TECHNICAL BRIEF

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Shore power in California: Impact on statewide grid and public health benefits

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INTRODUCTION

Ships equipped with internal combustion engines emit greenhouse gases (GHGs), as well as air pollutants with adverse health impacts such as nitrogen oxides (NO_x), sulfur oxides (SO_x), particulate matter (PM), carbon monoxide (CO), and volatile organic compounds (VOCs).[1] These pollutants are also precursors to the formation of ozone and secondary PM. Exposure to these pollutants can cause respiratory symptoms, increased susceptibility to respiratory infections, development of asthma and bronchitis, and premature mortality in people with heart or lung disease.[2] Diesel particulate matter from engine exhaust can also increase the risk of developing lung cancer.[3]

California's South Coast Air Basin—home to the Ports of Los Angeles and Long Beach—fails to meet the federal ambient air quality standards for ozone and $PM_{2.5}$.[4] Moreover, many communities around ports are classified by the Office of Environmental Health Hazard Assessment as disadvantaged based on environmental pollution burden and socio-economic indicators.[5] To reduce air pollution from ships, California Air Resources Board (CARB) implemented emissions control regulations for oceangoing vessels (OGVs) and

1 Particulate matter is defined by its diameter. PM_{10} refers to inhalable particles with diameters of 10 micrometers and smaller. $PM_{2.5}$ is a subset of PM_{10} with diameters of 2.5 micrometers and smaller.

2 "Health and Environmental Effects of Particulate Matter (PM)," U.S. Environmental Protection Agency, updated May 23, 2025, https://www.epa.gov/pm-pollution/health-and-environmental-effects-particulate-matter-pm.

3 California Air Resources Board, *Public Hearing to Consider the Proposed Control Measure for Ocean-Going Vessels at Berth - Staff Report: Initial Statement of Reasons* (2019), https://ww3.arb.ca.gov/regact/2019/ogvatberth2019/isor.pdf.

4 South Coast Air Quality Management District, *2022 Air Quality Management Plan*, December 2, 2022, https://www.aqmd.gov/docs/default-source/clean-air-plans/air-quality-management-plans/2022-air-quality-management-plan/final-2022-aqmp/final-2022-aqmp.pdf?sfvrsn=edcebd61_16.

5 California Air Resources Board, *Public Hearing*; "SB 535 Disadvantaged Communities," California Office of Environmental Health Hazard Assessment, accessed December 1, 2025, https://oehha.ca.gov/calenviroscreen/sb535.

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commercial harbor craft (CHC), with shore power identified as a key compliance strategy to reduce emissions from auxiliary engines while ships are at berth.[6]

Shore power allows ships to plug into shore-based electrical power sources to operate their electrical systems while turning off their auxiliary engines, effectively eliminating local air pollutant emissions, which is expected to improve public health.[7] As California aims for 100% of its retail electricity sales to be supplied by renewable and zero-carbon resources by 2045, the use of shore power also has potential to reduce GHG emissions.[8] However, increased electricity demand from shore power could put pressure on local electrical grids, impacting both utilities serving ports and power distribution infrastructure within the ports. Despite shore power's role in California's emissions control regulations and its growing adoption internationally, the magnitude of electricity demand from widespread shore power use and its implications for grid planning remain unclear.[9]

To address this knowledge gap, this brief estimates the annual and hourly demand from shore power in California through 2050 under four scenarios, comparing these projections against statewide electricity demand forecasts. We also quantify air quality and health benefits—represented by a reduction in $PM_{2.5}$ concentrations and the resulting avoided premature mortality—from maximizing shore power use in California. These estimates can inform future regulations, shore power installations, and grid planning while highlighting the public health value of reducing at-berth emissions in port communities.

REGULATORY AND TECHNICAL CONTEXT

CALIFORNIA'S EMISSIONS CONTROL REGULATIONS

To reduce air pollution from ships at berth, CARB has implemented emissions control regulations for both OGVs and CHC.

The Ocean-Going Vessels At Berth Regulation was initially approved in 2007 and amended in 2020.[10] Oceangoing vessels have three emission sources: main engines, auxiliary engines, and auxiliary boilers. While at berth, ships turn off their main engines but run auxiliary engines for electricity generation and auxiliary boilers for heat and steam generation. Under the amended regulation, container vessels, refrigerated cargo vessels, passenger vessels, roll-on/roll-off vessels, and tanker vessels berthing for 3 hours or more at a California marine terminal are required to reduce auxiliary engine emissions using a CARB approved emission control strategy (CAECS). A CAECS must meet the emission requirements for NO_X, $PM_{2.5}$, and reactive organic gases and

6 Commercial harbor craft are usually smaller than OGVs, engage in intrastate voyages, and include passenger ferries, excursion vessels, tugboats, pilot vessels, fishing vessels, and research vessels, among others.

7 Haifeng Wang et al., *Costs and Benefits of Shore Power at the Port of Shenzhen* (International Council on Clean Transportation, 2015), https://theicct.org/publication/costs-and-benefits-of-shore-power-at-the-port-of-shenzhen/.

8 California Renewables Portfolio Standard Program: Emissions of Greenhouse Gases, N.Y SB-100 (2018), https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201720180SB100.

9 Jasper Faber et al., *The Role of Shore Power in the Future Maritime Fuel Mix* (CE Delft, 2022), https://cedelft.eu/wp-content/uploads/sites/2/2023/04/CE_Delft_210314_The_role_of_shore_power_in_the_future_maritime_fuel_mix_DEF.pdf.

10 Final Regulation Order: Control Measure for Ocean-Going Vessels at Berth, 13, 17 CCR § 2299.3, 93118.3, 93130- 93130.22 (2020), https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2019/ogvatberth2019/fro.pdf; "Ocean-Going Vessels At Berth Regulation," California Air Resources Board, accessed December 1, 2025, https://ww2.arb.ca.gov/our-work/programs/ocean-going-vessels-berth-regulation.

not result in higher GHG emission rates than the statewide grid. Examples of CAECS include, but are not limited to, shore power, barge- or land-based emission capture and control systems, and alternative fuels.[11]

The energy demand from boilers at berth varies by ship type and size, with tankers usually using large boilers that generate steam to power pumps for off-loading cargo (e.g., crude oil).[12] For this reason, under the OGVs At Berth Regulation, if tankers with steam-driven pumps use a CAECS other than shore power, they must use a CAECS for auxiliary boilers as well.[13]

The compliance schedule varies by ship type and port visited (Table 1). Container and refrigerated cargo vessels, along with passenger vessels, have been required to comply since January 1, 2023, and roll-on/roll-off vessels and tankers visiting the ports of Los Angeles and Long Beach since January 1, 2025. All remaining tanker vessels are required to comply beginning January 1, 2027. While bulk and general cargo vessels are not currently subject to the emissions control requirement due to their operating patterns and physical constraints at the terminals they use, they still have visit reporting and opacity requirements.[14]

Table 1
At-berth emissions control requirement schedule by ship type and port visited

Start date	Ship type
January 1, 2023	Container and refrigerated cargo vessels
January 1, 2023	Passenger vessels
January 1, 2025	Roll-on and roll-off vessels
January 1, 2025	Tanker vessels that visit the ports of Los Angeles and Long Beach
January 1, 2027	All remaining tanker vessels

California Air Resources Board published a dashboard showing compliance status of the regulation in 2024.[15] During this time, CARB audited over 99% of the vessel visits subject to the emissions control; the statewide compliance rate for these audited visits was 97%. Of the audited visits, 75% used shore power, 3% used an alternative CAECS, and 22% were granted an exception as allowed by the regulation.[16]

While most ships so far have complied with the OGVs At Berth Regulation using shore power, most tanker and tanker terminal operators currently plan to use barge-based capture and control systems because of a perception that shore-based solutions are

11 Emission capture and control systems utilize an exhaust gas scrubber connected to the vessel's exhaust stack to treat the exhaust before it is released to the atmosphere.

12 Xiaoli Mao et al., *Systematic Assessment of Vessel Emissions (SAVE) V2025.03.1 Documentation*, v. 2025.1, International Council on Clean Transportation, 2025, https://theicct.github.io/SAVE-doc/versions/v2025.1/; California Air Resources Board, *Public Hearing*.

13 The exemption for tankers using shore power is intended to encourage tankers to use shore power rather than other emissions control strategies.

14 California Air Resources Board, *Interim Evaluation Report: Control Measure for Ocean-Going Vessels At Berth* (2022), https://ww2.arb.ca.gov/sites/default/files/2022-12/At%20Berth%20Interim%20Evaluation%20Report_Final_Remediated.pdf.

15 "2024 Shore Power Enforcement," California Air Resources Board, accessed August 29, 2025, https://ww2.arb.ca.gov/our-work/programs/enforcement-policy-reports/enforcement-data-portal/2024-shore-power-enforcement.

16 The exceptions apply to, but are not limited to, vessel safety and emergency events, commissioning or research visits, visits to a low activity terminal that receive few regulated vessels, and a certain percentage of visits where vessel operators and terminal operators are not required to reduce emissions.

more difficult and potentially dangerous for tankers.[17] However, emerging examples suggest shore power connection for tankers is technically feasible, which could expand the potential for emission reductions. Shore power is already in use at a tanker terminal at the Port of Long Beach, and shore power is available at the Port of Gävle in Sweden.[18] The Port of Rotterdam in the Netherlands is conducting feasibility studies on shore power for tankers to help standardize the system and facilitate a demonstration project.[19]

The Commercial Harbor Craft Regulation was adopted in 2008 and amended in 2022.[20] One of the many requirements under the amended regulation is that no CHC shall idle propulsion engines or idle or operate auxiliary engines with a power rating of 99 kW or less used for electricity generation for more than 15 consecutive minutes when docked, berthed, or moored at a facility. California Air Resources Board chose 99 kW as the threshold as auxiliary engines used for electricity generation are typically not rated above 99 kW.[21] Shore power may be used for auxiliary power at berth.

SHORE POWER IN BROADER POLICY CONTEXT

In both the OGVs At Berth Regulation and the CHC Regulation, shore power is a key compliance method to reduce emissions from auxiliary engines. International regulations could potentially accelerate shore power adoption beyond what state regulations alone would achieve. International Maritime Organization (IMO) member states plan to regulate ships' GHG intensity and charge ships for GHG emissions above certain thresholds. However, the vote to formally adopt the regulation—the Net-Zero Framework—in October 2025 has now been delayed for at least a year.[22] This regulation can incentivize ships to use more shore power. In its current design, a ship's GHG intensity is calculated by dividing the life-cycle GHG emissions from the fuels it used by its total energy consumption in a given year. Energy consumption from sources other than fuels, such as electricity delivered from shore power, wind propulsion, and solar power, lowers a ship's GHG intensity and reduces its compliance costs.

Given California's regulatory framework and the potential for expanded shore power adoption under international regulations, understanding the electricity demand and air quality implications of widespread shore power use is important for infrastructure planning and policy development. The following sections describe our approach to quantifying these impacts.

17 California Air Resources Board, *Interim Evaluation Report*; "Terminal and Port Plan Submissions," California Air Resources Board, accessed December 5, 2025, https://ww2.arb.ca.gov/our-work/programs/ocean-going-vessels-berth-regulation/terminal-and-port-plan-submissions.

18 California Air Resources Board, *Public Hearing*; Naida Hakirevic Prevljak, "Port of Gävle: Tanker Switches to Shore Power during Unloading Operation for the First Time," *Offshore Energy*, November 17, 2023, https://www.offshore-energy.biz/port-of-gavle-tanker-switches-to-shore-power-during-unloading-operation-for-the-first-time/.

19 Port of Rotterdam, "Shore Power for Tankers Has a Significant Potential to Reduce In-Port Emissions," press release, June 18, 2024, https://www.portofrotterdam.com/en/news-and-press-releases/shore-power-tankers-has-significant-potential-reduce-port-emissions.

20 "Commercial Harbor Craft," California Air Resources Board, accessed November 30, 2025, https://ww2.arb.ca.gov/our-work/programs/commercial-harbor-craft/about.

21 California Air Resources Board, *Public Hearing to Consider the Proposed Amendments to the Commercial Harbor Craft Regulation - Staff Report: Initial Statement of Reason* (2021), https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2021/chc2021/isor.pdf.

22 International Maritime Organization, "MEPC 83/17/Add.1 Report of the Marine Environment Protection Committee on its Eighty-Third Session," May 9, 2025, https://docs.imo.org.

METHODS

This analysis models shore power electricity demand through 2050 and estimates the potential air quality and health benefits of using shore power. It employs the ICCT's Systematic Assessment of Vessel Emissions (SAVE) model, paired with detailed vessel activity data from California in 2022, followed by air quality and impacts modeling using the open-source Intervention Model for Air Pollution (InMAP) model.

Baseline energy demand and emissions in 2022

The baseline captures energy consumption and emissions from all berthing events at California ports in 2022. A forthcoming paper by Sturrup et al. estimated energy consumption and tank-to-wake (TTW) emissions from ship activities within 24 nautical miles of the California coastline in 2022 using the ICCT's SAVE model.[23] This emissions inventory includes GHG (carbon dioxide, methane, and nitrous oxide) and air pollutant (NO_x, SO_x, PM, CO, VOCs) emissions. We filtered the inventory to include only the energy demand and emissions from ships when they were at berth in California ports.[24] Because the 24 nautical mile boundary includes parts of waters regulated by Oregon and Mexico, we also excluded the energy demand and emissions from the berthing events whose nearest port was not in California. The classification of OGVs, CHC, and all other vessels—grouped in this paper as "Others"—was taken from Sturrup et al.[25]

Although the original OGVs At Berth Regulation was already in effect in 2022 for certain container, passenger, and refrigerated cargo vessels, our emissions inventory did not consider any shore power usage and assumed that all auxiliary engines were operating at berth, in line with the SAVE methodology.[26]

Predicting shore power demand to 2050

We projected that shore power energy demand would grow 6% by 2030, 16% by 2040, and 26% by 2050 compared with a 2022 baseline, assuming California's maritime transport demand grows at the same rate predicted for global demand in the ICCT's Polaris model. The Polaris model is a global maritime emissions model that projects GHG emissions from 2019 through 2070, taking into account transport work demand growth and international GHG reduction regulations.[27]

Shore power use scenarios

We evaluated the energy demand for shore power under four scenarios that span current regulatory requirements to maximum potential.

23 Sturrup et al., *Profiling Shipping Activities To or From California Ports: Energy Demand, Greenhouse Gas Emissions and the Technological Feasibility of Repowering Them with Renewable Hydrogen and its Derivatives* (International Council on Clean Transportation, forthcoming); Mao et al., *Systematic Assessment of Vessel Emissions*.

24 A ship's operational phase is determined by its proximity to land or port and its speed over ground. A ship is considered to be at berth if it is in a river or within one nautical mile (and within five nautical miles in case of liquid tankers) from a port and its speed over ground is less than one knot.

25 Sturrup et al., *Profiling Shipping Activities*. The classification is aligned with CARB's definitions of OGVs and CHC to the extent possible. Oceangoing vessels include larger cargo ships and cruise ships. Commercial harbor craft include, but are not limited to, fishing vessels, passenger ferries, excursion vessels, and tugboats. Ships that did not fit the size requirements to classify as OGVs and were not classified by CARB as CHC were classified as Others.

26 Mao et al., *Systematic Assessment of Vessel Emissions*; Airborne Toxic Control Measure for Auxiliary Diesel Engines Operated on Ocean-Going Vessels At-Berth in a California Port, California Code of Regulations § 93118.3 (2009), https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2007/shorepwr07/93118-t17.pdf.

27 Gabriel Hillman Alvarez et al., *Polaris v1.3 Documentation*, v. 1.3, International Council on Clean Transportation, released 2025, https://theicct.github.io/polaris-doc/versions/v1.3/.

- In the **Baseline Excluding Tankers** scenario, we assumed all CHC and all OGV types subject to emissions control requirements under the OGVs At Berth Regulation except for tankers used shore power.[28] This reflects current industry plans, as most tanker operators intend to use capture and control systems rather than shore power.
- In the **Baseline Including Tankers** scenario, we assumed all CHC and all OGV types subject to emissions control requirements under the OGVs At Berth Regulation including tankers used shore power. This accounts for potential increased shore power utilization among tankers beyond current plans.
- In the **High Uptake** scenario, we assumed all OGVs and all CHC used shore power, extending beyond vessels currently subject to regulatory requirements.
- In the **Maximum Uptake** scenario, we assumed all OGVs, CHC, and Others used shore power, eliminating all energy demand and emissions from auxiliary engines at berth.

Average and peak demand from shore power

Understanding both average and peak hourly demand is critical for shore power capacity planning and electricity grid infrastructure, as all components of an electrical system must be designed to handle peak loads. For each scenario, we calculated the energy demand from auxiliary engines of all applicable ships at berth for every hour in 2022 (8,760 hours in total). We next identified the average and peak hourly energy demands and applied the projected energy demand growth rates described above. We then compared average and peak hourly demands against statewide peak demand projections to contextualize the magnitude of shore power requirements relative to California's overall electricity system.

Air quality and health benefit analysis

We estimated the air quality and public health benefits of eliminating all auxiliary engine emissions at berth using InMAP, a reduced-complexity air quality model.[29] This model uses outputs from WRF-Chem, a widely used chemical transport model, to extract meteorological, chemical transporting, atmospheric chemistry, and physical parameters.[30] We input 2022 emissions inventories, including TTW pollutant emissions of SO_X, PM_{10}, $PM_{2.5}$, NO_X, CO, and VOCs, to estimate the annual average ambient $PM_{2.5}$ concentration attributable to shipping emissions. The $PM_{2.5}$ concentration result includes directly emitted (primary) $PM_{2.5}$ as well as secondary $PM_{2.5}$ formed from SO_X, NO_X, and VOCs through atmospheric chemical reactions.

We quantified air quality benefits by comparing the $PM_{2.5}$ concentration results from two emission inventories. First, we calculated the $PM_{2.5}$ concentrations using the unmodified 2022 emissions inventory of all California-related shipping activities as defined in Sturrup et al.[31] Then, we calculated the $PM_{2.5}$ concentrations using a modified inventory that eliminated all pollutant emissions from auxiliary engines during the berthing phase within 24 nautical miles of the California baseline. The difference in

28 All CHC were assumed to use shore power because we could not exclude CHC with auxiliary engines of power rating greater than 99 kW due to the lack of data.

29 The original codes of InMAP can be found in: https://github.com/spatialmodel/inmap

30 Christopher W. Tessum et al., "InMAP: A Model for Air Pollution Interventions," *PLOS ONE* 12, no. 4 (2017): e0176131, https://doi.org/10.1371/journal.pone.0176131.

31 The scope includes all voyages starting or ending in California ports. As such, emissions in the berthing phase under this scope include those from ships berthing in non-California ports. Sturrup et al., *Profiling Shipping Activities*.

$PM_{2.5}$ concentrations between these two scenarios represents the potential air quality benefit of using shore power for all ships berthing in California ports.

We estimated public health benefits using gridded population data, mortality rate data, and a custom concentration-response function between $PM_{2.5}$ exposure and premature mortality integrated in the InMAP model. The model employs a variable spatial resolution grid based on population density, ranging from 1 km x 1 km in populated urban areas to 48 km x 48 km in rural areas for greater computational efficiency. Population data are derived from U.S. Census block groups, averaged over 2011–2015.[32] All-cause mortality rates at the county level in 2013 come from the U.S. Centers for Disease Control and Prevention and serve as the baseline for estimating the mortality rate changes due to exposure to $PM_{2.5}$.[33] InMAP estimates premature deaths caused by $PM_{2.5}$ by multiplying the population and $PM_{2.5}$-attributable mortality rate in each grid cell. Consistent with a previous ICCT study of U.S. shipping emissions, we used the linear concentration-response function from the American Cancer Society study instead of InMAP's default function, with a 6% increase in mortality rate per 10 micrograms per cubic meter ($\mu g/m^3$) increase in $PM_{2.5}$ concentration. More details on the concentration-response function and how it converts the baseline all-cause mortality rates into $PM_{2.5}$-attributable mortality rates can be found in a previous ICCT study.[34]

We also converted avoided premature deaths to economic benefits by applying a value of statistical life assumption from the U.S. Environmental Protection Agency, which was $7.9 million per case in 2008.[35] The value was adjusted for inflation to $10.7 million per case in 2022 using inflation data from the World Bank.[36]

RESULTS

Energy demand and emissions in 2022

In 2022, auxiliary engines used at berth consumed less energy than boilers but generated disproportionately high NO_x and VOC emissions—81% (5,609 tonnes) of NO_x and 77% (208 tonnes) of VOC emissions—despite accounting for only 45% (524 GWh) of total energy demand. While boilers consumed 55% (633 GWh) of total energy demand, they were responsible for 67% of total GHG emissions (660,796 t CO_2e) and 64% of SO_x emissions (208 tonnes). Boilers are typically steam turbines, so they have different specific fuel consumptions and emission factors than auxiliary engines.[37] Specifically, boilers have higher specific fuel consumption (i.e., they burn more fuel per unit of energy produced) and auxiliary engines operate at a higher temperature and thus have higher NO_x emission rates. OGVs accounted for 90% of total at-berth energy demand (1,049 GWh), followed by CHC (8%, or 89 GWh) and those classified as Others (2%, or 19 GWh). Table 2 provides a complete breakdown of energy demand and emissions by source and vessel classification.

32 "National Historical Geographic Information System," Minnesota Population Center, 2017, https://www.nhgis.org/revision-history#EE-2-0.

33 Centers for Disease Control and Prevention, "Underlying Cause of Death 1999-2015" CDC WONDER Online Database [data set], 2016, https://wonder.cdc.gov/controller/datarequest/D76.

34 Zhihang Meng and Bryan Comer, *Electrifying Ports to Reduce Diesel Pollution from Ships and Trucks and Benefit Public Health: Case Studies of the Port of Seattle and the Port of New York and New Jersey* (International Council on Clean Transportation, 2023), https://theicct.org/publication/marine-ports-electrification-feb23/.

35 United States Environmental Protection Agency, *Guidelines for Preparing Economic Analyses* (2014), https://www.epa.gov/sites/default/files/2017-08/documents/ee-0568-50.

36 "Inflation, Consumer Prices (Annual %)," World Bank Group, 2025, https://data.worldbank.org/indicator/FP.CPI.TOTL.ZG.

37 Mao et al., *Systematic Assessment of Vessel Emissions*.

Table 2

Energy demand and emissions from auxiliary engines and boilers at berth, 2022

Metric	Source	Oceangoing vessels	Commercial harbor craft	Others	Total
Energy demand (GWh)	Auxiliary engines	422	89	13	524
	Boilers	627	0	6	633
GHG (t CO_2e)	Auxiliary engines	258,695	56,288	8,286	323,269
	Boilers	654,380	0	6,416	660,796
$PM_{2.5}$ (t)	Auxiliary engines	85	14	2	102
	Boilers	103	0	1	104
NO_x (t)	Auxiliary engines	4,431	1,018	161	5,609
	Boilers	1,315	0	13	1,328
SO_x (t)	Auxiliary engines	95	20	3	119
	Boilers	205	0	3	208
CO (t)	Auxiliary engines	219	48	7	274
	Boilers	169	0	1	170
VOCs (t)	Auxiliary engines	168	36	5	208
	Boilers	63	0	1	64

Notes: The GHG emissions are reported as carbon dioxide equivalents (CO_2e) based on the global warming potentials (GWPs) for 100-year (GWP100) time horizon. This inventory used the GWP100 values from the Intergovernmental Panel on Climate Change's Sixth Assessment Report: 29.8 for methane and 273 for nitrous oxide. See Intergovernmental Panel on Climate Change, *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (2021), https://www.ipcc.ch/report/ar6/wg1/.

Annual energy demand for shore power

Even under maximum shore power adoption, electricity demand would remain modest relative to California's overall electricity system—less than 0.2% of forecasted statewide deliveries in 2050.[38] Annual shore power demand would reach 378–660 GWh by 2050 depending on the scenario, compared with 440,518 GWh in total electricity deliveries to end users forecasted by the California Energy Commission (CEC). Under the Maximum Uptake scenario where all ships use shore power, OGVs would account for 80% (532 GWh) of energy demand from ships, CHC 17% (112 GWh), and Others 3% (17 GWh). Table 3 shows the annual energy demand projections for each scenario.

38 "California Energy Demand Update (CEDU) 2024 Forecast Planning Forecast LSE and BAA Tables Form 1.1c," California Energy Commission, 2025, https://www.energy.ca.gov/data-reports/california-energy-planning-library/forecasts-and-system-planning/demand-side-2.

Table 3

Annual energy demand (GWh) for shore power from ships at berth

Scenario	Ship type	2022	2030	2040	2050
Baseline Excluding Tankers	Oceangoing vessels	211	224	245	266
	Commercial harbor craft	89	94	103	112
Total		**300**	**318**	**348**	**378**
Baseline Including Tankers	Oceangoing vessels	393	417	456	496
	Commercial harbor craft	89	94	103	112
Total		**482**	**511**	**560**	**608**
High Uptake	Oceangoing vessels	422	447	489	532
	Commercial harbor craft	89	94	103	112
Total		**511**	**542**	**593**	**644**
Maximum Uptake	Oceangoing vessels	422	447	489	532
	Commercial harbor craft	89	94	103	112
	Others	13	14	15	17
Total		**524**	**556**	**608**	**660**

Note: The 2022 results show the modeled energy demands from auxiliary engines at berth of the ship types that would use shore power under each scenario.

California's existing regulations already capture most potential shore power demand. The two Baseline scenarios show significant variation (482 versus 300 GWh in 2022) depending on tanker participation, but the High and Maximum Uptake scenarios show only modest increases beyond the Baseline Including Tankers scenario. This is because the OGVs At Berth regulation already covers the ship types responsible for over 90% of auxiliary engine energy demand. By ship type, container ships and oil tankers would each account for more than 30% of the OGV auxiliary engine energy demand, followed by cruise ships (13%) and chemical tankers (12%).

Average and peak demand from shore power

Under the Maximum Uptake scenario, peak shore power demand would remain a small fraction of California's electricity system capacity, accounting for less than 0.2% of statewide peak demand. By 2050, peak hourly demand would reach 122–152 MW across scenarios, compared with forecasted statewide 1-in-2 peak demands of 66 GW in 2030, 82 GW in 2040, and 90 GW in 2050.[39] Average hourly demand would reach 43–75 MW. Peak demand is more than double the average demand, driven largely by instances where large cruise ships berth at the same time. In 2022, six cruise ships berthing simultaneously generated 69 MW out of 97 MW total peak demand under the Baseline Excluding Tankers scenario. Cruise ships have substantially higher auxiliary engine power demand than other ship types as they serve as hotels with restaurants and entertainment facilities even at berth, making the number of simultaneously berthing cruise ships a decisive factor for peak demand.[40] Table 4 shows average and

39 1-in-2 peak demand refers to peak demand under baseline temperature conditions that have a 50% chance of being met or exceeded. This is used as a baseline for grid reliability planning. California Energy Commission, "California Energy Resource and Reliability Outlook, 2025," July 1, 2025, https://www.energy.ca.gov/publications/2025/california-energy-resource-and-reliability-outlook-2025; "California Energy Demand Update (CEDU) 2024 Forecast Planning Forecast LSE and BAA Tables Form 1.5b," California Energy Commission, 2025, https://www.energy.ca.gov/data-reports/california-energy-planning-library/forecasts-and-system-planning/demand-side-2.

40 Mao et al., *Systematic Assessment of Vessel Emissions*.

peak hourly demand projections for each scenario, with 2022 demand by ship type provided in the appendix.

Table 4
Average and peak hourly energy demand from shore power

Scenario	Average hourly demand (MW)				Peak hourly demand (MW)			
	2022	2030	2040	2050	2022	2030	2040	2050
Baseline Excluding Tankers	34	36	40	43	97	103	113	122
Baseline Including Tankers	55	58	64	69	114	121	133	144
High Uptake	58	62	68	73	119	126	138	149
Maximum Uptake	60	63	69	75	121	128	140	152

Air quality and health benefits

We first modeled the air quality and public health impacts of TTW pollutant emissions from all California-related shipping activities in 2022 using InMAP. Shipping emissions are expected to result in 86 premature deaths each year in California. The impact is concentrated in Southern California near the Port of Long Beach and the Port of Los Angeles, where emissions from California-related shipping activities account for up to 3.5 $\mu g/m^3$ of annual average $PM_{2.5}$ concentration—which is substantial compared to the annual average $PM_{2.5}$ concentration of 8.1 $\mu g/m^3$ as monitored by a station in the Port of Long Beach in 2022.[41]

The OGVs At Berth Regulation and CHC Regulation, which require the use of shore power or other emission control strategies, reduce near-port emissions from auxiliary engines of applicable berthing vessels. Eliminating all at-berth emissions from auxiliary engines of the vessels in California in 2022 could have reduced NO_x emissions by 5,609 tonnes (a 1.9% reduction), SO_x by 119 tonnes (a 0.5% reduction), and $PM_{2.5}$ by 102 tonnes (a 1.0% reduction) compared with emissions from all California-related shipping activities in the same year, according to our modeling.[42] Despite representing a relatively modest reduction in total shipping-related emissions, the expected reduction in $PM_{2.5}$ concentration would have avoided approximately 30 premature deaths in California annually. The avoided premature deaths translate to an economic benefit of $321 million in 2022 U.S. dollars—about 5.6% of the California Department of Public Health's total budget in fiscal year 2022–2023.[43] The benefits would be greatest near the Ports of Los Angeles and Long Beach (Figure 1), because they are densely populated areas that also have intense shipping activity.

These health benefits would accrue primarily to communities near ports, many of which are designated as disadvantaged communities based on pollution burden and population characteristics including health conditions, age, educational attainment,

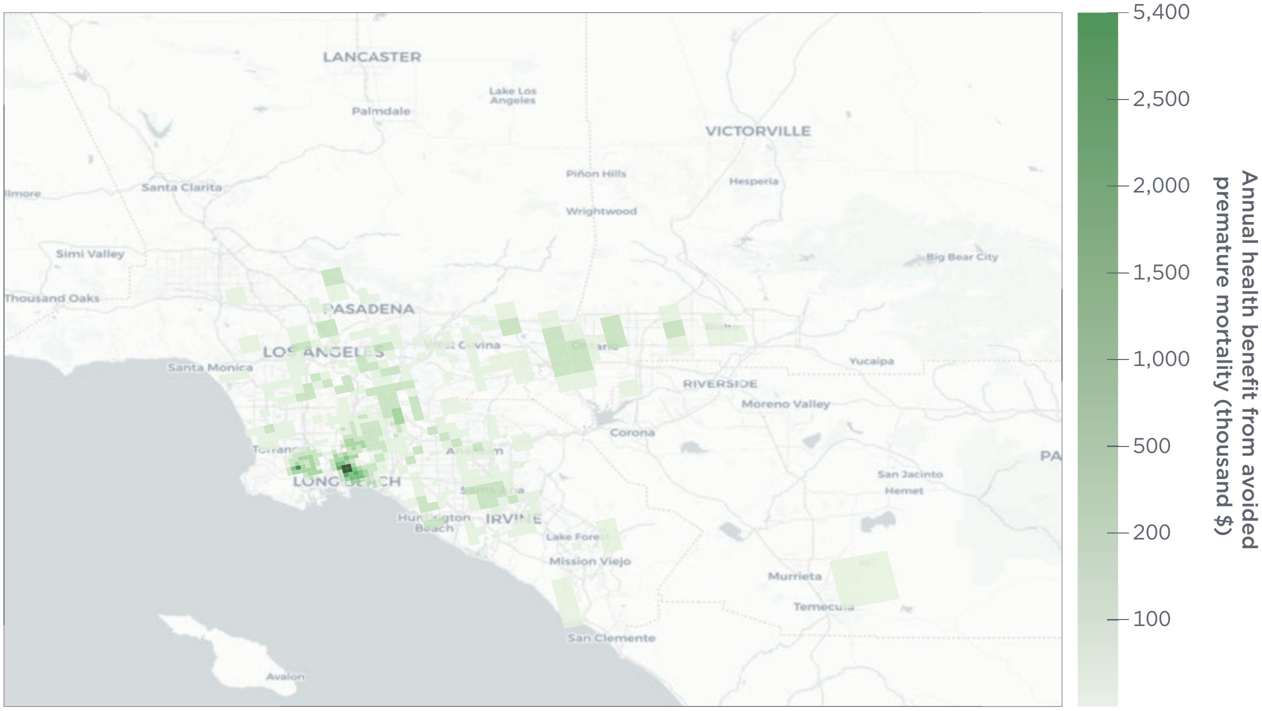
41 Leidos, *Air Quality Monitoring Program at the Port of Long Beach Calendar Year 2022* (2023), https://monitoring.cleanairactionplan.org//wp-content/uploads/2023/10/POLB-2022-Annual-Monitoring-Report-FINAL-09-29-23.pdf.

42 This includes all voyages starting or ending in California ports (see note 31).

43 California Department of Public Health, *Governor's Budget Highlights Fiscal Year 2022-23* (2022), https://www.cdph.ca.gov/Documents/CDPH-2022-23_Governor-Budget-Highlights.pdf.

income, and unemployment rate.[44] These disadvantaged communities are also disproportionately inhabited by Latino and Black residents.[45]

Figure 1
Health benefits from eliminating air pollution from auxiliary engines at berth in Southern California, 2022



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DISCUSSION

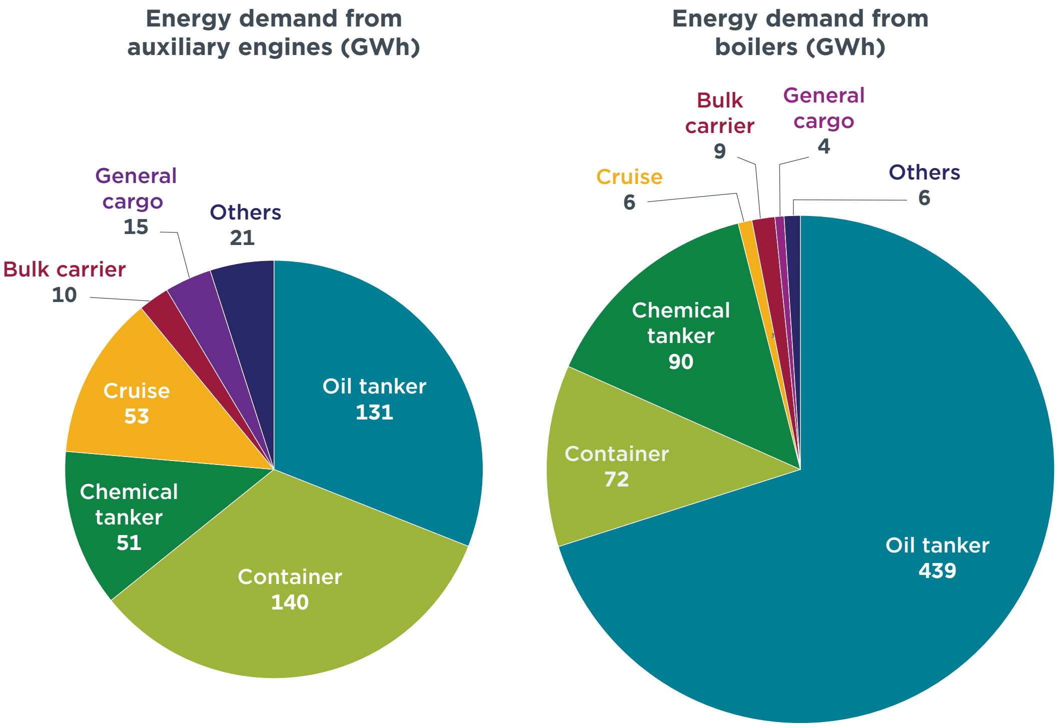
Our analysis captures only part of the potential for emission reductions from ships at berth. Shore power for auxiliary engines addresses 45% of total at-berth energy demand, but boilers account for the remaining 55% (633 GWh). Oil and chemical tankers account for 84% (529 GWh) of boiler energy demand (Figure 2). We only considered shore power for auxiliary engines because existing shore power regulations across the world, including California's OGVs At Berth Regulation, focus on controlling emissions from auxiliary engines, as ship boilers are not electrical systems.

44 Laura August et al., *CalEnviroScreen 4.0* (Office of Environmental Health Hazard Assessment, 2021), https://oehha.ca.gov/sites/default/files/media/downloads/calenviroscreen/report/calenviroscreen40reportf2021.pdf.

45 Office of Environmental Health Hazard Assessment and California Environmental Protection Agency, *Analysis of Race/Ethnicity and CalEnviroScreen 4.0 Scores*, accessed November 14, 2025, https://oehha.ca.gov/sites/default/files/media/downloads/calenviroscreen/document/calenviroscreen40raceanalysisf2021.pdf.

Figure 2

Energy demand from oceangoing vessels at berth in by ship type and source, 2022



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Currently, the OGVs At Berth Regulation applies to boiler emissions only from tankers with steam-driven pumps using non-shore power CAECS, while exempting tanker boilers from emissions control when shore power is used for auxiliary engines—an incentive structure designed to encourage shore power adoption. However, an ICCT study reviewed technologies that could allow boilers to electrify and therefore use shore power at berth.[46] As these technologies mature, California policymakers could consider adding emissions control requirements for boilers, which would substantially increase both emission reductions and shore power infrastructure requirements.

Port-specific electricity demand estimates are crucial for planning shore power requirements in each port as well as transmission and distribution infrastructure serving each port. However, data limitations prevented us from accurately allocating demand to specific ports in this analysis. Processing hourly Automatic Identification System data in bulk cannot reliably distinguish between geographically adjacent ports (e.g., Ports of Los Angeles and Long Beach, Ports of Oakland and San Francisco).[47] Future analysis using official port boundaries could provide more accurate port-specific energy demand estimates to support local infrastructure planning.

46 Liudmila Osipova and Camilla Carraro, *Shore Power Needs and CO_2 Emissions Reductions of Ships in European Union Ports: Meeting the Ambitions of the FuelEU Maritime and AFIR* (International Council on Clean Transportation, 2023), https://theicct.org/publication/shore-power-eu-oct23/.

47 This caveat is described in more detail in Tom Decker and Elise Sturrup, *Nationwide Port Emissions Screening for Berthed Vessels: Prioritizing U.S. Port Electrification to Improve Air Quality for Near-Port Communities* (International Council on Clean Transportation, 2024), https://theicct.org/publication/us-port-emissions-screening-berthed-vessels-sept24/.

Our estimates may overstate or understate the health benefits of shore power, due to factors in our analytical approach. On one hand, we did not consider any usage of emissions control strategies in our 2022 emissions modeling, although certain ship types visiting major ports were already required to reduce their at-berth emissions. We likely overestimated the 2022 emissions and, by extension, the benefits of eliminating all auxiliary engine emissions at berth. On the other hand, we quantified only $PM_{2.5}$-attributable premature mortality, excluding other health impacts. Ozone, formed by chemical reactions between NO_X and VOCs, is a major component of smog that causes respiratory problems and increases mortality rates. Due to the limitation of the InMAP model, we did not estimate the ozone concentration change and ozone-attributable health benefits from reduced shipping emissions. Based on previous ICCT work that estimated the health benefits of establishing North-Atlantic emission control area for shipping, the ozone-attributable premature deaths were around 0.7%–2% of the $PM_{2.5}$-attributable premature deaths.[48] We also excluded non-mortality health benefits such as avoided morbidity and illness-related productivity losses.

California's increasingly low-GHG intensity electricity grid positions the state to achieve GHG reductions from shore power alongside air quality benefits. As of 2022, California's grid had an average GHG intensity of 58 g CO_2e/MJ, and, as noted previously, the state aims to supply 100% of its retail electricity sales from renewable and zero-carbon resources by 2045.[49] However, the grid's intensity varies by season and time of the day depending on the share of renewable generation sources.[50] The extent of GHG reductions from shore power depends on the GHG intensity of the local grid, and shore power could even increase GHG emissions if the grid is mainly powered by fossil fuels.[51] Distributed electricity generation and storage solutions at or near ports could further reduce GHG emissions by providing electricity from renewable sources during peak demand hours while reducing the need for additional power distribution infrastructure for utilities serving ports.

CONCLUSIONS

Shore power electricity demand would remain modest even under maximum adoption scenarios. Annual demand would reach 378–660 GWh by 2050 depending on adoption levels—less than 0.2% of the forecasted electricity deliveries to end users in California. Peak hourly demand would also account for less than 0.2% of the statewide peak demand, reaching 122–152 MW by 2050.

Our analysis also indicates that eliminating all at-berth auxiliary engine emissions through shore power could have avoided approximately 30 premature deaths annually in California—representing $321 million in economic benefits—while reducing NO_X emissions by 1.9% and $PM_{2.5}$ emissions by 1.0%, compared with the total emissions from California-related shipping activities, based on 2022 vessel activity. These health

48 Liudmila Osipova et al., *Environmental and Health Benefits of a Designated North Atlantic Emission Control Area* (2024), https://theicct.org/publication/environmental-and-health-benefits-of-a-designated-north-atlantic-emission-control-area-nov24/.

49 United States Environmental Protection Agency, "eGRID Summary Table 3. State Output Emission Rates," version eGRID2022, January 30, 2024, https://www.epa.gov/system/files/documents/2024-01/egrid2022_summary_tables.xlsx.

50 California Air Resources Board, *2022 Scoping Plan for Achieving Carbon Neutrality* (2022), https://ww2.arb.ca.gov/sites/default/files/2023-04/2022-sp.pdf.

51 Ketan Gore and Bryan Comer, "India's Plan to Expand Shore Power Infrastructure at Major Ports," *ICCT Staff Blog*, June 2, 2024, https://theicct.org/indias-plan-to-expand-shore-power-infrastructure-at-major-ports-june24/; Wang et al., *Costs and Benefits*.

benefits would accrue primarily to disadvantaged communities near ports that are disproportionately impacted by shipping emissions. For the year 2022, we estimated that the emissions from California-related shipping activities were responsible for 86 premature deaths in California due to increased exposure to $PM_{2.5}$.

Our estimates account only for auxiliary engine electricity demand, excluding any energy demand from boilers, which account for 55% of the energy demand from OGVs at berth. As technologies mature for electrification of boiler functions, California could extend emissions control requirements to boilers, substantially increasing both air quality benefits and shore power infrastructure requirements. Such expansion would require coordinated planning between ports, utilities, and regulators to ensure adequate generation, transmission, and distribution capacity.

APPENDIX

Table A1

Average hourly demand from auxiliary engines at berth by ship type

Classification	Ship type	Hourly demand (MW)
Oceangoing vessels	Bulk carrier	1.2
	Chemical tanker	5.9
	Container	16.0
	Cruise	6.1
	General cargo	1.7
	Liquefied gas tanker	0.0
	Miscellaneous-other	0.3
	Oil tanker	14.9
	Refrigerated bulk	0.8
	Roll-on/roll-off	0.1
	Service-other	0.1
	Vehicle	1.1
Commercial harbor craft		10.2
Others		1.5
Total		**59.8**

Table A2

Peak hourly demand from auxiliary engines at berth by ship type

Classification	Ship type	Hourly demand (MW)	Number of ships at berth
Oceangoing vessels	Bulk carrier	1.6	11
	Chemical tanker	5.1	7
	Container	17.2	16
	Cruise	57.5	5
	General cargo	2.2	3
	Miscellaneous-other	0.3	2
	Oil tanker	19.4	12
	Refrigerated bulk	2.9	1
	Service-other	0.2	1
	Vehicle	2.6	3
Commercial harbor craft		9.7	61
Others		2.4	14
Total		**121.0**	**136**

Note: In 2022, the statewide hourly peak demand from auxiliary engines at berth occurred at 21:00 on March 25. For comparison, the statewide net peak demand–highest demand after accounting for the impacts of self-generation–typically occurs from 16:00 to 21:00 as solar generation rapidly declines.

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