatives that may capture emissions at berth.

This *Shore Power Technology Assessment at U.S. Ports* reviews the availability of shore power at ports throughout the U.S., and characterizes the technical and operational aspects of shore power systems installed at U.S. ports. Technical information was gathered working in partnership with ports that have installed shore power. The second part of the assessment presents a new methodology for estimating emission reductions from shore power systems for vessels docked and connected to shore power. A calculator tool provided with this report can be used to estimate how harmful air pollutants could be reduced at U.S. ports through the use of shore power systems; benefiting air quality, human health, the economy, and the environment. The estimates can be used in conjunction with EPA's Diesel Emissions Reduction Act (DERA) program to help evaluate potential shore power projects for grant applications, and for reporting emission reductions from grant projects

Additionally, the *National Port Strategy Assessment* (NPSA), which is a national scale assessment, was released in September of 2016. The NPSA explored the potential of a range of available strategies, including shore power, to

[1] *Near Roadway Air Pollution and Health: Frequently Asked Questions*, EPA, EPA-420-F-14044, August 2014. https://nepis.epa.gov/Exe/ZyPDF.cgi/P100NFFD.PDF?Dockey=P100NFFD.PDF;
Third Report to Congress: Highlights from the Diesel Emission Reduction Program, EPA, EPA-420-R-16-004, February 2016. https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100OHMK.pdf;
Health Assessment Document for Diesel Engine Exhaust, prepared by the National Center for Environmental Assessment for EPA, 2002; and
Diesel and Gasoline Engine Exhausts and Some Nitroarenes, International Agency for Research on Cancer (IARC), World Health Organization, June 12, 2012. http://monographs.iarc.fr/ENG/Monographs/vol105/

[2] *Control of Emissions from New Marine Compression-Ignition Engines at or Above 30 Liters per Cylinder*, EPA, 75 FR 24802, April 30, 2010. https://www.epa.gov/regulations-emissions-vehicles-and-engines/final-rule-control-emissions-new-marine-compression-0

reduce port-related emissions throughout the U.S. The NPSA report can be found at: https://www.epa.gov/ports-initiative/national-port-strategy-assessment. The NPSA and the *Shore Power Technology Assessment at U.S. Ports* support EPA's Ports Initiative to improve air quality around ports.

Key Findings of the Shore Power Technology Assessment

- **Shore power can be effective at significantly reducing ship pollutant emissions at dock.** Under the right circumstances when a vessel is connected to shore power, overall pollutant emissions can be reduced by up to 98% when utilizing power from the regional electricity grid, (depending on the mix of energy sources).
    - The potential emission reduction benefits may be estimated for a particular vessel, at berth when connected to shore power. Factors such as the amount of time actually connected, power consumption rate, energy costs and total time at berth are described in the assessment and relate to the overall effectiveness of shore power. Because these factors must be evaluated for each situation, total emission reductions may vary.
    - The assessment suggests that shore power may be most effective when applied at terminals and ports with a high percentage of frequently returning vessels, typically cruise ships and container ships.
- **Application of shore power for commercial marine vessels in the United States is relatively new and at present, not commonly available.** There are currently ten ports using high voltage systems, serving cruise, container and refrigerated ("reefer") vessels, and 6 ports using low voltage systems, serving tugs and fishing vessels. Though the technology is relatively new 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.
- **Vessels that frequently call on the same ports and remain at berth for longer times are potentially the best applications for shore power.**
- **Many ports do not have the appropriate infrastructure to connect to vessels with shore power components.** Ships can be retrofitted with vessel-side infrastructure to connect to port shore power systems. International shore power standards are in place to make it easier for ports to select the proper equipment.
- **Barriers to shore power installation include infrastructure and electricity costs.** Shore power requires landside infrastructure, electrical grid improvements, and vessel modifications. The relative cost of using shore power instead of a vessel's own fuel sources is more attractive when fuel costs are greater than electricity costs.
- **The Shore Power Emissions Calculator (SPEC) developed for this report can be an effective tool to assess environmental benefits of shore power when a vessel is connected.** Port authorities can use SPEC to assess the environmental benefits of using shore power by vessel type in an area where shore power is being considered.
    - SPEC will be helpful for states and port authorities in evaluating potential benefits and in determining whether shore power would be an appropriate means to reduce pollution at a port.

- SPEC quantifies the changes in emissions when switching off engines of vessels and using shore power systems. The tool uses vessel and activity inputs, as well as offsetting emissions of electrical power use from shore-side power to determine emission changes for most pollutants. To analyze the shore-side power, the tool uses emission values from EPA's Emissions & Generation Resource Integrated Database (eGRID). The eGRID contains the environmental characteristics of electrical power generation for almost all regions in the United States.

- While the SPEC is intended to provide consistency in estimating shore power benefits primarily for DERA purposes, the SPEC is not appropriate for certain analyses like those performed in support of State Implementation Plans (SIPs) and Conformity.

- SPEC offers users two ways to estimate emissions. The first is a "General Model", for users with limited project information to estimate emissions reduction benefits through the use of a set of default data and assumptions. The General Model may be updated with more recent information, as available and appropriate. Secondly, a "User Input Model" is provided, which can generate more accurate estimates through user-defined inputs for the vessel auxiliary power, load factor, engine emission factors, and through the selection of specific electric generation facilities and their grid emissions mix, if that information is available to users.

For more information about the Shore Power Technology Assessment

Web: www.epa.gov/ports-initiative/shore-power-technology-assessment-us-ports

Email: Tech_Center@epa.gov or Arman Tanman at tanman.arman@epa.gov

Contents

Tables

Figures

GLOSSARY

A Amperes
AIS Automatic Identification System
AMEC Advanced Maritime Emission Control
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 tug boats
Berth A ship's assigned place at a dock
Bulk vessels Ships that transport bulk cargo such as coal, iron ore, etc.
Bunker fuel Fuel used in marine vessels
CARB California Air Resources Board
CH_4 Methane
CO Carbon monoxide
CO_2 Carbon dioxide
CO_2eq Carbon dioxide equivalent
Container vessels Ships that transport containerized cargo
Cruise vessels Ships that transport passengers to various ports-of-call
ECA Emission Control Area
EERA Energy & Environmental Research Associates, LLC.
eGRID Emissions & Generation Resource Integrated Database
EIA Energy Information Administration
ERG Eastern Research Group
Fishing vessels Commercial fishing vessels
FRCE First Reliability Corporation – East
g Grams
HC Hydrocarbons
HFO Heavy fuel oil
Hotelling Vessel operations while stationary at the dock
hrs Hours
Hz Hertz
IEC International Electrotechnical Commission
IEEE Institute of Electrical and Electronics Engineers
iENCON Incentivized Shipboard Energy Conservation
IMO International Maritime Organization
ISO International Organization for Standardization
kV Kilovolts
kWh Kilowatt-hours
Laker A ship that operates on the North American Great Lakes
LNG Liquefied natural gas
LPG Liquid petroleum 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
nm Nautical miles
NRT Net registered tonnage
NO_x Oxides of nitrogen
NY/NJ Port of New York/New Jersey
OPS Onshore Power Supply
OTAQ 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 Shore-side electrical power that marine vessels can plug into while at berth to power ancillary systems including on-board electrical systems, loading/unloading equipment, refrigeration, heating, and cooling
Short ton 2,000 pounds
SO_2 Sulfur dioxide
SO_x sulfur oxides
SPADE Shore Power and Diesel Emissions
Tanker vessels Ships that transport bulk liquids
TEU Twenty-foot equivalent unit
Tug vessels Ships that assist larger vessels with maneuvering in port
U.S. EPA United States Environmental Protection Agency
U.S. United States
UK United Kingdom
USACE United States Army Corps of Engineers
V Volts
Wharfinger The keeper or owner of a wharf or dock
yr Year

EXECUTIVE SUMMARY

Shore power has the potential to reduce air pollutant emissions associated with energy consumption from commercial marine vessels at berth. With shore power, the electricity ships need to power their ancillary systems while at berth may be produced with fewer air pollution emissions from land-side electricity power sources (e.g., power plants) as compared with onboard diesel-powered auxiliary engines. However, the magnitude of potential emissions savings depends on the fuel mix and electricity generation technology mix of the power source.

Given the potential air pollutant emissions reductions from shore power, the United States (U.S.) Environmental Protection Agency (EPA) is evaluating the feasibility of baseline requirements for EPA-approved shore power systems through the Shore Power Technology Assessment project. This project is led by Eastern Research Group (ERG) and Energy & Environmental Research Associates, LLC (EERA) and provides the EPA Office of Transportation and Air Quality (OTAQ) with information about the characteristics, benefits, and costs of shore power systems. This report summarizes the findings and proposed methodology developed by the EERA team as the Task 3 deliverable of EPA Contract No. EPC-11-046, Work Assignment No. 4-06.

This report characterizes the technical and operational aspects of shore power systems in the U.S. and also demonstrates an approach for comparing shore power and vessel emissions while at berth. The report demonstrates that shore power is a relatively new technology in the United States, with most systems coming into service in the last 10 years. While high capacity shore power systems in the U.S. have similar technical specifications and meet international operation and safety standards, the characteristics of low capacity systems in the U.S. vary considerably. High capacity systems are mainly used by cruise, container, and refrigerated vessels, while low capacity systems are used by fishing and tug vessels. The time vessels spend at berth, which affects how much shore power the vessel could potentially use, varies from port-to-port and by vessel type, with cruise ships and roll-on/roll-off (RORO) vessels hotelling for shorter periods than container and bulk cargo vessels.

To compare shore power and vessel emissions while at berth, this report recommends an approach similar to the California Air Resources Board (CARB) (2007) and Corbett and Comer (2013) as outlined in Section 5. The approach outlined here builds upon previous work as it enables an analyst to (1) estimate the amount of air pollutants that would be emitted by a vessel operating its onboard diesel-powered auxiliary engines; (2) estimate the amount of air pollutants that would be emitted by the regional, land-side electricity grid to provide the same amount of power to the vessel; and (3) compare those emissions. Additionally, the model presented here allows for fine tuning through selection of specific generation facilities, and user-defined inputs for the grid emissions mix, vessel auxiliary power, load factor, and engine emission factors. The approach outlined in this report can be used to estimate how harmful air pollution emissions could be reduced at U.S. ports through the use of shore power systems, benefiting air quality, human health, the economy, and the environment.

Despite these potential benefits, an examination of studies and reports about shoreside power in 13 individual ports suggests that the use of shore power may face a variety of implementation barriers. Ships must have the necessary vessel-side infrastructure to connect to shore power systems, requiring a substantial investment. Depending on the relative costs of marine bunker fuels and shore-side electricity, it may be less expensive to operate auxiliary engines rather than connect to shore power. However, harmonized international standards for shore power installations may reduce those costs by reducing uncertainty for fleet owners and operators with respect to the vessel-side infrastructure needed to enable the ship to connect to shore power. In addition, states and port authorities may be able to reduce costs through incentive programs.

Finally, these studies suggest that shore power may be most effective when applied at terminals and ports with a high fraction of frequent callers, which are typically cruise ships and container ships. For other types of ships and, in particular, for ships that call infrequently, programs should carefully consider the costs of obtaining and maintaining the equipment, both on ships and on shore.

Under the right conditions, shore power can be effective at reducing ship NO_x, $PM_{2.5}$ and CO_2 emissions. The modeling tools set out in this study will be helpful to states and port authorities in evaluating and designing shore side power programs.

1.0 INTRODUCTION

The Shore Power Technology Assessment (Assessment) is a project led by ERG and EERA to provide the EPA OTAQ with information about shore power systems, including their characteristics, emissions benefits, and costs. This report characterizes the technical and operational aspects of shore power systems in the U.S., demonstrates an approach for comparing shore power and vessel emissions while at berth, and summarizes the experience of 13 ports shore side power programs. The U.S. EPA is evaluating the technical feasibility of baseline requirements for EPA-approved shore power systems; this report supports that evaluation.

The Assessment was broken down into three tasks:

- Task 1: Compile shore power information
- Task 2: Develop a preliminary approach or methodology to calculate ship emissions reductions from shore power
- Task 3: Produce a shore power report that characterizes shore power systems in the U.S. and demonstrates a preliminary approach or methodology to calculate ship emissions reductions from shore power

EERA delivered this report to EPA to fulfill Task 3 under EPA Contract No. EPC-11-046, Work Assignment No. 4-06. This report is comprised of six sections. Section 1 introduces the Assessment project. Section 2 provides a brief background on shore power and its potential emissions reduction benefits for at-berth vessels. Section 3 evaluates the characteristics of existing shore power systems in the U.S. Section 4 reviews existing approaches to compare shore power and vessel emissions while at berth. Section 5 describes a recommended preliminary approach for comparing shore power and vessel emissions while at berth. Section 6 presents some conclusions.

There are three appendices to this report. Appendix A summarizes a set of reports that provide information on shore side power programs at 13 ports, including environmental benefits and costs of those programs. Appendix B provides a demonstration of the recommended preliminary approach and methodology for comparing shore power and vessel emissions as outlined in Section 5 of this report. Appendix C contains maps showing the locations of shore power installations at U.S. ports.

2.0 BACKGROUND

Ports are the main gateway for U.S. trade and are essential to the economies of many cities and regions nationwide. In recent years, there has been a growing emphasis on the globalization of trade and the transportation infrastructure needed to support it. The EPA's OTAQ recognizes the economic and environmental significance of the U.S. port industry sector and is developing a comprehensive Ports Initiative to explore and identify ways to incentivize and evaluate technologies and strategies to reduce emissions at ports. One way to reduce emissions at ports is using "shore power" technology. Shore power allows ships to "plug into" electrical power sources on shore. Turning off ship auxiliary engines at berth would significantly reduce ship diesel emissions, but these emission savings must be compared to the emissions generated by the land electrical grid.

More specifically, the basis for emissions reduction claims when using shore power stems from the potential to produce the electricity ships need to power their ancillary systems with fewer air pollution emissions from land-side electricity power sources (e.g., power plants) as compared with onboard diesel-powered auxiliary engines. The potential emissions savings will depend on the fuel and electricity generation technology mix of the power source.

Typically shore power systems are supplied by the regional electricity grid. Thus, the emissions associated with producing electricity for shore power will vary depending on the relative shares of zero/low-emission sources (e.g., hydro, wind, solar, nuclear) and higher emission sources (e.g., coal- and natural gas-fired power plants). The relative shares of fuel sources can change over time (and even vary hour-to-hour depending on electricity demand). Shore power proponents note that as the electricity grid becomes cleaner and more efficient, the potential emissions reductions compared to auxiliary engines will grow. However, the cost of shore power electric generation and delivery, for both the vessels and the terminal, can be substantial.

The emissions reduction benefits of shore power have been estimated or reported by a number of organizations and researchers. For example, CARB (2007) estimated that their At-Berth Regulation, which is designed to reduce air emissions from diesel auxiliary engines on container ships, passenger ships, and refrigerated-cargo ships while at-berth ("hotelling") at California ports, would reduce localized emissions of particulate matter (PM) by 75% and oxides of nitrogen (NO_x) by 74% in 2020. These emissions reductions are expected to be achieved in one of two ways. First, fleet operators can use the "limited engine use" compliance approach by shutting off auxiliary engines (except for three or five hours of total operation), during 80% of port visits in 2020 and connect to grid-supplied shore power instead. Second, fleet operators can use the "emissions reduction option" compliance approach by reducing their fleet auxiliary engine emissions at a port by 80%; this implies that auxiliary power would come from other, lower emission sources (e.g., fuel cells) or through the use of emissions control technologies.

Note that compliance requirements were 50% in 2014 and will increase to 70% in 2017 and then 80% in 2020. CARB (2007) estimated that the At-Berth Regulation would achieve a net reduction of 122,000-242,000 metric tons of carbon dioxide (CO_2) in 2020 for California ports through the use of shore power. This is equivalent to a 38-55% net reduction in CO_2 emissions, even after accounting for the emissions associated with producing the power from the regional electricity grid.

Other studies also suggest the benefits of shore power A study by ENVIRON (2004) estimated that shore power would reduce emissions of NO_x and PM by more than 99% and 83-97%, respectively, for vessels calling on the Port of Long Beach (POLB), CA. A report by Yorke Engineering (2007) estimated that shore power could reduce emissions of NO_x, 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, CA in 2007.

A 2013 analysis by Corbett and Comer (2013) estimated the potential emissions reductions from shore power for at-berth cruise vessels at the Port of Charleston, SC. They found that shore power would greatly reduce air pollution from these ships, as shown in Table 1. Emissions reductions were estimated to be greater in 2019 as the local power company reduces the share of coal in its electricity generation portfolio.[1]

Table 1. Criteria and greenhouse gas estimated emissions reductions from using shore power over auxiliary engines at the Port of Charleston (Corbett and Comer, 2013)

Pollutant	Percent Reduction Using Shore Power
Carbon Monoxide (CO)	92%
Nitrogen Oxides (NO_x)	98%
PM_{10}	59%
$PM_{2.5}$	66%
Sulfur Dioxide (SO_2)	73%
Carbon Dioxide (CO_2)	26%

Additional studies have focused on ports outside the United States. Hall (2010) 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 UK's national electric grid. Chang and Wang (2012) 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. (2014) estimated that shore power could reduce CO_2 emissions by up to 42%, using a RORO port in Spain as a case study.

It should be noted, particularly with respect to the U.S ports studies, that the North American Emission Control Area (ECA) had not yet been established at the time the studies were performed. The ECA entered into force in 2012 and resulted in the use of cleaner, low-sulfur fuels in commercial marine vessels and will reduce NO_x emissions from engines on newer-built vessels within 200 nautical miles (nm) of the U.S. coast. Under the ECA, fuel sulfur (S) content was limited to 1.00% S when the ECA entered into force in August 2012 and was further limited

[1] 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% nuclear or hydro.

to 0.10% S on 1 January 2015. Additionally, marine engines installed on vessels built on or after 1 January 2016 and operating within the ECA will be subject to stringent Tier III NO_x standards. These standards reduce NO_x emissions by 80% compared with Tier I standards. Despite the ECA, 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 even lower emissions rates from land-based sources.

In addition, with respect to U.S. ships, auxiliary engines are subject to the federal Clean Air Act program. Ship auxiliary engines typically fall under Category 1 (< 5L displacement per cylinder) or Category 2 (5L to 30L displacement per cylinder), as classified by the U.S. EPA. Tier 3 and 4 exhaust emission standards put forward by EPA require Category 1 and 2 engine manufacturers to reduce NO_x, HC, and PM emissions in newer engines for US-flagged vessels (EPA, 2016).

The combination of the ECA NOx emission requirements and the federal CAA standards for engines on U.S. ships means that auxiliary engines are getting cleaner. Therefore, the expected and observed emissions reductions from shore power will vary depending on the fuel mix of the electricity source. Nevertheless, shore power is expected to reduce air pollutant emissions from at-berth vessels in nearly all cases.

The studies examined in Appendix A suggest that shore power may be an important way to reduce in-port and near-port emissions of air pollution, benefiting air quality for communities located near or adjacent to the port, many of which are non-attainment areas for criteria air pollutants.[2] A 2004 study commissioned by the POLB (ENVIRON, 2004) found that shore power is most cost-effective when annual electricity consumption while hotelling is 1.8 million kWh or more. Shore power becomes more economically attractive when bunker prices are high. Moreover, improved air quality can improve human health and reduce environmental damages, resulting in economic benefits from reduced medical costs and environmental remediation expenses. The Appendix A studies show that many ports have seen reductions in criteria pollutants of between 60% and 80%. There can also be reduced port noise benefits as auxiliary engines are turned off. Using shore power also allows for maintenance crews to repair and maintain machinery that might otherwise be inaccessible if the engines were running.

Shore power is a relatively new technology in the U.S., with most OPS systems coming into service in the last 10 years. While high capacity OPS systems have similar technical specifications and meet international standards, low capacity OPS systems vary considerably. High capacity OPS systems are mainly used by cruise, container, and reefer vessels, while low capacity systems are used by fishing and tug vessels. The time vessels spend at berth, which affects how much shore power the vessel could potentially use, varies from port-to-port and by vessel type, with cruise and RORO ships hotelling for shorter periods than container and bulk cargo vessels.

[2] 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: http://www.epa.gov/airquality/greenbook/mapnpoll.html.

3.0 U.S. SHORE POWER CHARACTERISTICS

This section identifies and describes 15 U.S. shore power facilities, also called Onshore Power Supply (OPS) systems. These systems are owned and managed either by the ports or by individual terminal tenants.

3.1 Capacity

These OPS systems fall into two main categories:

- High capacity
    - o > 6.6 kilovolts (kV)
    - o Typically service large cruise, container, and reefer vessels.
- Low capacity
    - o 220-480 volts (V)
    - o Typically service smaller vessels such as fishing vessels and tugs

Table 2 summarizes existing U.S. OPS system installations by capacity and the vessel type(s) served. The locations of these OPS systems are shown in Figure 1.

Table 2. United States OPS system installations by capacity and vessel type(s) served.

Vessel Type(s)	OPS Installation
High Capacity	
Cruise only	4
Cruise and Container	2
Cruise and Reefer	1
Container only	2
Reefer only	1
Subtotal	**10**
Low Capacity	
Fishing vessels	3
Tugs	3
Subtotal	**6**
Total	**16**

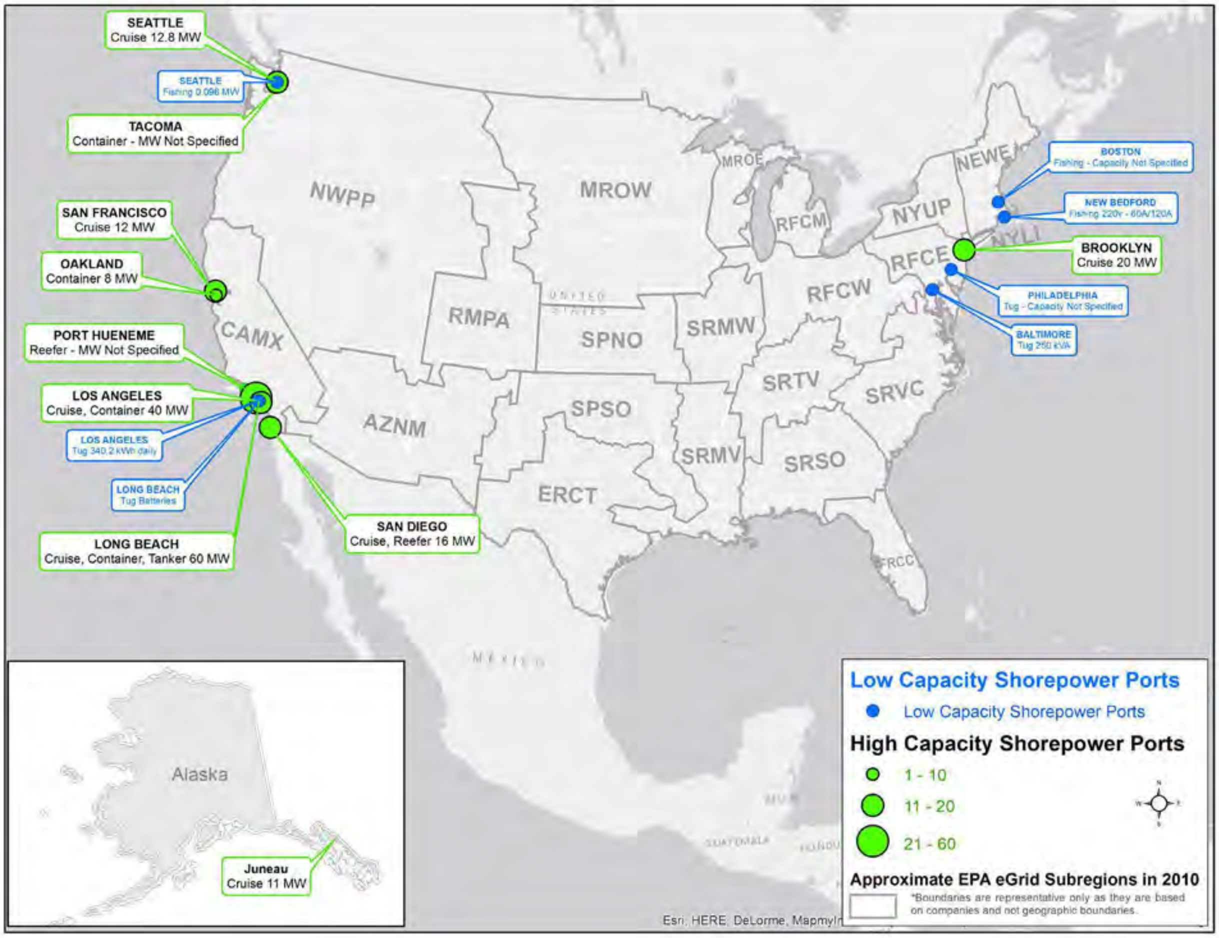

Figure 1. Existing shore power installations at U.S. ports and U.S. EPA eGRID subregions.

3.2 Design

Shore power systems can be dock-mounted, containerized, or barge-mounted. Dock-mounted systems developed by Cochran Marine have been installed at seven U.S. ports. They require power metering and transformer equipment to be mounted on the dock and have a cable-positioning device to help at-berth vessels connect to the system.

Containerized shore power systems are also in use. SAM Electronics and Cavotec have developed containerized shore power solutions that are comprised of a cable reel, switchboard, transformers, and power monitoring and control systems. Modular containerized systems allow for flexibility in positioning the shore power connection to accommodate different loading or berthing arrangements while reducing the need for quayside space as compared to dock-mounted systems. However, unlike dock-mounted systems, containerized systems are not available for use on cruise vessels due to constraints in cable handling and the location of the shore power socket outlet on the lower decks.

Barge-mounted systems require little or no dockside space. These systems are self-contained power plants that provide power for at-berth vessels. Barge-mounted systems typically use alternative fuels or technologies such as liquefied natural gas (LNG) and fuel cells.

3.3 Standards

All high capacity OPS installations meet IEC/ISO/IEEE 80005-1:2012 industry standards,[3] mandatory for all cruise vessels (L. Farguson, Port of Halifax, personal communication, February 6, 2015). In contrast, only some low capacity OPS installations adhere to an international standard. The IEC/ISO/IEEE 80005-3:2014 standard[4] for low voltage shore connection (LVSC) systems for shore-to-ship connections, transformers, and associated equipment for vessels requiring up to 1 mega volt-ampere (MVA, equivalent to 1 megawatt (MW) at a power factor of 1) 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. OPS systems are known to meet the standard currently.

3.4 Technical Specifications

The technical specifications for OPS systems installed at 14 U.S. ports are summarized in Table 3. These specifications were compiled from a number of different sources outlined in the Table 3 footnotes. Information is from the World Ports Climate Initiative shore power database[5] unless otherwise noted. EERA attempted to fill data gaps by reaching out to ports directly, although some missing information persists. Nevertheless, one can see that high capacity OPS serve cruise, container, tanker, and reefer vessels, whereas low capacity systems serve fishing and tug vessels. All U.S. systems use 60 hertz (Hz) frequency and were installed beginning in the year 2000. High capacity systems use 6.6 kV, 11 kV, or both; low capacity systems use 220-480 V. Average usage is reported in various ways; watt-hours, electricity cost, or days of usage.

---

3 http://www.iso.org/iso/catalogue_detail.htm?csnumber=53588
4 http://www.iso.org/iso/catalogue_detail.htm?csnumber=64718
5 http://www.ops.wpci.nl/ops-installed/ports-using-ops/

Table 3. Technical specifications for OPS systems installed at U.S. ports.

	Port Name	Vessel Types using OPS	Year of Installation	Maximum Capacity (MW)	Average Usage	Frequency (Hz)	Voltage (kV)	Manufacturer
High Capacity	Juneau[8]	Cruise	2001	11.00	4,107 MWh	60	6.6 & 11	Cochran Marine
	Seattle	Cruise	2005-2006	12.80		60	6.6 & 11	Cochran Marine
	San Francisco[9]	Cruise	2010	12.00	6,720 MWh (2013) 7,182 MWh (2014)	60	6.6 & 11	Cochran Marine
	Brooklyn	Cruise	2015	20		60	6.6 & 11	Cochran Marine
	Los Angeles	Container Cruise	2004	40.00	19,560 MWh[10]	60	6.6	Cavotec
	Long Beach	Cruise Container Tanker	2011 2009 2000	16.00		60	6.6 & 11	Cavotec; Cochran Marine
	San Diego	Cruise Reefer	2010	16.00	12,871 MWh[11] 8,004 MWh	60	6.6 & 11	Cochran Marine
	Oakland[12]	Container	2012-2013	8	2 MW	60	6.6	Cavotec
	Hueneme	Reefer	2014		2,411 MWh (2013)	60		
	Tacoma	Container RORO	2009			60	6.6	Wood Harbinger
Low Capacity	Seattle[13]	Fishing		0.096	1 week - 6 months	60	0.4	
	Boston[14]	Fishing						
	New Bedford[15]	Fishing	2011	0.0264	5-330 Days connection time ~12,450 MWh	60	0.22	
	Philadelphia[16]	Tug						
	Baltimore	Tug		0.250	daily	60	0.480	
	Los Angeles / Long Beach	Tug	2009	0.3402	340.2 kWh daily	60		

[8] Juneau (2011)
[9] ENVIRON (2015)
[10] $4.2 million in utilities at an average electricity cost of $0.215/kWh (Port of Los Angeles (POLA), 2014)
[11] Yorke Engineering (2007)
[12] Personal Communication: Chris Peterson, Wharfinger, Port of Oakland
[13] Personal Communication: Ellen Watson, Port of Seattle
[14] https://www.massport.com/port-of-boston/maritime-properties/boston-fish-pier/
[15] 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
[16] ICF (2009)

3.5 Usage and Price

Vessel activity at OPS terminals in the 13 ports presented in Appendix A and the price for connecting to OPS are summarized in Table 4. Activity was determined from the most recent publicly available information but complete information was not available for all ports, as indicated by blank cells. Cruise activity at the Ports of Juneau and Brooklyn was determined by cross-referencing cruise schedules with lists of shore power equipped cruise vessels. Cruse OPS activity for the Port of Seattle was provided to EERA by a port representative. The number of shore power connections at the Ports of San Francisco (ENVIRON, 2015a), Los Angeles (Starcrest, 2014c), Long Beach (Starcrest, 2014a), San Diego (ENVIRON, 2015b), and Oakland (ENVIRON, 2013) were estimated based on the most recently available port emissions inventories. Vessel activity for the Ports of Juneau (CLAA, 2015) and Seattle (Port of Seattle, 2015) were estimated from cruise ship schedules. Port of Hueneme calls were estimated based on the Hueneme Vessel Schedule (Port of Hueneme, 2015). Service prices for connecting to OPS were available from various sources shown in the associated footnotes.

Table 4. Vessel activity and service price at OPS facilities in the U.S.

Capacity	Port Name	Vessel Types using OPS	# OPS Berths	# Unique OPS Vessels	Annual OPS Calls	Total Calls on OPS-capable Berths (yr)	Service Price
High Capacity	Juneau	Cruise	2	12	213	498 (2015)	$4000-5000/day (ENVIRON, 2004)
	Seattle	Cruise	2	5	97	111 (2014)	P: $0.068/kWh OP: $0.045/kWh[17]
	San Francisco	Cruise	2	20	49	128 (2013)	
	Brooklyn	Cruise	1	2	18[18]	42 (2015)	$0.12/kWh ($0.26/kWh to deliver)
	Los Angeles	Container & Cruise	25	54	141	2014* (2013)	$150 service charge + $1.33/kW facilities charge + $0.05910/kWh energy charge (additional charges may be applied - see the source)
	Long Beach	Cruise	1		81	2018* (2013)	Varies - each SP terminal has its own account and rate structure with Southern California Edison
		Container	15		125		
		Tanker	1		16		

[17] For Port of Seattle electricity rates from Seattle City Light, see http://www.seattle.gov/light/rates/ratedetails.asp. P denotes peak energy rates, OP denotes off-peak energy rates. Additional peak demand charges of $2.02/kW, and off-peak demand charges of $0.22/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.

[18] The Queen Mary 2 and the Caribbean Princess are currently listed as equipped to plug in to shore power at the Brooklyn terminal. Nycruise.com lists the two vessels as visiting the Brooklyn Terminal 18 times in 2016, up from 15 visits in 2015.

Table 5. Vessel activity and service price at OPS facilities in the U.S.

Capacity	Port Name	Vessel Types using OPS	# OPS Berths	# Unique OPS Vessels	Annual OPS Calls	Total Calls on OPS-capable Berths (yr)	Service Price
High Capacity	San Diego	Cruise	2	4	16	87 (2012)	
	Oakland	Container	14	200 commissioned[19]		1812* (2012)	$267 per hour[20]
	Hueneme	Reefer	3			391*	
	Tacoma	Container	1	2	100	100	
Low Capacity	Seattle	Fishing	300				$0.079/kWh[21]
	Boston	Fishing	18				$0.042/kWh[22]
	New Bedford	Fishing	50				$0.079/kWh[23]
	Philadelphia	Tug					
	Baltimore	Tug	3	3	Daily		
	Los Angeles / Long Beach	Tug	1	2	Daily		

* Denotes total port-wide vessel calls, not specific to OPS-equipped berths or terminals.

19 See http://goo.gl/entmdD for a list of OPS commissioned vessels at the Port of Oakland.

20 http://www.portofoakland.com/maritime/shore power.aspx

21 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 $2.24/kW also apply. Note that this is the publicly offered rate and the port may have negotiated an alternate rate.

22 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 $20.22 + $15.95/kW apply along with monthly customer charge of $18.19. See source for additional charges (https://www.eversource.com/Content/docs/default-source/rates-tariffs/2015-ema-business-electric-rates-1.pdf?sfvrsn=6).

23 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 $4.86/kW occur over 10 kW (https://www.eversource.com/Content/docs/default-source/rates-tariffs/2015-ema-business-electric-rates-2.pdf?sfvrsn=6).

3.6 Time at Berth

EERA reviewed time at berth at the Port of Long Beach, Port of New York/New Jersey, Seattle/Tacoma, and Port of Los Angeles and found that at-berth time varies from port-to-port and by vessel type (Table 6). Cruise and RORO vessels tend to spend the least amount of time at berth when compared to cargo vessels. POLB reports vessel berthing times ranging from 13 to 121 hours in their Cold-Ironing Cost Effectiveness Summary (ENVIRON, 2004). At the POLB, container vessel dwell times increased as vessel size (i.e., capacity) increased. Similarly, time at berth for container vessels at the Port of New York/New Jersey (NY/NJ) increased from 18 hours for a 1,000 twenty-foot equivalent unit (TEU) vessel, to 40 hours for a 9,000 TEU vessel (Starcrest, 2014b), although the at-berth time was considerably lower than that of POLB. Cruise and container dwell times at Port of Seattle/Tacoma are consistent with those observed at NY/NJ (Starcrest, 2013).

Table 6. Average time at berth (hrs) by port and vessel type for select U.S. ports.

Vessel Type	POLB	NY/NJ	Seattle/Tacoma	POLA[a]
Container[b]	68	26	31	48
Tanker	35	29[c]	21	39
General Cargo	31	14	41	53
RORO	12	12	16	17
Cruise	12	10	10	10
Reefer	-	8	-	27
Dry Bulk	54	35	89	70

[a]Starcrest (2014c); [b]Average of all container vessel sizes; [c]Chemical tanker only

ERG estimated average time at berth for all U.S. ports by vessel type for a recent, unpublished, analysis of arrival and departure data from the U.S. Army Corps of Engineers' (USACE) Entrances and Clearances dataset. The data were reported in "days at berth" and converted to hours. The results of this analysis are presented in Table 7. Results exclude domestic (i.e., U.S.-flag) vessel activity but still inform estimates of average vessel berthing times at U.S. ports.

Table 7. Average time at berth by vessel type for U.S. ports.

Vessel type	Average time at berth (hrs)
Barge	89
Bulk Carrier	91
Bulk Carrier (Laker)	28
Container	33
Crude Oil Tanker	54
Fishing	58
General Cargo	58
LNG Tanker	30
Liquid Petroleum Gas (LPG) Tanker	52
Miscellaneous	37
Cruise/Passenger	27
Reefer	60
RORO	29
Supply	39
Support	75
Tanker	61
Tug	49

Vessel type	Average time at berth (hrs)
Vehicle Carrier	33

3.7 Costs and Benefits

This study does not contain a comprehensive analysis of the costs and benefits of shore side power. However, certain observations from various studies performed for particular ports are noteworthy. A summary of published studies examining various aspects of the economic and environmental costs and benefits of shore power for 13 U.S. ports is included as Appendix A. The following discussion is based on those studies.

A 2004 study commissioned by the POLB (ENVIRON, 2004) found that shore power is most cost-effective when annual electricity consumption while hotelling is 1.8 million kWh or more, equivalent to a cruise ship drawing 7 MW of shore power for 260 hours annually. For a smaller vessel drawing 1.5 MW, this threshold is equivalent to 1,200 hours annually. Cost-effectiveness for vessels operating above the 1.8 million kWh annual threshold was $9,000 - $15,000/short ton of combined criteria pollutants (ENVIRON, 2004).

At present, shore power has not been extensively adopted outside of European and North American ports. However, there is an increase in efforts to encourage ports throughout the world to adopt shore side power system. In Europe, under Directive 2014/94/EU, the European Commission mandated the installation of shore power in all ports "unless there is no demand and the costs are disproportionate to the benefits, including environmental benefits." In Asia, the Port of Shenzen offers subsidies for vessels switching to shore power or low-sulfur fuels while at berth. Additionally, the Port of Shanghai has entered into an "ecopartnership" with the POLA to facilitate sharing shore power information; Shanghai plans to offer shore power beginning in 2015.

Studies suggest that shore power becomes economically attractive when bunker fuel costs are high relative to local, land-based, electricity prices. Maersk claims that shore power is not a cost-effective emission reduction strategy for vessels calling at U.S. ports for short periods of time (American Shipper, 2014). At current bunker prices, the industry argues shippers are less likely to use shore power rather than marine gas oil (MGO) due to high up-front vessel commissioning costs associated with shore power, the cost of purchasing the electricity while in port, and lower cost options available such as Advanced Maritime Emission Control (AMEC) systems that scrub exhaust gases and do not require shore power retrofits. However, if distillate oil prices rise relative to electricity prices, then shore power may become more favorable than switching to MGO fuel.

3.8 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 (U.S. Navy, 2015). The iENCON program mainly focuses on energy reductions while 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 Shipboard Shore Energy Management Handbook[24] shows load profiles for the USS Peleliu during baseline (2,500 kW) and reduced load (1,600 kW) periods. The average daily electricity consumption across 14 vessels was 35,000 kWh at a cost of $5,000 per day ($0.146/kWh). However, not all naval vessels draw so much power. For instance, the Port of San Francisco 2013 Emissions Inventory (ENVIRON, 2015) lists five U.S. Navy vessels using shore power while docked at Pier 70 for maintenance. The average at-berth load for these vessels was between 497 kW and 790 kW, with dwell times ranging from eight to 192 hours. Total naval energy use at San Francisco's Pier 70 was approximately 284,000 kWh in 2013.

The example of the US Navy's earlier adoption of shorepower can provide a relevant example for which commercial vessel types may find adoption of shorepower most feasible. Naval vessel power demand at dock 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.

3.9 California Air Resources Board's Experience with Shore Power

The California Air Resources Board (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. The At-Berth Regulation is designed to reduce at-berth diesel auxiliary emissions from container, passenger, and refrigerated cargo vessels at California ports. Vessel fleet operators have two options for compliance; they can turn off auxiliary engines and connect to shore power, or they can use control technologies that achieve equivalent emission abatement. The At-Berth Regulation is designed to include large, frequent calling fleets. At-berth regulations apply to container and reefer fleets whose vessels cumulatively make 25 or more annual calls at one California port or passenger fleets whose vessels cumulatively make five or more calls to one port.

Twenty-three terminals and 63 berths at 6 ports in California are shore power-equipped. CARB reports that of the 4,400 vessel calls to California ports in 2014, 2,750 were expected shore power visits, reflecting the influence of California's at-berth shore power regulations. However, CARB issued two regulatory advisories to provide certainty to fleets making good faith effort to comply. The first advisory, issued in December 2013, addressed the implementation period of the regulation from January 1, 2014 to June 30, 2014. This advisory covered situations outside a fleets control including berth availability, vessel OPS commissioning, OPS connection times, and OPS installation delays. In fact, CARB reported that 34 fleets submitted requests for relief under the 2013 advisory. The second advisory, issued March 2015, proposed a schedule for amendments to permanently address the implementation issues, and provides regulatory certainty until the rulemaking process concludes.

[24] http://www.i-encon.com/PDF_FILES/ssem_handbook/SSEM_Handbook.pdf

3.10 Future Shore Power Technologies and Projects

Recently, there have been advances in developing shore power systems that operate on alternative fuels and technologies, resulting in very clean (i.e., low- or zero-emission) OPS systems. For instance, Sandia National Laboratories has been working with Young Brothers' Shipping at the Port of Honolulu, HI to develop a hydrogen fuel cell-based shore power system. The 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 and it will be able to operate independent of the grid. This fuel cell technology is currently a prototype.

Foss Maritime is currently operating two hybrid tug vessels, the *Carolyn Dorothy* and the *Campbell Foss* at the POLB. 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. From an emissions perspective, the tugs reduce PM 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. Hotelling loads for the *Campbell Foss* are about 50 kW (Foss, 2011).

Liquefied natural gas is also being considered as a fuel source for OPS. 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.

Totem Ocean Trailer Express (TOTE) currently operates two container vessels, the *Midnight Sun* and *North Star,* on their Tacoma-Anchorage trade route. The two vessels combine for 100 shore power calls at Tacoma, WA, annually. TOTE is currently in the process of converting the *Midnight Sun* and *North Star* to LNG fueled vessels.

Unlike some long-haul ferries in Europe, most US ferries operate across relatively short distances, at relatively short intervals, and within limited daily service hours. As such, ferries in most US ports are operated such that their engines are fully turned off during long periods at dock, i.e. overnight. Therefore, US ferries are generally less ideal candidates than some international ferry services for shore power application.

European ferries are often larger and operated on longer routes than their US 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 (2 RORO, 2 ROPAX) to operate on shore power in 2012[25]. Stena Line's vessels plugging in to shore power at Hoek van Holland have electrical systems that operate at 60Hz. In order to connect to the local grid, which operates at 50Hz, Stena Line employed an 11kV static frequency conversion shore power system from ABB 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

[25] https://library.e.abb.com/public/69e4dc9bd3afc54ac1257a2900310ac0/Case%20study%20ferries%20-%20Stena%20Hoek%20van%20Holland%20NL.pdf

ferry berths in western Norway[26]. The automated mooring and shore power system will serve two battery powered ferries operated by Norled between the two terminals, which each make around 8 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 towards total project costs of $179,300. The shore power system is anticipated to reduce greenhouse gas emissions by 120 tons annually at the terminal.[27]

China's Ministry of Transport has announced that seven terminals will begin trial implementations of shore power, including cruise, bulk, and container terminals.[28] Three vessels will be used to test the emissions reductions and operational challenges of shore power, including a 10,000 TEU COSCO container vessel. Chinese authorities anticipate 99% reductions in NO_x emissions, and 3-17% reductions in PM compared to vessels burning conventional HFO.

4.0 EXISTING APPROACHES, METHODS, AND TOOLS TO COMPARE SHORE POWER AND VESSEL EMISSIONS

CARB and others have developed approaches, methods, and tools for comparing shore power and vessel emissions while the vessel is at berth. This section provides a description of these approaches, methods, and tools, beginning first with CARB and then describing how others have conducted similar estimations.

4.1 CARB (2007): Emissions Inventory Comparisons Pre- and Post-Shore Power

In the 2007 Technical Support Document for their At-Berth Regulation, CARB (2007) estimated expected NO_x and PM emissions reductions from the regulation using a 2006 base year and projecting to 2014 and 2020.

4.1.1 Inputs

Model inputs included:

- Vessel inputs:
  - Base year vessel population
  - Auxiliary engine power
  - Vessel-type-specific auxiliary engine load
  - Auxiliary engine emissions factors
- Activity inputs:
  - Port-specific hotelling time

[26] http://www.cavotec.com/mediacentre/page/7/279/cavotec-to-supply-the-world-s-first-combined-automated-mooring-and-shore-power-system/
[27] http://shipandbunker.com/news/am/341961-canadian-ferry-terminal-to-get-shore-power
[28] http://shipandbunker.com/news/apac/613843-china-announces-seven-terminals-to-trial-shore-power?utm_source=newsletter&utm_medium=email&utm_campaign=newsletter-07/13/16

    - Vessel-type-specific and port-specific growth rates
- Shore power inputs
    - Shore power emissions factors

4.1.2 Data and Assumptions

4.1.2.1 Vessel Inputs

Base year vessel population. Using a California Lands Commission database, CARB estimated that approximately 2,000 ocean-going vessels made 5,915 port calls in California ports in 2006. Most of the port calls were from container vessels (4,960) followed by cruise ships (667) and reefers (288).

Auxiliary engine power and vessel-type-specific auxiliary engine load factors. As described in CARB (2007), the primary source of auxiliary engine power and vessel-type-specific auxiliary engine load factors was the 2005 ARB Ocean Going Vessel Survey. ENVIRON's estimates for auxiliary engine power for ships calling on the Port of Oakland in 2005 were also used, as well as a limited number of auxiliary engine power data from Starcrest's vessel boarding program and Lloyd's-Fairplay. Vessel-type-specific auxiliary engine power and load factors used by CARB (2007) are summarized in Table 8. As an aside, the EPA (2009) used CARB's 2005 Ocean Going Vessel Survey as the basis for developing auxiliary engine hotelling load factors for a broader array of vessel types as part of their 2009 *Proposal to designate an Emission Control Area for nitrogen oxides, sulfur oxides and particulate matter: Technical support document*. This information is presented in Table 9 for the reader's information.

Table 8. Average installed auxiliary engine power and load factor by vessel type used in CARB (2007).

Vessel Type	Size (TEU)	Avg. Installed Aux. Power (kW)	Load Factor while Hotelling
Container	<2000	3536	18%
Container	2000-2999	5235	22%
Container	3000-3999	5794	22%
Container	4000-4999	8184	22%
Container	5000-5999	11,811	18%
Container	6000-6999	13,310	15%
Container	7000-7999	13,713	15%
Cruise	N/A	45,082[a]	16%
Reefer	N/A	3696	32%

[a] Most cruise vessels do not have auxiliary engines, instead they utilize a fraction of main engine power at berth.

Table 9. Auxiliary engine power, auxiliary to main engine ratio, and hotelling load factor derived from CARB's 2005 Ocean Going Vessel Survey and used in EPA (2009).

Vessel Type	Average Main Engine Power (kW)	Average Auxiliary Power (kW)	Auxiliary to Main Ratio	Hotelling Load Factor
Auto Carrier	10,700	2,850	0.266	24%
Bulk Carrier	8,000	1,776	0.222	22%
Container Ship	30,900	6,800	0.220	17%
Passenger Ship	39,600	11,000	0.278	64%
General Cargo	9,300	1,776	0.191	22%
Miscellaneous	6,250	1,680	0.269	22%
RORO	11,000	2,850	0.259	30%
Reefer	9,600	3,900	0.406	34%
Tanker	9,400	1,985	0.211	67%

Auxiliary engine emissions factors. CARB used emissions factors that are consistent with those used in emissions inventories for the Ports of San Diego, Los Angeles, Long Beach, and Oakland, although CARB staff made some adjustments to the SO_2 and PM emissions factors for auxiliary engines that burned heavy fuel oil (HFO) based on results of the 2005 ARB Ocean Going Vessel Survey and a review of emissions tests and scientific literature. For the 2006 inventory, some of the auxiliary engines were assumed to operate on HFO; however for 2014 and 2020 emissions estimates, auxiliary engines were assumed to operate on 0.1% S marine diesel oil (MDO) in compliance with a California regulation requiring the use of 0.1% S fuel in auxiliary engines for vessels within 24 nautical miles of shore. Actual fuel S levels may be lower than the 0.1% S standard depending on regional refinery capabilities. Auxiliary engine emissions factors are presented in Table 10.

Table 10. Auxiliary engine emissions factors used in CARB (2007) (g/kWh).

Fuel Type	PM	NO_x	SO_2	HC	CO
HFO	1.5	14.7	11.1	0.4	1.1
MDO	0.3	13.9	2.1	0.4	1.1
MDO (0.1% S)	0.25	13.9	0.4	0.4	1.1

4.1.2.2 Activity Inputs

Port-specific hotelling time. Port-specific hotelling times were estimated using observed or average hotelling times from Wharfinger data. Hotelling time by port and vessel type used by CARB are presented in Table 11. Note that hotelling times for container vessels at POLA/POLB are longer due to the high number of containers being unloaded and transported at POLA/POLB ports compared to other U.S. ports.

Table 11. Port-specific hotelling times used by CARB (2007).

Port	Vessel Type	Avg. Hotelling Time (hrs)
POLA/POLB	Container	49.0

Port	Vessel Type	Avg. Hotelling Time (hrs)
POLA/POLB	Cruise	11.2
POLA/POLB	Reefer	33.0
Oakland	Container	19.9
Hueneme	Reefer	66.9
San Diego	Cruise	12.6
San Diego	Reefer	61.6
San Francisco	Cruise	11.6

Vessel-type-specific and port-specific growth rates. CARB estimated vessel-type-specific and port-specific auxiliary engine growth rates based on growth in net registered tonnage (NRT) by vessel type and port from 1994-2005. CARB would have preferred to base growth rates on changes in main engine power; however, those data were not available for many records, whereas NRT data were available for more than 99% of records. Growth rates are presented in Table 12.

Table 12. Vessel-type-specific and port-specific growth rates used by CARB (2007); 2006 base year.

Port	Vessel Type	2014	2020
POLA/POLB	Container	162%	234%
POLA/POLB	Cruise	136%	172%
POLA/POLB	Reefer	48%	28%
Oakland	Container	156%	218%
Hueneme	Reefer	114%	127%
San Diego	Cruise	195%	322%
San Diego	Reefer	204%	348%
San Francisco	Cruise	150%	204%

4.1.2.3 Shore Power Inputs

Shore power emissions factors. CARB estimated shore power emissions factors by assuming that shore power electricity would be produced by natural-gas fired power plants using selective catalytic reduction emissions control technologies. CARB only estimated reductions in NO_x and PM_{10} due to shore power. Shore power emissions factors are presented in Table 13. CARB estimated these emissions factors by multiplying the emissions rate of each power source by the total amount of power to be transferred from the shore to the ships. Therefore, these emissions factors do not factor in transmission losses, which the California Energy Commission estimates to be from 5.4 to 6.9%;[29] however, this estimate will vary at the local level depending on transmission distance and voltage.

Table 13. Shore power emissions factors used in CARB (2007).

Pollutant	Emissions factor (g/kWh)
NO_x	0.02
PM_{10}	0.11

[29] http://www.energy.ca.gov/2011publications/CEC-200-2011-009/CEC-200-2011-009.pdf

4.1.3 Equations

CARB used the following basic equation to estimate annual vessel emissions when hotelling and using auxiliary power:

$$E = EF * KW * LF * Hr$$

Where:

E = Amount of emissions of a pollutant emitted during one period
EF = Auxiliary engine emissions factor in grams per kilowatt-hour
KW = Power of the auxiliary engine in kilowatts
LF = Vessel-type and engine-use-specific auxiliary engine load factor
Hr = Hotelling time in hours

The value of each variable changes depending on the vessel, activity, and shore power inputs used.

4.1.4 Outputs

CARB estimated vessel-type-specific and port-specific emissions for a year 2006 baseline and then projected emissions to 2014 and 2020. Year 2014 and 2020 emissions are estimated with and without the implementation of the At-Berth Regulation. Expected hotelling emissions reductions from the use of shore power under the At-Berth Regulation are presented in Table 14.

Table 14. Expected hotelling emissions reductions from shore power (tons/day), as presented in CARB (2007).

Year	NO_x	PM_{10}
2014	13.28	0.13
2020	27.76	0.50

4.2 Corbett and Comer (2013): The Shore Power and Diesel Emissions Model

In 2013, Corbett and Comer (2013) estimated the potential emissions savings from shore power for at-berth cruise vessels at the Port of Charleston, SC for the years 2015 and 2019. They created and used the Shore Power and Diesel Emissions (SPADE) model to conduct the analysis. The model incorporates vessel emissions factors from CARB (2011) and EPA (2009) and calculates shore power emissions factors based on the generation mix of the local utility that serves the port.

4.2.1 Inputs

Model inputs included:

- Vessel inputs:
  - Installed vessel engine power
  - Hotelling load factor

    - Hotelling power (product of installed vessel engine power and hotelling load factor)
    - Vessel emissions factors
- Activity inputs:
    - Vessel port calls per year
    - Hotelling hours per port call
    - Hotelling hours per year (product of vessel port calls per year and hours per port call)
    - Annual power consumption at berth (product of hotelling power and hours per year)
- Shore power inputs:
    - Electricity generation by facility (MWh)
    - Emissions (SO_2, NO_x, PM_{10}, $PM_{2.5}$, CO, CO_2) by facility
    - Shore power emissions factors (quotient of total emissions and total electricity generation)

4.2.2 Data and Assumptions

4.2.2.1 Vessel Inputs and Activity Inputs

Assumptions for vessel and activity inputs are summarized in Tables 13, 14, 15, and 16. Specific sources for vessel assumptions are described below.

Installed vessel engine power. Corbett and Comer were interested in modeling the emissions reduction potential of shore power for one specific 2,000-passenger cruise vessel: the *Carnival Fantasy*. They used the reported installed vessel engine power for that vessel (Table 15). They also were interested in modeling emissions from a larger, 3,500-passenger cruise vessel, assuming that larger cruise ships would be expected to call on the port in the future. They used installed engine power for the *Carnival Dream*, a 3,500-passenger vessel, as reported by Carnival (Table 18).

Hotelling load factor. Instead of having separate, dedicated auxiliary engines, cruise vessels typically use a portion of their installed engine power for hotelling. Corbett and Comer used the passenger vessel hotelling load factor (16%) as reported in CARB (2011) (Table 15 and Table 18).

Vessel emissions factors. Corbett and Comer used emissions factors for medium speed engines as found in CARB (2011) and EPA (2009). The emissions factors in the CARB and EPA reports are both primarily based in earlier emissions factor estimates developed by Entec (2002). Vessel emissions factors used in their analysis are presented in Table 16 and Table 19.

Vessel port calls per year. Vessel port calls per year were estimated for 2015 and 2019 based on a 2011 emissions inventory that reported that the *Carnival Fantasy* made 68 port calls in 2011. Corbett and Comer assumed that both the 2,000-passenger and 3,500-passenger cruise vessels would make 68 port calls each year (Table 15 and Table 18).

Hotelling hours per port call. Hotelling hours per port call were estimated for 2015 and 2019 based on a Trinity Consultants memorandum that estimated that cruise ships that call on the cruise terminal at the Port of Charleston hotel for an average of 10 hours. Corbett and Comer assumed that both the 2,000-passenger and 3,500-passenger cruise vessels would hotel for an average of 10 hours per call (Table 15 and Table 18).

Table 15. Assumptions for 2,000-passenger cruise vessel characteristics and activity in 2013 and 2019 in Corbett and Comer (2013).

Description	Value	Units
Installed power	42,240	kW
Hotelling load factor	0.16	hotelling power/installed power
Hotelling power	6,758	kW
Port calls per year	68	port calls/yr
Hotelling hours per call	10	hr
Hotelling hours per year	680	hr/yr
Annual power consumption at berth	4,595	MWh

Table 16. Emissions factors (g/kWh) used to calculate 2,000-seat cruise vessel emissions in 2013 in Corbett and Comer (2013).

	2013 (1% S fuel)	2013 (0.5% S fuel)	2015 (0.1% S fuel)
CO	1.10	1.10	1.10
NO_x	13.9	13.9	13.9

Table 17. Emissions factors (g/kWh) used to calculate 2,000-seat cruise vessel emissions in 2013 in Corbett and Comer (2013).

	2013 (1% S fuel)	2013 (0.5% S fuel)	2015 (0.1% S fuel)
PM_{10}	0.49	0.38	0.25
$PM_{2.5}$	0.45	0.35	0.23
SO_2	4.24	2.12	0.42
CO_2	690	690	690

Table 18. Assumptions for 3,500-passenger cruise vessel characteristics and activity in 2019 in Corbett and Comer (2013).

Description	Value	Units
Installed power	63,335	kW
Hotelling load factor	0.16	hotelling power/installed power
Hotelling power	10,134	kW
Port calls per year	68	port calls/yr
Hotelling hours per call	10	hr
Hotelling hours per year	680	hr/yr
Annual power consumption at berth	6,890	MWh

Table 19. Assumptions for 3,500-passenger cruise vessel characteristics and activity in 2019 in Corbett and Comer (2013).

Pollutant	0.1% S fuel
CO	1.10
NO_x	13.9
PM_{10}	0.25
$PM_{2.5}$	0.23
SO_2	0.40
CO_2	690

4.2.3 Shore Power Inputs

Electricity grids operate on a distributed basis, balancing and pooling generation from a number of geographically distributed sources in order to provide electricity in a reliable and cost-effective manner. The distributed nature of electricity grids means that although energy may be delivered in one location, that energy may have been generated by a variety of sources, some of which may be further away than other locally available sources.

Shore power connections are predictable and thus ports can coordinate with grid operators to adjust base load energy production to conform to the increased demand from ports with shore power connections in the region. If grid operators know which specific power plants will be used to meet shore power demands then it is possible to assess the emissions associated with a marginal increase in electricity production by observing the emissions factors for those specific facilities as described below.

Electricity generation by facility. Corbett and Comer used 2011 electricity generation data for the facilities that generate power for the local utility that service the Port of Charleston to estimate 2015 and 2019 generation. These data were available from the U.S. Energy Information Administration (EIA). Corbett and Comer assumed that electricity generation was the same for 2011, 2015, and 2019. Electricity generation by facility is shown in Table 20.

Emissions by facility. Corbett and Comer used 2011 emissions data from each facility that generated power for the utility that services the port, as reported by the South Carolina Department of Health and Environmental Control. Despite expected future emissions reductions from the utility, Corbett and Comer assumed the same fuel mix as 2011 for the 2015 scenario. This helps avoid overestimating the emissions reduction benefits of shore power. Emissions by facility in 2011, and the calculated 2015 shore power emissions factors, are shown in Table 20. For the 2019 scenario, Corbett and Comer adjusted the shore power emissions factors to reflect an expected shift away from coal in favor of natural gas and nuclear in response to EPA mercury rules for power plants. The authors assumed that electricity generated by coal and natural gas in 2019 would be produced by the "dirtiest" (i.e., most polluting) remaining coal and natural gas plants to ensure that the emissions reduction benefits of shore power were not overestimated.

Table 20. Electricity generation and emissions by facilities that would provide shore power, in Corbett and Comer (2013).

Facility Name	Net Generation (MWh)	CO (MT)	NO_x (MT)	PM_{10} (MT)	$PM_{2.5}$ (MT)	SO_2 (MT)	CO_2 (MT)
Canadys Steam	1,558,389	883.33	2,409.91	2,070.54	1,639.68	14,180.75	1,386,546
Coit GT	870	0.28	4.92	0.05	0.05	0.12	1,045
Cope Station	2,459,909	94.96	956.24	536.26	425.90	1,428.92	2,038,986
Hagood	55,604	38.95	37.02	1.40	1.40	0.68	38,287
Hardeeville	11	0.01	0.38	0.00	0.00	0.00	64
Jasper County Generating Facility	5,549,564	34.69	138.48	113.09	113.09	10.31	1,955,072
McMeekin	1,204,643	152.41	1,638.15	525.12	515.25	6,548.88	1,033,022
Parr	51,659	0.55	7.72	0.09	0.09	0.18	1,717
Urquhart	2,186,990	547.99	753.73	589.02	421.50	4,279.52	1,163,511
Wateree	3,973,744	383.58	1,970.64	1,156.82	707.04	3,523.06	3,874,183
Williams	2,742,673	239.59	1,400.17	505.95	301.76	550.60	2,429,011
Neal Shoals (Hydro)	11,169	0.00	0.00	0.00	0.00	0.00	0.00
Stevens Creek (Hydro)	53,984	0.00	0.00	0.00	0.00	0.00	0.00
Saluda (Hydro)	41,426	0.00	0.00	0.00	0.00	0.00	0.00
Fairfield Pumped Storage (Hydro)	(229,744)	0.00	0.00	0.00	0.00	0.00	0.00
V C Summer (Nuclear)	7,426,232	0.00	0.00	0.00	0.00	0.00	0.00
Total	27,087,123	2,376	9,317	5,498	4,125	30,523	13,921,444
2015 emissions factor (g/kWh)[a]		**0.088**	**0.344**	**0.203**	**0.152**	**1.13**	**514**

[a] To calculate emissions factor for each pollutant in grams per kilowatt hour (g/kWh), multiply the total emissions of each pollutant by 10^6 to convert from metric tons (MT) to grams (g); then, multiply net generation by 10^3 to convert from megawatt hours (MWh) to kilowatt hours (kWh); finally, divide total emissions (g) by total net generation (kWh).

In the case of many electricity grids it is difficult to predict which facilities will be used to meet electricity demand increases associated with shore power. In such instances it is possible to consider generation within the entire grid region that the port is in. A regional approach, described next, thus captures the range of possible electricity generation sources and estimates grid-level emissions factors from the average annual emissions and electricity generation of those facilities.

EPA Emissions & Generation Resource Integrated Database (eGRID[30])

EPA's eGRID is a comprehensive database detailing the environmental characteristics of electricity generated in the U.S. Characteristics include total annual air emissions, as well as emissions rates, net generation, and generation type system mix. These data are provided at the level of each generation facility and are aggregated up to the state, subregional, regional, and national levels. Regional emissions factor estimates from eGRID can be used when individual facility responses to shore power are unknown; however, eGRID does not provide emissions factor estimates for all criteria pollutants, omitting PM and CO. Methodology for estimating PM

30 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 http://www.epa.gov/cleanenergy/energy-resources/egrid/.

and CO emissions, where emission factors are known but not included in eGRID, is shown in Appendix B. Table 21 shows emission rates for the coastal and Great Lakes subregions shown in Figure 2.

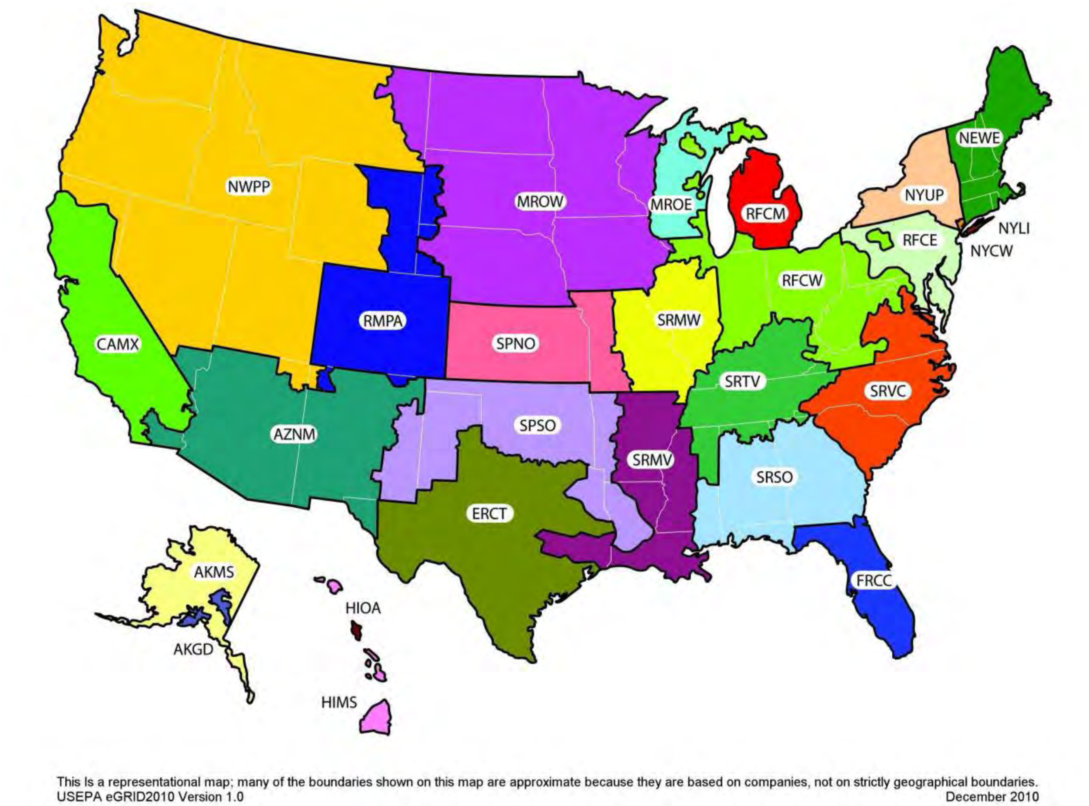

Figure 2. U.S. EPA eGRID subregions in 2010.

Table 21. 2010 eGRID Annual Emissions Rates for Coastal Subregions.

Coastal and Great Lakes Subregion		**Annual Region Emissions Rate (g/kWh)**					
eGRID Subregion	**Subregion Name**	**NO_X**	**SO_2**	**CO_2**	**CH_4**	**N_2O**	**CO_2eq**
AKGD	ASCC Alaska Grid	1.15	0.21	570.12	0.012	0.003	571.37
AKMS	ASCC Miscellaneous	2.69	0.08	203.47	0.009	0.002	204.17
CAMX	WECC California	0.18	0.08	277.07	0.013	0.003	278.18
ERCT	ERCOT All	0.30	1.02	552.56	0.008	0.006	554.70
FRCC	FRCC All	0.32	0.64	542.83	0.018	0.006	545.13
HIMS	HICC Miscellaneous	2.54	1.71	603.36	0.034	0.006	606.02
HIOA	HICC Oahu	1.13	1.82	735.68	0.045	0.010	739.78
MROE	MRO East	0.63	2.37	730.66	0.011	0.012	734.76
MROW	MRO West	0.90	1.72	696.89	0.013	0.012	700.86
NEWE	NPCC New England	0.24	0.64	327.53	0.033	0.006	330.04
NWPP	WECC Northwest	0.46	0.46	382.19	0.007	0.006	384.19
NYCW	NPCC NYC/Westchester	0.12	0.04	282.33	0.011	0.001	282.95
NYLI	NPCC Long Island	0.43	0.25	606.06	0.037	0.005	608.28
RFCE	RFC East	0.39	0.97	454.38	0.012	0.007	456.79

eGRID Subregion	Subregion Name	NO_X	SO_2	CO_2	CH_4	N_2O	CO_2eq
RFCM	RFC Michigan	0.76	2.38	739.09	0.014	0.012	743.15
RFCW	RFC West	0.63	2.26	681.97	0.008	0.011	685.63
SRMV	SERC Mississippi Valley	0.61	0.66	467.13	0.009	0.005	468.83
SRSO	SERC South	0.51	1.62	614.22	0.010	0.009	617.37
SRVC	SERC Virginia/Carolina	0.36	0.92	487.01	0.010	0.008	489.69

4.2.4 Equations

The equation to estimate annual vessel emissions when using auxiliary power when hotelling is as follows:

$$VE_{i,j,k} = P_j * LF_j * \frac{C_{j,k}}{yr} * \frac{T_{j,k}}{call} * VEF_{i,j,k}$$

Where:

$VE_{i,j,k}$ = Vessel emissions for pollutant *i*, for vessel *j*, in year *k*
P_j = Total engine power in kW for vessel *j*
LF_j = Hotelling load factor in percent of total engine power for vessel *j*
$C_{j,k}$ = Vessel calls for vessel *j* in year *k*
$T_{j,k}$ = Hotelling hours at berth for vessel *j* in year *k*
$VEF_{i,j,k}$ = Vessel emissions factor for pollutant *i*, for vessel *j*, in year *k*

The equation to estimate annual shore power emissions when hotelling is as follows:

$$SPE_{i,j,k} = P_j * LF_j * \frac{C_{j,k}}{yr} * \frac{T_{j,k}}{call} * SEF_{i,k}$$

Where:

$SPE_{i,j,k}$ = Shore power emissions for pollutant *i*, for vessel *j*, in year *k*
P_j = Total engine power in kW for vessel *j*
LF_j = Hotelling load factor in percent of total engine power for vessel *j*
$C_{j,k}$ = Vessel calls for vessel *j* in year *k*
$T_{j,k}$ = Hotelling hours at berth for vessel *j* in year *k*
$SEF_{i,k}$ = Shore power emissions factor for pollutant *i* in year *k*

An example shorepower emissions calculation, using values employed by Corbett and Comer from the Port of Charleston, is shown in Appendix B.

5.0 RECOMMENDED PRELIMINARY APPROACH AND METHODOLOGY FOR COMPARING SHORE POWER AND VESSEL EMISSIONS

Developing a robust approach for calculating emissions reductions from switching off auxiliary engines and using shore power systems requires a methodology that is flexible. This is because potential emissions reductions from shore power will depend on a number of local and regional factors. These include, among other things, the operating characteristics of the vessels that will use shore power, the types of fuels they burn, and the current and future electric energy source mix of the shore-side electricity generation portfolio. Thus, the approach for calculating emissions reductions from shore power must be able to incorporate changes to vessel characteristics; marine fuel characteristics; ship-side and shore-side emissions control technologies; and shore-side electricity generation fuel mix, among others. While many of the model input assumptions provided by the user will be relatively certain (e.g., the number of port calls expected over a given timeframe, the average hotelling time), others may be less certain and the Emissions Calculator provides average fleet-wide estimates (e.g., auxiliary engine power, auxiliary engine load factor, shore-side electric power emissions).

This section describes recommended inputs; data and assumptions; equations; and outputs that can be used to calculate emissions reductions from switching off auxiliary engines and using shore power systems. These recommendations are based on a review of the existing approaches, methods, and tools described in Section 4. Step-by-step instructions to quantify emission reductions using the recommended approach are provided using the emissions calculator in Appendix B.

5.1 Inputs

An approach for calculating emissions reductions from shore power compared to operating auxiliary engines will likely include the following inputs:

- Vessel inputs:
    - Installed main engine power (kW)
    - Auxiliary engine fraction of installed main engine power (%)
    - Auxiliary engine load factor at berth, or "hotelling" (%)
    - Auxiliary engine emissions factors (g/kWh)
- Activity inputs:
    - Vessel port calls per year
    - Hotelling hours per port call
- Shore power inputs:
    - Electricity generation by facility contributing to the shore power system (MWh)
    - Emissions by facility contributing to shore power system (e.g., metric tons of SO_2, NO_x, PM_{10}, $PM_{2.5}$, CO, CO_2)
    - Shore power emissions factors (quotient of total emissions and total electricity generation)

5.2 Data and Assumptions

For each model (equation) input, one will need to enter a value. Some assumptions will need to be made, and some assumptions will be more certain than others. In some cases it may be appropriate to use a range of estimates. Keep in mind that the value of each assumption may change depending on the timeframe being modeled. If the analysis is retrospective, one can use actual recorded data for some model (equation) inputs (e.g., vessel calls for a particular year); however, some inputs (e.g., vessel emissions factors) will still need to be estimated. If the analysis is prospective, one will need to make assumptions for all model inputs based on trends in previous data for the study area or published literature. The model presented here does not currently incorporate vessel efficiency improvements for vessels built after 1 January 2013 as specified by the IMO's Energy Efficiency Design Index (EEDI). EEDI regulations require a minimum energy efficiency level for CMVs. Using the emissions calculator presented here, the user may specify improvements in vessel efficiency for EEDI vessels, such as lower emission factors for greenhouse gases. Users may need to estimate growth rates for particular variables, as CARB (2007) did for growth in vessel activity in California ports (Table 12) for prospective or predictive analyses. This section outlines where one can find defensible data and assumptions for each input.

5.2.1 Vessel Inputs

5.2.1.1 Installed main engine power

Installed main engine power is often needed because installed auxiliary engine power is typically not publicly available. As a result, auxiliary engine power is commonly estimated as a fraction of main engine power, which is publicly available.

If one knows the specific vessels that have called or will call on the port for which the analysis of potential emissions reductions from shore power analysis will occur, one can usually find the vessel's name and IMO number.[31] The name may be enough information to look up the vessel's installed main engine power online. Many companies list the specifications of their vessels, 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 vessel registry databases (subscription needed). Additionally, there are websites where one can search for vessel characteristics, such as installed main engine power, by name or IMO number. For ships that operate on the Great Lakes, for example, installed main engine power is available through Greenwood's Guide to Great Lakes Shipping.[32] EPA is also developing a methodology for generating ocean-going vessel emission inventories, which will aid ports in independently constructing their own inventories.

5.2.1.2 Auxiliary engine fraction of installed main engine power

Some vessels may report auxiliary engine power in Lloyd's PC Register of Ships. Alternatively, one may be able to access detailed auxiliary engine data from the vessel owner/operator. However, in many cases one has to estimate the total installed power for auxiliary engines by assuming it is some fraction of installed main engine power. This fraction varies depending on the vessel type. The EPA (2009) and others who incorporate CARB methodologies in their work (e.g., Corbett and Comer, 2013) have used data from Starcrest's Vessel Boarding Program to estimate the auxiliary engine fraction of installed main engine power. Therefore, if auxiliary engine power is not readily available, the estimated auxiliary engine fraction of installed main engine power found in EPA (2009) and summarized in Table 9, should be used to estimate installed auxiliary engine power.

---

31 The US Corps of Engineers maintains Entrance and Clearance vessel data for most major ports: http://www.navigationdatacenter.us/data/dataclen.htm.

32 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/.

5.2.1.3 Auxiliary engine load factor at berth

Vessels operate their auxiliary engines when at berth (hotelling) to generate electric power needed to run ancillary equipment and provide heating, cooling, refrigeration, and so forth. 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.” This load factor almost always needs to be assumed, as vessels do not routinely report auxiliary engine load factor. The EPA (2009) and others who incorporate CARB methodology into their analyses (e.g., Corbett and Comer, 2013) have primarily used 2005 ARB Ocean Going Vessel Survey to estimate vessel-type-specific auxiliary engine load factors. CARB also used auxiliary engine load factors from ENVIRON, Starcrest’s vessel boarding program, and Lloyd’s-Fairplay. The auxiliary engine load factors while hotelling from EPA (2009), as found in Table 9, provide reasonable values for inputs to a model to estimate emissions reductions from shore power.

5.2.1.4 Auxiliary engine emissions factors

Auxiliary engine emissions factors are critically important to estimating the amount of air emissions from hotelling when ships are operating their onboard auxiliary engines (as opposed to alternative power sources, such as shore power). CARB (2007, 2011) and others (Corbett and Comer, 2013; EPA, 2009) have based their auxiliary emissions factors on a study by Entec (2002). These emissions factors, as summarized in Table 22, provide representative fuel type-specific auxiliary engine emissions factors. For most estimates, the emissions factors listed next to MDO (0.1% S) should be used. Note that the emission factors shown in Table 22 should be applied to vessels built prior to 2011. Vessels built on or after 1 January 2011 should use the NO_x emission factors for Tier II and Tier III vessels described below.

Table 22. Auxiliary engine emissions factors for medium speed engines (g/kWh), as found in CARB (2011).

Fuel	CH_4	CO	CO_2	NO_x	PM_{10}	$PM_{2.5}$	SO_x
MDO (0.1% S)	0.09	1.10	690	13.9	0.25	0.23	0.40
MDO (0.5% S)	0.09	1.10	690	13.9	0.38	0.35	2.10
HFO	0.09	1.10	722	14.7	1.50	1.46	11.10

Vessels operating within the North American ECA will be required to operate on fuel with a maximum S content of 0.1% as of 1 January 2015, per MARPOL Annex VI Regulation 14. Additionally, under MARPOL Annex VI Regulation 13, Tier II 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 1 January 2011. Moreover, Tier III standards require an 80% reduction from Tier I NO_x standards for vessels built on or after 1 January 2016 and operating within an ECA. Thus, if the vessels that are calling on the port(s) being studied are newer builds, their emissions 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)

5.2.2 *Activity Inputs*

5.2.2.1 Vessel port calls per year

Historical data on vessel port calls per year can be used in an analysis of the potential emissions reduction benefits of shore power. One will want to obtain, at a minimum, estimated annual port calls by vessel type (e.g., container, passenger, reefer, etc.). Some of the larger ports will have these data on hand. Additionally, the USACE maintains a publicly available database of entrances and clearances for foreign vessel traffic for major U.S. ports.[33] However, many domestic port calls, which typically make up only a small percent of total calls, will be absent from this database. The best way to estimate annual vessel port calls will vary depending on the port that is being analyzed.

5.2.2.2 Hotelling hours per port call

Average hotelling hours per port call by vessel type is important in order to estimate power demand for at-berth vessels. CARB (2007) used Wharfinger data in their analysis. Wharfinger data are desirable because they represent observed hotelling times, reducing uncertainty in estimating this variable. Average hotelling hours may also be obtained by previously conducted emissions inventories for the port being analyzed or for a similar port. Finally, Automatic Identification System (AIS)[34] data, available from the U.S. Coast Guard and private companies, could be used to track vessel movements to estimate hotelling times. For instance, when a vessel arrives at a port terminal its speed will reduce to zero and when the vessel leaves the terminal, its speed will become non-zero. The difference in the two time stamps from when the vessel arrived at berth and stopped moving (when its speed became zero) until its departure (when its speed became non-zero) would equal the hotelling time. This approach would not account for the time it takes to connect the vessel to shore power while it is at berth; however, one may be able to estimate that connection time and subtract it from the shore power hotelling time.

5.2.3 *Shore Power Inputs*

5.2.3.1 Electricity generation by facility

One ought to be able to identify the utility that services the port. From there, one can determine the names of the generating facilities. Historical data on electricity generation by facility can be obtained from the U.S. EIA and EPA's eGRID. Previous years' electricity generation by facility can be used to estimate the current or future year generation. One could also include an adjustment for transmission losses to reflect the additional electricity that would need to be generated to meet shore power demand. For instance, if shore power demand was 10,000 MWh and transmission losses were estimated at 6%, the grid would need to generate approximately 10,640 MWh of energy to meet demand (Power Demand / (1 - transmission losses)). An estimate of annual electricity generation by facility is important because the next step is to determine air pollutant emissions from each facility. Together, this information is used to derive shore power

---

[33] USACE U.S. waterway entrances and clearances data can be found at their Navigation Data Center website: http://www.navigationdatacenter.us/data/dataclen.htm.

[34] http://www.navcen.uscg.gov/?pageName=aismain

emissions factors. Of course, if available, aggregate electricity generation estimates for the utility that services the port would suffice, provided aggregate emissions could also be obtained.

5.2.3.2 Emissions by facility

Historical air pollutant emissions by electricity generating facility can usually be obtained from the state agency responsible for regulating air pollution and/or protecting human health or for select years using eGRID (although eGRID omits emissions factors for some pollutants such as PM and CO). State air quality agencies may collect these data as part of their Clean Air Act State Implementation Plan, or as part of their submission to EPA's National Emissions Inventory. One can contact the appropriate state air quality agency for additional information. If these data are not readily available (e.g., already reported on a website), one can request the relevant information from the agency.[35]

Emissions by facility and electricity generation by facility are used to estimate shore power emissions factors. Specifically, one divides the mass of total emissions of a pollutant from all facilities that provide power to the utility by the total amount of electricity generated by all of those facilities in a given year to estimate the emissions factor for that pollutant. Table 20 and the footnote below it gives an example of estimating emissions factors from shore power. Again, if one has aggregate electricity generation estimates and aggregate air pollutant emissions from those same sources, that information can also be used to estimate shore power emissions factors.

5.3 <u>Equations</u>

Based on CARB's (2007) basic equation and the equation used in Corbett and Comer (2013), some form of the following equations can be used to estimate annual vessel emissions when using auxiliary power when hotelling as shown in Sections 5.3.1 and 5.3.2 below.

5.3.1 Vessel Emissions When Operating Auxiliary Engines

The equation to estimate annual vessel emissions when using auxiliary power when hotelling is as follows:

$$VE_{i,j,k} = MEP_j * AEF_j * LF_j * \frac{C_{j,k}}{yr} * \frac{T_{j,k}}{call} * VEF_{i,j,k}$$

Where:

$VE_{i,j,k}$ = Vessel emissions for pollutant *i*, for vessel type *j*, in year *k*
MEP_j = Average main engine power, in kW, for vessel type *j*
AEF_j = Fraction of main engine power attributable to auxiliary engine power, in kW, for vessel type *j*
LF_j = Auxiliary engine hotelling load factor, in percent, for vessel type *j*
$C_{j,k}$ = Vessel calls for vessel type *j* in year *k*
$T_{j,k}$ = Hotelling hours at berth for vessel type *j* in year *k*
$VEF_{i,j,k}$ = Vessel type emissions factor for pollutant *i*, for vessel type *j*, in year *k*

[35] These data are now available on many government websites. If necessary, one may consider consulting Freedom of Information Act requirements for the relevant state(s) for additional access options.

5.3.2 Shore Power Emissions

The equation to estimate annual shore power emissions when hotelling is as follows:

$$SPE_{i,j,k} = MEP_j * AEF_j * LF_j * \frac{C_{j,k}}{yr} * \frac{T_{j,k}}{call} * SEF_{i,k}$$

Where:

$SPE_{i,j,k}$ = Shore power emissions for pollutant *i*, for vessel type *j*, in year *k*
MEP_j = Average main engine power, in kW, for vessel type *j*
AEF_j = Fraction of main engine power attributable to auxiliary engine power, in kW, for vessel type *j*
LF_j = Auxiliary engine hotelling load factor, in percent, for vessel type *j*
$C_{j,k}$ = Vessel calls for vessel type *j* in year *k*
$T_{j,k}$ = Hotelling hours at berth for vessel type *j* in year *k*
$SEF_{i,k}$ = Shore power emissions factor for pollutant *i* in year *k*

Alternatively, one may be able to obtain actual annual shore power demand from the port, if available. In that case, one can simply multiply shore power energy demand by $SEF_{i,k.}$ to estimate shore power emissions for each pollutant in a given year.

5.4 Outputs

The outputs of an approach or methodology to calculate emissions reductions from switching off auxiliary engines and using shore power systems will need to compare actual or estimated emissions with and without shore power. An example of this comparison can be found in Corbett and Comer (2013). Typically, emissions of pollutants that are linked to negative human health effects and climate change are reported. One may consider reporting on the differences in emissions of NO_x, SO_x, PM_{10}, $PM_{2.5}$, CO_2, CO, and HC.

In evaluating the benefits of a shore power project, it may also be important to consider the proximity of local communities to the vessel terminal and to the electrical generating plants. For example, if the terminal is located adjacent or near a residential area, then the benefits of shore power from reducing nearby population exposure would be greater.

5.4.1 Outputs

Corbett and Comer (2013) report SPADE model outputs that compare the air pollution emissions from operating a 2,000-passenger cruise vessel on shore power as compared to diesel auxiliary power under various years and fuel S content (Table 23). They report similar results for a 2,000-passenger and 3,500-passenger cruise vessel for the year 2019 (Table 24). Note that shore power emissions decline by 2019 (Table 24), compared to 2013 and 2015 (Table 23). This is due to a shift away from coal to natural gas, nuclear, and scrubbed coal-fired plants in response to EPA's Mercury Air Toxic Standards. As a result, shore power emissions for SO_2 and other pollutants are well below vessel power emissions in 2019.

Table 23. Potential 2013 emissions (metric tons) generated by the 2,000-passenger cruise vessel while at berth using shore power compared with onboard engines operating on 1%, 0.5%, and 0.1% S fuel, respectively, in Corbett and Comer (2013).

	Shore Power	2013 (1% S fuel)	2013 (0.5% S fuel)	2015 (0.1% S fuel)
CO	0.40	5.06	5.06	5.06
NO_x	1.58	63.9	63.9	63.9
PM_{10}	0.93	2.25	1.75	1.15
$PM_{2.5}$	0.70	2.07	1.61	1.06
SO_2	5.18	19.5	9.75	1.95
CO_2	2,362	3,171	3,171	3,171

Table 24. Potential 2019 emissions (metric tons) generated by a 2,000 passenger cruise vessel and a 3,500 passenger cruise vessel while at berth using shore power compared with using onboard engines operating on 0.1% S fuel, in Corbett and Comer (2013).

	2,000 Passenger		3,500 Passenger	
	Shore Power	Vessel Power	Shore Power	Vessel Power
CO	0.16	5.06	0.24	7.58
NO_x	0.80	63.9	1.20	95.8
PM_{10}	0.48	1.15	0.72	1.72
$PM_{2.5}$	0.30	1.06	0.46	1.58
SO_2	1.36	1.95	2.04	2.92
CO_2	2,033	3,171	3,049	4,755

6.0 CONCLUSIONS

This report has characterized the technical and operational aspects of shore power systems in the U.S., summarized certain aspects of studies that looked at shore side power, and developed an approach for comparing shore power and vessel emissions while at berth.

This approach is flexible enough to be applied to nearly any port in the U.S. and, indeed, around the world, provided the necessary inputs can be obtained. This report advises how one can observe or estimate these inputs. This approach can be used to estimate how harmful air pollution emissions may be reduced at U.S. ports through the use of shore power systems and would allow the analysis of potential human health and environmental benefits.

Finally, this report describes some of the barriers to the adoption of shore side power. The existence of such barriers for particular programs would need to be addressed as part of a shore side power program. 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 bunker fuels to shore-side electricity, it may be cheaper to operate auxiliary engines rather than connect to shore power. Additionally, fleets must have the necessary vessel-side infrastructure to connect to shore power systems, requiring a substantial investment. These barriers can be overcome by further research into ways of implementing or incentivizing the use of shore power or advanced emissions reduction technologies. Further, harmonized standards for OPS installations can reduce uncertainty for fleet owners and operators in deciding what vessel-side infrastructure in which to invest to enable them to connect to shore power.

REFERENCES

American Shipper. (2014). *Shore power disruptor?* Retrieved from http://www.americanshipper.com/Main/News/Shore_power_disruptor_57985.aspx - hide

CARB. (2007). *Technical support document: Initial statment 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.

CARB. (2011). *Initial statement of reasons for proposed rulemaking - Proposed amendments to the regulations "fuel sulfur and other operational requirements for ocean-going vessels within California waters and 24 nautical miles of the California baseline"*. Sacramento, CA: California Air Resources Board. Retrieved from http://www.arb.ca.gov/regact/2011/ogv11/ogv11.htm.

Chang, C.-C., & Wang, C.-M. (2012). Evaluating the effects of green port policy: Case study of Kaohsiung harbor in Taiwan. *Transportation Research Part D: Transport and Environment, 17*(3), 185-189.

CLAA (2015) *Cruise line agencies of Alaska: Cruise ship calendar for 2015, Juneau.* Retrieved from http://claalaska.com/wp-content/uploads/2014/07/Juneau-JNU-2015.pdf

Cochran Marine. (2015). *Cochran Marine: Our experience.* Retrieved from http://www.cochranmarine.com/our-experience/

Corbett, J. J., & Comer, B. (2013). *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. Retrieved from http://coastalconservationleague.org/wp-content/uploads/2010/01/EERA-Charleston-Shoreside-Power-Report-.pdf.

Entec. (2002). *Quantification of emissions from ships associated with ship movements between ports in the European community*. Brussels: European Commission. Retrieved from http://ec.europa.eu/environment/air/pdf/chapter2_ship_emissions.pdf.

ENVIRON. (2004). *Cold ironing cost effectiveness study: Volume I report*. Los Angeles: ENVIRON. Retrieved from http://www.polb.com/civica/filebank/blobdload.asp?BlobID=7718.

ENVIRON. (2013). *Port of Oakland 2012 seaport air emissions inventory.* Prepared for Port of Oakland. Retrieved from http://www.portofoakland.com/pdf/environment/maqip_emissions_inventory.pdf

ENVIRON. (2015a). *Port of San Francisco seaport air emissions inventory 2013*. Prepared for Port of San Francisco. Retrieved from http://www.sfport.com/modules/showdocument.aspx?documentid=9576

ENVIRON. (2015b). *Port of San Diego 2012 maritime air emissions inventory.* Prepared for San Diego Unified Port District. Retrieved from https://www.portofsandiego.org/bpc-policies/doc_view/6325-2012-maritime-air-emissions-inventory-report.html

EPA. (2009). *Proposal to designate an Emission Control Area for nitrogen oxides, sulfur oxides and particulate matter: Technical support document*. (EPA-420-R-09-007). Washington,

DC: U.S. Environmental Protection Agency. Retrieved from http://www.epa.gov/nonroad/marine/ci/420r09007.pdf.
Foss. (2011). *Campbell Foss Hybrid Marine Power System functional specification.* Retrieved from http://www.arb.ca.gov/msprog/aqip/demo/demo%20final%20reports/campbell_foss_hybrid_final_report_052913.pdf
Hall, W. J. (2010). Assessment of CO_2 and priority pollutant reduction by installation of shoreside power. *Resources, Conservation and Recycling, 54*(7), 462-467.
ICF. (2009). *Tug/towboat emission reduction feasibility study: Draft final report.* Prepared for U.S. EPA.
Juneau. (2011). *Juneau cruise ship docks electrical systems: Conceptual design.* Retrieved from http://www.juneau.org/harbors/documents/conceptualdesign-electricalsystems022211.pdf
Port of Hueneme. (2015). Port of Hueneme: Vessel Schedule. Retrieved from http://www.portofhueneme.org/vesselschedule/
POLA. (2014). *Comprehensive annual financial report for the fiscal year ended June 30, 2014.* Retrieved from http://www.portoflosangeles.org/Publications/Financial_Statement_2014.pdf
Port of Seattle. (2015). *Cruise Seattle: 2015 sailing schedule.* Retrieved from https://www.portseattle.org/Cruise/Documents/2015_cruise_schedule.pdf
Starcrest. (2013). *2011 Puget Sound maritime air emissions inventory (May 2013 update).* Prepared for Puget Sound Maritime Air Forum. Retrieved from http://www.pugetsoundmaritimeairforum.org/uploads/PV_FINAL_POT_2011_PSEI_Report_Update__23_May_13__scg.pdf
Starcrest. (2014a). *Port of Long Beach air emissions inventory - 2013.* Prepared for Port of Long Beach. Retrieved from http://www.polb.com/environment/air/emissions.asp
Starcrest. (2014b). *2012 Multi-facility emissions inventory of cargo handling equipment, heavy-duty diesel vehicles, railroad locomotives, and commercial marine vessels.* Prepared for the Port Authority of New York and New Jersey. Retrieved from https://www.panynj.gov/about/pdf/panynj-multi-facility-ei-report_2012.pdf
Starcrest. (2014c). *Inventory of air emissions for calendar year 2013: Technical report ADP# 131016-541. Prepared for the Port of Los Angeles.* Retrieved from https://portoflosangeles.org/pdf/2013_Air_Emissions_Inventory_Full_Report.pdf
Sciberras, E. A., Zahawi, B., Atkinson, D. J., Juandó, A., & Sarasquete, A. (2014). Cold ironing and onshore generation for airborne emission reductions in ports. *Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment*. doi: 10.1177/1475090214532451
U.S. Navy. (2015). *iENCON: Incentivized Shipboard Energy Conservation.* Retrieved from http://www.i-encon.com/reference.htm
Yorke Engineering. (2007). *Port of San Diego: Cold ironing study*. Prepared for the Port of San Diego. Retrieved from https://www.portofsandiego.org/component/docman/doc_download/672-shore-power-cold-ironing-study.html.

Appendix A: SUMMARY OF 13 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 spent approximately $5.5 million to construct the shore-side facilities and to retrofit the vessels (about $500,000 each). Princess 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 POLA (DERA 09-10) $23.73 million in Proposition 1B funding from the state of California for development of shore power at 10 berths	The Port 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 http://www.epa.gov/cleandiesel/projects-national.htm Proposition 1B: http://www.aqmd.gov/home/programs/business/goods-movement-ships-at-berth
Seattle	$1.49 million ARRA (2009) grant 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% annually. 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 http://www.pugetsoundmaritimeairforum.org/uploads/PV_FINAL_POT_2011_PSEI_Report_Update__23_May_13__scg.pdf EPA Grant: http://www.epa.gov/cleandiesel/projects-national.htm

Port Name	***Economic Costs and Benefits***	***Environmental Costs and Benefits (if quantified)***	***Source Link***
San Diego	Smaller ships visit San Diego (SD) ports and electricity rates are higher than POLA. Cost effectiveness for cruise ships is $23,500/ton NO_x and for Dole (reefer) Vessels $13,700/ton NO_x. 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 California ARB Carl Moyer grant in 2010 for shore power at the Cruise Ship Terminal		Port of San Diego: Cold Ironing Study May 2007 Port of San Diego 2012 Maritime Air Emissions Inventory Report https://www.portofsandiego.org/bpc-policies/doc_view/6325-2012-maritime-air-emissions-inventory-report.html
San Francisco	Electrical energy supply costs are a significant consideration in the feasibility of shore-side 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 shore-side power while at port than shipboard generated electrical power. The “break-even” point for this portion of the cost is $0.05-0.10/kW-hr. The port of San Francisco was awarded a $1 million grant from EPA to support OPS installation $1.9 million California ARB Carl Moyer grant (year 8/9 funding) for Cruise Ship shore-side power installation	Use of shore power leads to 60-80% estimated reduction in emissions according to ENVIRON’s 2005 Shoreside Power Feasibility Study for Cruise Ships Berthed at Port of San Francisco.	http://www.sf-port.org/ftp/uploadedfiles/community_meetings/CTEAC/info/ENVIRON_Final_Report_091305_main%20body_Rev.pdf EPA grant: http://www.epa.gov/region9/mediacenter/posf-dera/SF-Port-Shore-Power.pdf Carl Moyer Grant: http://www.baaqmd.gov/Divisions/Strategic-Incentives/Funding-Sources/Carl-Moyer-Program.aspx
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 at $16,000/ton.	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. Drops to 1,500,000 kWh for new builds to be cost-effective.	http://www.polb.com/civica/filebank/blobdload.asp?BlobID=7718

Port Name	*Economic Costs and Benefits*	*Environmental Costs and Benefits (if quantified)*	*Source Link*
	$30 million in Proposition 1B funding from the state of California for shore power development at 12 berths ($2.5/berth)		
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".	http://www.martrans.org/docs/theses/papoutsoglou.pdf Grants: http://www.portofoakland.com/pdf/newsroom/pressrel_319.pdf
Hueneme	ARB 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 Hueneme and POLA have lower electricity rates than 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 Hueneme to POLA and Port of San Diego, ARB indicates that the average cost-effective values for Hueneme are the lowest, followed by San Diego, then POLA, 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 (six visits or more) than the other two ports. Conversely, POLA has the highest average installations. At 2MW load, both Hueneme and San Diego are more cost-effective than container ships using OPS at POLA/POLB.	http://www.arb.ca.gov/ports/marinevess/documents/coldironing0306/appi.pdf EPA Grant: http://www2.epa.gov/ports-initiative/funding-projects-improve-air-quality-ports
Boston	Mixed opinion about use of shore power for tug and push boats. The general consensus is that it 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 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 EPA Grant: http://www.epa.gov/cleandiesel/projects-national.htm

Port Name	***Economic Costs and Benefits***	***Environmental Costs and Benefits (if quantified)***	***Source Link***
Brooklyn	August (2011) PA/NY/NJ 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; New York City Economic Development Corporation will cover the difference in costs.	Expected annual emission reductions: 6.5 tons of PM 95.3 tons of NO_x 1,487 tons of GHGs	EPA grants provided under American Reinvestment and Recovery Act (ARRA) of 2009 National Clean Diesel Funding Assistance Program http://www.epa.gov/cleandiesel/projects-national.htm https://www.panynj.gov/about/pdf/CAS_Implementation_Report.pdf
New Bedford	The port was awarded $1 million from the EPA, and $540,000 from the Federal Highway Administration's Congestion Mitigation and Air Quality Improvement (CMAQ) program to install OPS at its commercial fishing piers.	~3,000 tons GHG avoided annually Reduced diesel consumption of ~310,000 gallons annually from using shore power Environmental costs could be interesting here with the New Bedford Offshore Wind Power opportunities.	http://www.nbedc.org/why-off-shore-wind/ http://www.southcoasttoday.com/article/20120327/News/203270332 OPS Grants: http://www.epa.gov/region1/superfund/sites/newbedford/509390.pdf
Philadelphia	Tugboat shore power has been implemented at the Port of Philadelphia. Costs were approximately $1 million in capital costs per berth, unknown capital costs per tug. Total costs also affected by the price differential between electricity and bunker fuel.		ICF (2009) Tug/Towboat Emission Reduction Feasibility Study. Draft Final Report
Tacoma	Shore power at Port of Tacoma's TOTE terminal is estimated to reduce diesel particulate emissions by 3.4 tons annually, NO_x emissions by 24.5, CO emissions by 2.1, HC emissions by 0.8 tons, and CO_2 by over 1,360 tons annually.	50 jobs estimated to be created by the shore power project	https://yosemite.epa.gov/oarm/igms_egf.nsf/52f35d81cc937e5e85256fb6006df28e/c80dabb8b2597da185257d6f0071d31f!OpenDocument https://www.westcoastcollaborative.org/files/grants/DERA-ARRA-PortTacomaShorepowerFactSheet.pdf

Port Name	*Economic Costs and Benefits*	*Environmental Costs and Benefits (if quantified)*	*Source Link*
	$1,488,080 DERA ARRA grant from EPA (2011), with $1,101,303 in leveraged matching funds from TOTE and partners		
Other Resources			
ARB Preliminary Report	Preliminary Report (DO NOT CITE)	From ARB Preliminary Report 2006 - DO NOT CITE - If all ships visiting California ports use shore power, emissions would be reduced by 95% from the distillate emissions level. NO_x, PM, and HC emissions reduced by 22, 0.4, and 0.6 tons per day, respectively, based upon 2004 distillate emissions. For all ships visiting California three times per year, emissions would be reduced by 70%. NO_x, PM, and HC emissions would be reduced by 17, 0.4, and 0.5 tons per day, respectively. If ships making six or more visits a year to a California port were cold-ironed, the overall emissions reduced by about 50%.	http://www.arb.ca.gov/ports/marinevess/documents/coldironing0306/execsum.pdf

Appendix B: DEMONSTRATION OF RECOMMENDED PRELIMINARY APPROACH AND METHODOLOGY FOR COMPARING SHORE POWER AND VESSEL EMISSIONS

Step-by-Step Approach to Using the Shore Power Emissions Calculator

The model can calculate emissions in a general form based on generic vessels and the regional grid mix. Additionally, the model user can supply inputs to specify vessel characteristics and generation facilities if known. In addition to the following instructions, a Microsoft Excel® workbook is provided that includes the supporting data in the appendix and an example calculation of the general approach. User input is required in blue cells; model output is shown in grey cells in the Excel® spreadsheet example.

General Model

1. Use the dropdown menu to select the **eGRID Region** (shown in Figure 2 and the *eGRID Region* tab) in which to calculate shore power emissions.
2. Use the dropdown menu to select the **Vessel Type**. Nine vessel types are included, up to 36 individual vessels may be entered.
3. The **Auxiliary engine Size (kW)** and **Load Factor** fields will populate automatically.
4. Enter the **Number of Annual Vessel Calls** for each **Vessel Type** entered. Note that the model assumes a single vessel for each vessel type selected.
5. Enter the average number of hotelling hours per vessel call.
6. **Annual Energy Consumption (kWh)**, **Vessel Power Emissions (MT)**, **Shore Power Emissions (MT)**, and **Difference (MT)** outputs are now available in the grey cells. NOTE: The General Model assumes 6% power transmission losses and does not estimate PM_{10}, $PM_{2.5}$, or CO emissions.

User Input Model

1. Use the dropdown menu to select the **eGRID Region** (shown in Figure 2 and the *eGRID Region* tab) in which to calculate shore power emissions. The user may additionally specify an grid emissions mix in the *eGrid Region* tab, in the USER ENTRY row, and select USER ENTRY in the **eGRID Region** cell dropdown. Users may also specify **PM_{10}**, **$PM_{2.5}$**, and **CO** emission factors in the USER ENTRY row. PM_{10}, $PM_{2.5}$, and CO emissions <u>will not be estimated</u> unless specified here.
2. Emissions may also be calculated for a specific facility, using the dropdown menu for **Generation Facility**. The full list of generation facilities provided in eGRID2012 is available in the *PLNT12* tab. NOTE: Leave the eGRID region column blank, if an eGRID Region is specified, the model will not calculate emissions from a specific generation facility
3. Use the dropdown to select the vessel type. NOTE: **Auxiliary Engine Size (kw)** and **Load Factor** do not automatically populate in the User Input Model
4. Specify the **Vessel Fuel** mix. MDO 0.1% Sulphur, MDO 0.5% Sulphur, and HFO are available. Additionally, the user may specify their own auxiliary engine emission factors in the *Vessel Fuel Emission Factors* tab, and selecting USER ENTRY in the **Vessel Fuel** cell dropdown
5. Enter the vessel **Auxiliary Engine Size (kW)**
6. Enter the vessel **Load Factor** (Decimal value between 0 and 1, inclusive)

7. Enter the **Number of Annual Vessel Calls**
8. Enter the **Avg. Hotel Hours/Vessel Call**
9. Enter the percent **Transmission Losses** (Decimal value between 0 and 1. i.e. 6% transmission losses would be entered as 0.06)
10. **Annual Energy Consumption (kWh)**, **Vessel Power Emissions (MT)**, **Shore Power Emissions (MT)**, and **Difference (MT)** outputs are now available in the grey cells

We apply the methods outlined in Section 5 to demonstrate how to estimate changes in emissions of CO_2, SO_x, and NO_x associated with switching from bunker fuels at dock to shore power. We present two applications: first we use regional emissions factors from EPA's eGRID using the general model approach; second, we use a combination of plant-specific, eGRID, and user-defined emissions factors using the user input model approach.

Methodology Demonstration: General Model - eGRID Results

Table B-1 compares estimated vessel and shore power emissions for container, cruise, and reefer vessels at a high capacity OPS system. An assumption of 6% transmission losses is included in the calculation to estimate the additional shore power energy supply required to meet vessel power demand.

The largest emissions reductions associated with a switch to shore power were in CO_2, followed by NO_x. Due to the low sulfur content of ECA-compliant MDOs (0.1% S), SO_x emissions were estimated to increase slightly with a switch to shore power in some regions that rely on coal for large portions of their electricity generation portfolio.

Table B-1. Shore power emissions calculator using eGRID regional emissions factors.

Emissions Calculator: High Capacity Shore Power Connection (eGRID)

								Vessel Power Emissions (MT)			Shore Power Emissions (MT)			Difference (MT)		
Example	eGRID Region	Vessel Type	Auxiliary Engine Size (kW)	Load Factor	Number of Annual Vessel Calls	Avg. Hotel Hours/Vessel Call	Annual Energy Consumption (kWh)	NOx	SOx	CO2	NOx	SOx	CO2	NOx	SOx	CO2
Northeast	RFCE	Passenger/Cruise Ship	11000	0.64	26	10	1,947,234	27.07	0.78	1,343.59	0.81	2.00	937.87	-26.26	1.22	-405.72
	RFCE	General Cargo	1776	0.22	15	35	218,221	3.03	0.09	150.57	0.09	0.22	105.10	-2.94	0.14	-45.47
	RFCE	RORO	2850	0.3	20	25	454,787	6.32	0.18	313.80	0.19	0.47	219.05	-6.13	0.29	-94.76
Alaska	AKGD	Container Ship	6800	0.17	40	10	491,915	6.84	0.20	339.42	0.60	0.11	297.28	-6.24	0.09	42.15
	AKGD	Passenger/Cruise Ship	11000	0.64	50	12	4,493,617	62.46	1.80	3,100.60	5.47	0.99	2,715.60	-56.99	0.81	385.00
Florida	FRCC	Passenger/Cruise Ship	11000	0.64	100	10	7,489,362	104.10	3.00	5,167.66	2.57	5.11	4,309.36	-101.53	2.12	858.30
	FRCC	Tanker	1985	0.67	24	20	679,123	9.44	0.27	468.60	0.23	0.46	390.77	-9.21	0.19	77.83
							Sub-Total	**105.72**	**3.04**	**5247.98**	**7.16**	**3.79**	**4274.89**	**-98.56**	**0.75**	**-973.09**

								Percent Change		
Example	eGRID Region	Vessel Type	Auxiliary Engine Size (kW)	Load Factor	Number of Annual Vessel Calls	Avg. Hotel Hours/Vessel Call	Annual Energy Consumption (kWh)	NOx	SOx	CO2
Northeast	RFCE	Passenger/Cruise Ship	11000	0.64	26	10	1,947,234	-97%	157%	-30%
	RFCE	General Cargo	1776	0.22	15	35	218,221	-97%	157%	-30%
	RFCE	RORO	2850	0.3	20	25	454,787	-97%	157%	-30%
Alaska	AKGD	Container Ship	6800	0.17	40	10	491,915	-91%	-45%	-12%
	AKGD	Passenger/Cruise Ship	11000	0.64	50	12	4,493,617	-91%	45%	12%
Florida	FRCC	Passenger/Cruise Ship	11000	0.64	100	10	7,489,362	-98%	71%	17%
	FRCC	Tanker	1985	0.67	24	20	679,123	-98%	71%	17%
							Sub-Total			

Methodology Demonstration: User Input Model Results

Table B-2 shows an example calculation for the Port of Charleston, using values specified by Corbett and Comer (2013). Note that the emissions estimates presented here are slightly higher than those initially estimated by Corbett and Comer as the emissions calculator factors in energy losses in the grid as described in section 5.2.3.1.

Table B-2. Criteria pollutant and CO_2 emissions rates for selected eGRID regions with USER ENTRY specified for the Port of Charleston. USER ENTRY values transferred from Table 20.

Coastal and Great Lakes Subregion		Annual Region Emission Rate (g/kWh)								
eGRID Subregion	**Subregion Name**	**NOx**	**SO2**	**CO2**	**CH4**	**N2O**	**CO2eq**	**PM10**	**PM2.5**	**CO**
AKGD	ASCC Alaska Grid	1.15	0.21	570.12	0.012	0.003	571.37			
AKMS	ASCC Miscellaneous	2.69	0.08	203.47	0.009	0.002	204.17			
				…						
SRTV	SERC Tennessee Valley	0.52	1.49	630.14	0.008	0.010	633.46			
SRVC	SERC Virginia/Carolina	0.36	0.92	487.01	0.010	0.008	489.69			
USER ENTRY	USER ENTRY	0.344	1.13	514				0.203	0.152	0.088

Table B-3. Shore power emissions calculator using facility-specific emissions factors in Table B-2.

Emissions Calculator: High Capacity Shore Power Connection (User Input Model)

eGRID Region	Generation Facility	Vessel Type	Vessel Fuel	Auxiliary Engine Size (kW)	Load Factor	Number of Annual Vessel Calls	Avg. Hotel Hours/Vessel Call	Transmission Losses	Annual Energy Consumption (kWh)
USER ENTRY		2000 Passenger	MDO (0.1% S)	6758	1	68	10	0.06	4,888,766
USER ENTRY		3000 Passenger	MDO (0.1% S)	10134	1	68	10	0.06	7,330,979

	Vessel Power Emissions (MT)						Shore Power Emissions (MT)						Difference (MT)						Percent Difference					
Vessel Type	**NOx**	**SOx**	**CO2**	**PM10**	**PM2.5**	**CO**	**NOx**	**SOx**	**CO2**	**PM10**	**PM2.5**	**CO**	**NOx**	**SOx**	**CO2**	**PM10**	**PM2.5**	**CO**	**NOx**	**SOx**	**CO2**	**PM10**	**PM2.5**	**CO**
2000 Passenger	67.95	1.96	3,373.25	1.22	1.12	5.38	1.78	5.86	2,663.60	1.05	0.79	0.46	-66.17	3.90	-709.65	-0.17	-0.34	-4.92	-97%	199%	-21%	-14%	-30%	-92%
3000 Passenger	101.90	2.93	5,058.38	1.83	1.69	8.06	2.67	8.78	3,994.21	1.58	1.18	0.68	-99.23	5.85	-1064.16	-0.26	-0.50	-7.38	-97%	199%	-21%	-14%	-30%	-92%
Subtotal	**169.85**	**4.89**	**8431.62**	**3.05**	**2.81**	**13.44**	**4.46**	**14.64**	**6657.81**	**2.63**	**1.97**	**1.14**	**-165.40**	**9.75**	**-1773.82**	**-0.43**	**-0.84**	**-12.30**						

Appendix C: LOCATIONS OF SHORE POWER INSTALLATIONS AT U.S. PORTS

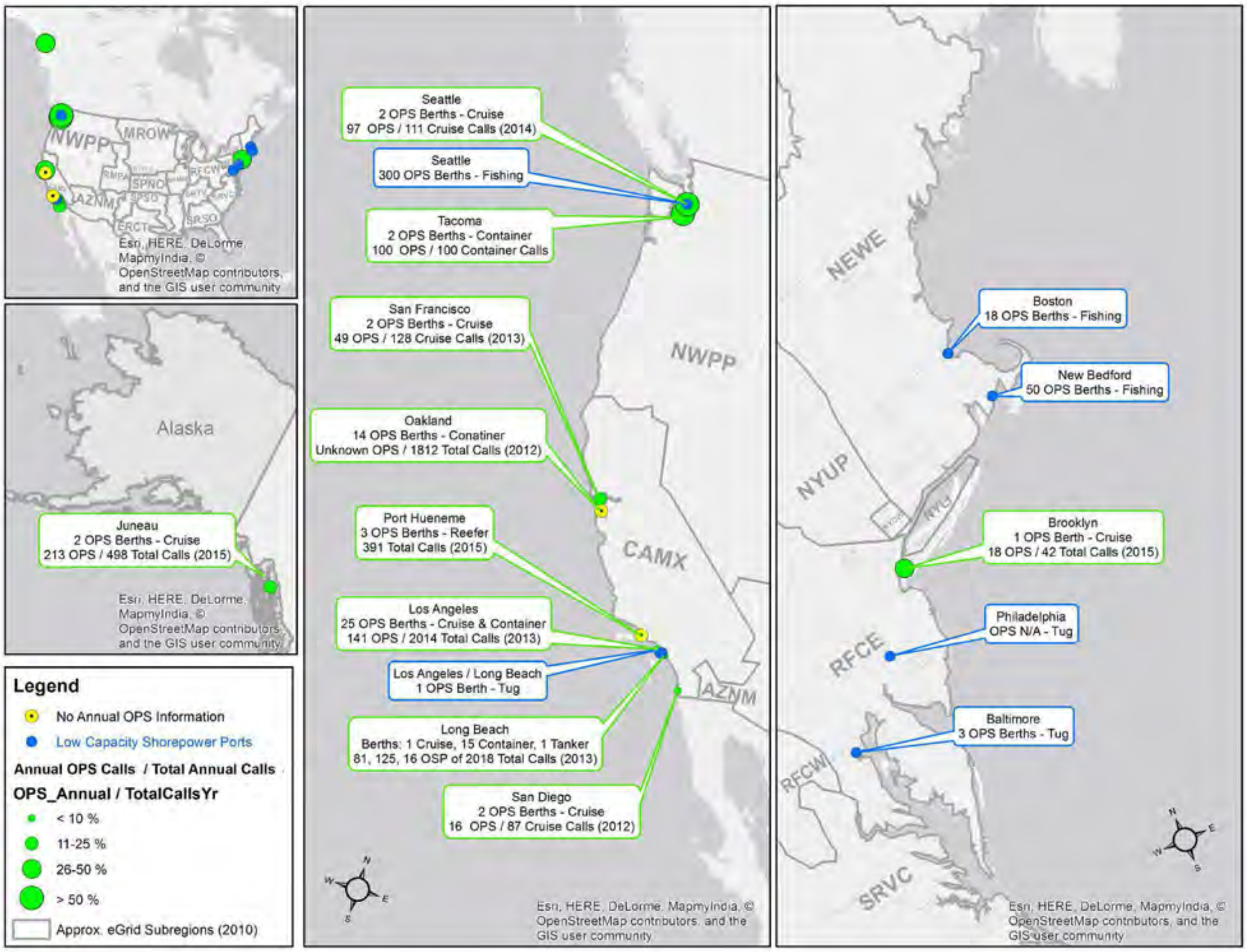

Figure C-1. Locations of shore power installations in the U.S., their capacity, number of shore power berths, and vessel calls.

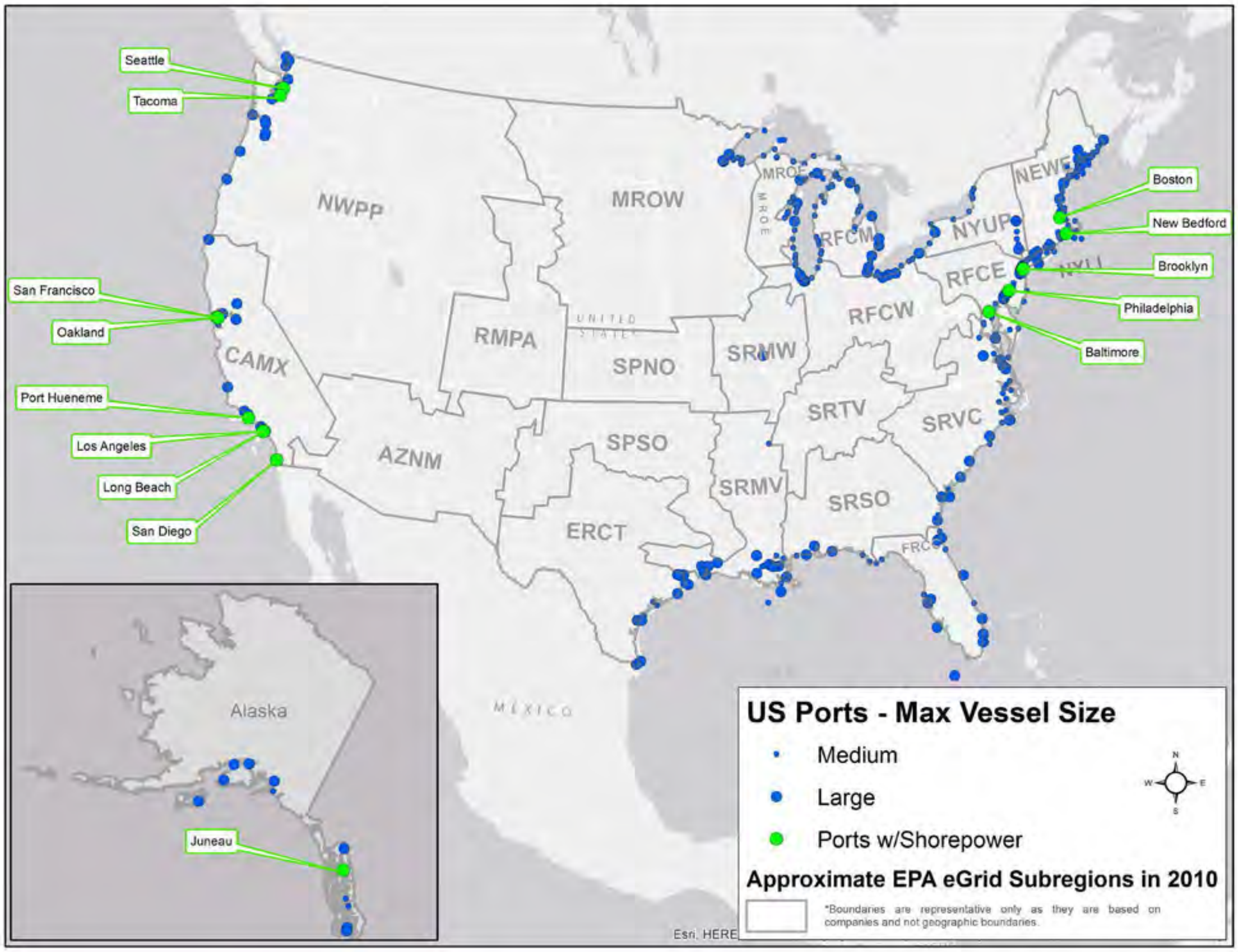

Figure C-2. Location of U.S. ports with shore power and other U.S. ports.