Background Policy Brief

Context for Advancing Green Shipping Partnerships between California and Shanghai

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Introduction

Shipping accounted for nearly 3% of global human-caused carbon dioxide (CO_2) emissions in 2018 and has increased its carbon dioxide equivalent (CO_2e) by 9.6% since 2012. If no further action is taken, it is estimated that international shipping emissions would represent 90%-130% of 2008 emission levels by 2050.[1] As nations, states, and cities ramp up their efforts to meet climate goals, the decarbonization of maritime operations has emerged as both a challenge and an opportunity for innovation. This brief examines maritime decarbonization policies across multiple governance levels- from global frameworks to local initiatives- highlighting how these efforts intersect and complement one another. By exploring solutions at international, national, state, and municipal levels, this brief aims to provide a comprehensive understanding of the pathways and strategies needed to achieve a cleaner, more sustainable future for the maritime sector.

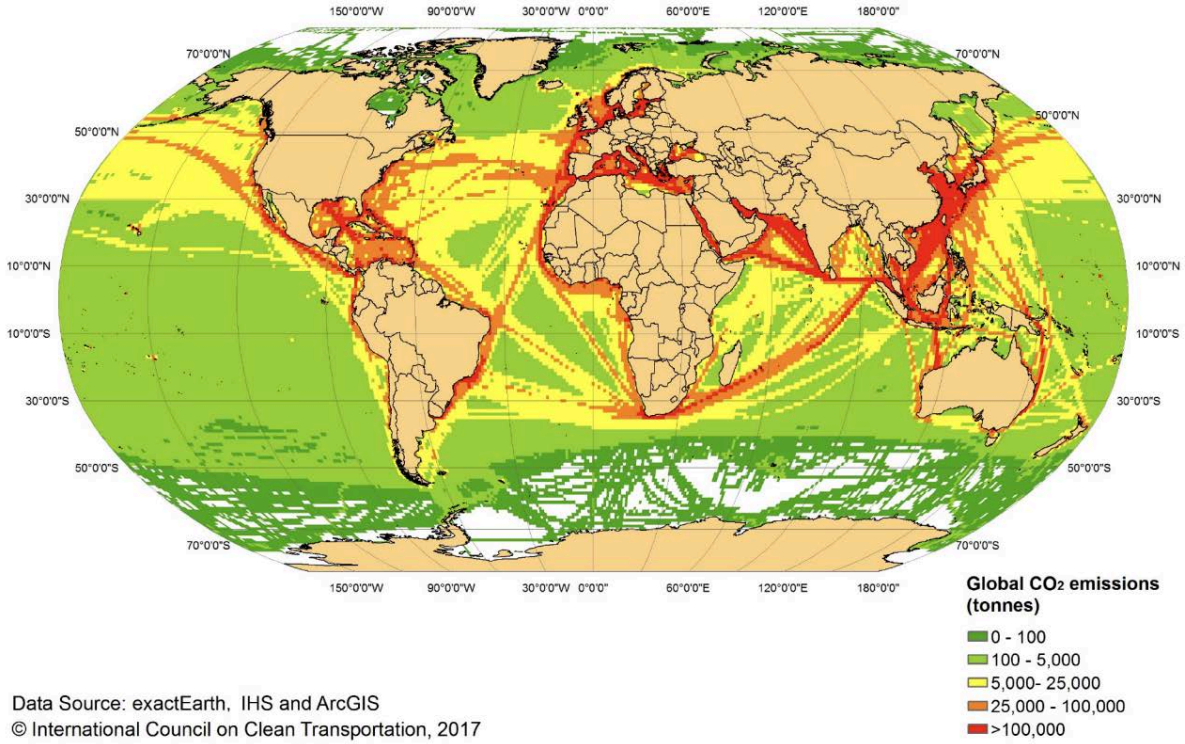

Figure 1. Global distribution of shipping CO2 emissions in 2015. Olmer et al. (2017) International Council on Clean Transportation.
https://theicct.org/publication/greenhouse-gas-emissions-from-global-shipping-2013-2015/

[1] Faber et al. 2021. Fourth IMO GHG Study 2020. https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/Fourth%20IMO%20GHG%20Study%202020%20-%20Full%20report%20and%20annexes.pdf

Global Maritime Decarbonization Policy

The International Maritime Organization (IMO), which sets the global rulings and oversees global shipping decarbonization through its Marine Environmental Protection Committee (MEPC), has established a strategy to reduce greenhouse gas (GHG) emissions. In its scheduled revision of the GHG strategy in 2023, the IMO committed to achieving net-zero emissions "by or around, i.e., close to 2050", with intermediate targets to reduce total GHG emissions by 20-30% by 2030 and 70-80% by 2040, relative to 2008 levels[2]. These updates mark a significant improvement over the initial 2018 strategy, which only aimed to cut emissions by 50% by 2050. Policies such as the IMO Sulphur Cap of 2020, which reduced sulfur content in marine fuels to 0.5%, alongside technical measures like the Carbon Intensity Indicator (CII) and Energy Efficiency Design Index (EEDI/EEXI), set efficiency standards for ship operations, engines, and newbuilds to help lower emissions.

To meet these ambitious goals set out in the revised strategy, the IMO can develop measures to ensure reporting and compliance with emissions regulations while encouraging collaboration among member states. Currently, member states are in discussion to finalize amendments to draft legal text on the midterm measures, for approval in April 2025, and formal adoption into the International Convention for the Prevention of Pollution from Ships (MARPOL) legal framework in October 2025. These proposed measures include a goal-based marine fuel standard that will phase in the mandatory use of fuels with less GHG intensity and an adjacent emissions pricing mechanism.

[2] International Maritime Organization, "MEPC 82 Makes Progress on IMO Net Zero Framework," *IMO* (January 2025), https://www.imo.org/en/MediaCentre/PressBriefings/pages/MEPC-82-makes-progress-IMO-netzero-framework.aspx.

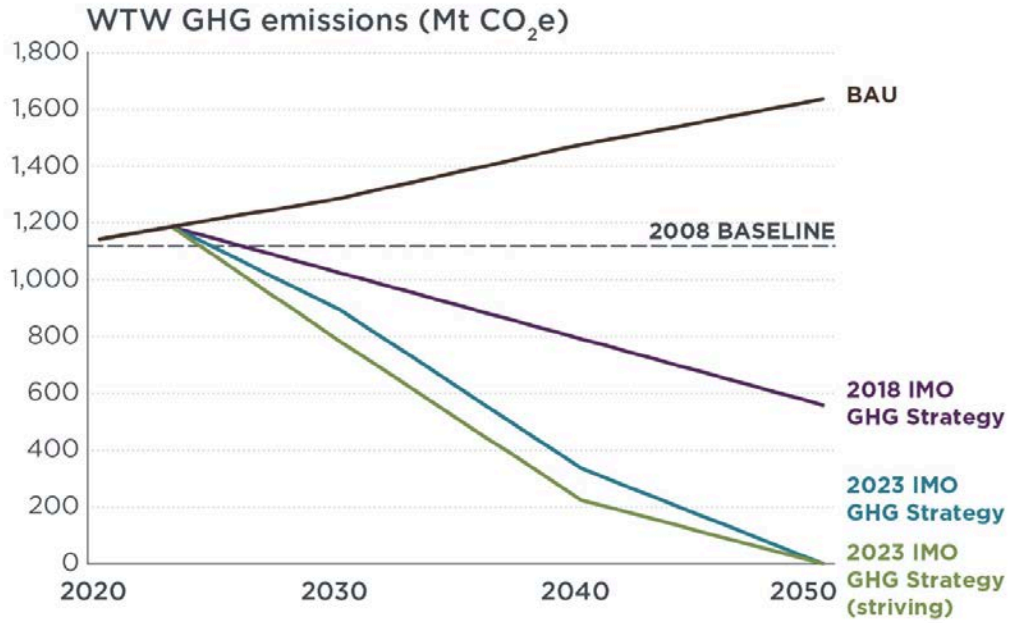

Figure 2. Well-to-wake GHG emissions pathways implied by the revised (2023) strategy, compared to the initial (2018) strategy, the emissions in 2008, and business-as-usual (BAU) emissions. Comer and Carvalho (2023) International Council on Clean Transportation.
https://theicct.org/marine-imo-updated-ghg-strategy-jul23/

Outside of global governing forums, international partnerships have largely driven momentum, leveraging existing trade relationships and combining these with commitments to adopt emission-reducing fuels and technologies at ports and on shipping routes. These collaborative agreements are formalized under the banner of "green shipping corridors." The only overarching green-corridor coalition is the Clydebank Declaration, launched at COP26 in 2021, which provides a framework for voluntary cooperation among 27 signatory nations to develop green shipping corridors.[3]

One of these corridors is the Los Angeles - Long Beach - Shanghai Green Shipping Corridor that connects one of the world's busiest container ship routes. Goals in this specific green corridor include developing operational efficiency strategies for all shipping lines that operate on the route, begin deploying reduced or zero lifecycle carbon emission capable ships by 2025, and facilitating investment in clean marine fueling infrastructure at the partner ports. Launched in January 2022, the partnership is

[3] UK Government, "COP 26 Clydebank Declaration for Green Shipping Corridors," *UK COP26* (November 2021), https://webarchive.nationalarchives.gov.uk/ukgwa/20230313124737/https://ukcop26.org/cop-26-clydebank-declaration-for-green-shipping-corridors/.

jointly led by the Port of Los Angeles, Port of Long Beach, and Shanghai Municipal Transportation Commission, the City of Los Angeles, in collaboration with the major container shipping lines, C40 Cities and other participating partners.[4] Significant milestones in the Los Angeles–Long Beach–Shanghai Green Shipping Corridor include the release of the "Green Shipping Corridor Implementation Plan Outline," the expansion of shore power facilities and clean energy refueling capacity at the Port of Shanghai, and ongoing engagement with fuel and bunkering service providers at the Ports of Los Angeles and Long Beach. The corridor partners have also been assessing alternative fuel demand and supply, developing a timeline for planned vessel, fuel, and technology launches, and nominating carrier services to participate in the initiative. Additionally, efforts have focused on collecting low-carbon fleet development roadmaps from carriers, defining the corridor's working structure, and holding regular virtual and in-person partnership meetings. A key milestone was a high-level meeting between Los Angeles Mayor Karen Bass and Shanghai Mayor Gong Zheng, reaffirming each city's commitment to the collaboration.[5]

U.S. Federal Maritime Decarbonization Policy

Within the last few years, the U.S. federal government has demonstrated a commitment to maritime decarbonization through domestic legislation and international leadership. Agencies like the Environmental Protection Agency (EPA), Department of Energy (DOE), and the Maritime Administration (MARAD) under the Department of Transport (DOT) play pivotal roles in advancing these efforts. The EPA enforces emissions reduction standards through regulations like those under the Clean Air Act, while MARAD oversees programs to promote cleaner shipping practices through programs such as the US Center for Maritime Innovation. Additionally, federal grants, including those under the Port Infrastructure Development Program (PIDP), fund projects to reduce emissions at ports by supporting electrification, alternative fueling stations, and other green technologies[6]. These initiatives align with the goals outlined in the Maritime Decarbonization Action Plan, published in December 2024 by the DOE

[4] Press Release "Port of Los Angeles, Port of Shanghai, and C40 Cities announce partnership to create world's first transpacific green shipping corridor between ports in the United States and China," January 28, 2022, https://www.c40.org/news/la-shanghai-green-shipping-corridor/

[5] Port of Los Angeles - Port of Long Beach - Port of Shanghai Green Shipping Corridor Partnership, *Annual Progress Report 2024*, September 2024, https://www.c40.org/wp-content/uploads/2024/03/GSC_Annual_Report_2024_EN_WEB.pdf.

[6] U.S. Department of Transportation, Maritime Administration, "Investing in America: Biden-Harris Administration Announces Nearly $580 Million for Ports to Strengthen American Supply Chains and Lower Costs," *Maritime Administration*, November 15, 2024, https://www.maritime.dot.gov/newsroom/investing-america-biden-harris-administration-announces-nearly-580-million-ports.

which identifies pathways to achieve a zero-emissions maritime sector by 2050. In tandem with these efforts, the U.S. DOE has invested in hydrogen hubs to catalyze the production and distribution of hydrogen. These hubs, funded through the Bipartisan Infrastructure Law, enhance the availability of hydrogen as a maritime fuel alternative. One such Hydrogen Hub is the California hub, also known as the Alliance for Renewable Clean Hydrogen Energy Systems (ARCHES) and is in its scope commenting period for evaluation of its DOE issued Environmental Impact Statement.[7]

To accelerate decarbonization in the United States, policy solutions must expand funding opportunities for innovative maritime technologies, green corridors, integrate federal incentives that coincide with the IMO revised strategy, and streamline permitting for green infrastructure projects. Coordinating domestic actions with international frameworks would ensure the U.S. remains a key player in maritime decarbonization while bolstering economic competitiveness. Such strategies not only reduce GHG emissions but also drive advancements in clean energy, positioning the maritime sector as a cornerstone of the broader energy transition. However, it should be noted that it is yet to be seen what new specific policy direction the Trump Administration will take regarding these federal policy developments.

[7] U.S. Department of Energy, *DOE/EIS-0570: California Hydrogen Hub*, https://www.energy.gov/nepa/doeeis-0570-california-hydrogen-hub.

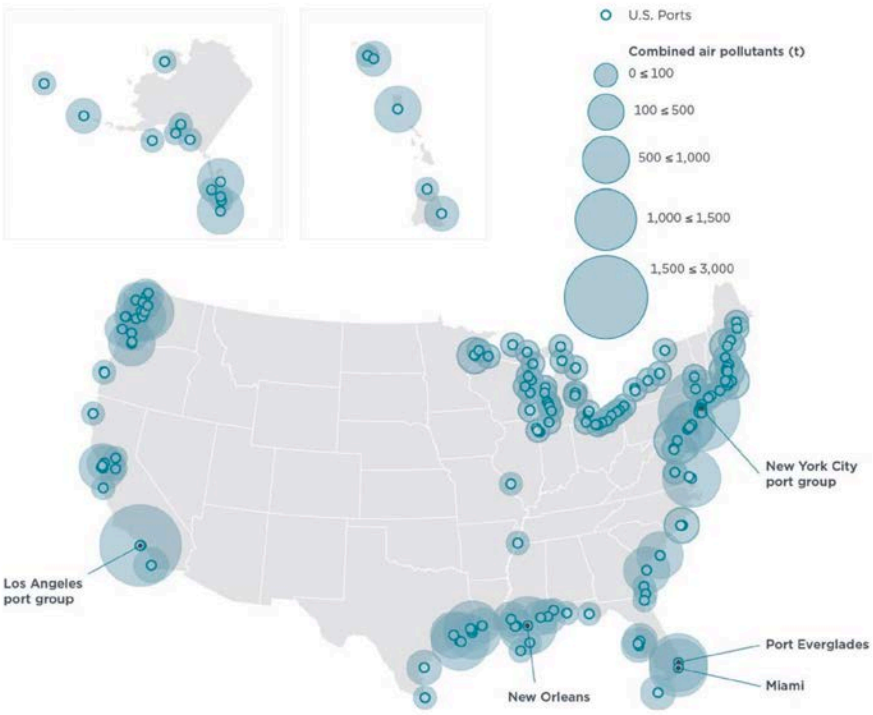

Figure 3. Combined NOx, SOx, and PM10 emission estimates from at-berth vessels in U.S. ports, 2019. Decker and Sturrup (2024)
https://theicct.org/publication/us-port-emissions-screening-berthed-vessels-sept24/

Chinese National Maritime Decarbonization Policy

China is advancing its maritime decarbonization agenda through port electrification, low carbon fuel development and green Ocean-Going Vessel (OGV) ship manufacturing. Port electrification is a key component of the nation's clean transportation strategies,[8] with a strong emphasis on the ports along the Yangtze River.[9] By 2020, more than 1,200 shore power facilities for 850 berths along the Yangtze River have been completed.[10] China is also prioritizing low carbon fuel development, electricity, methanol, and hydrogen, as part of its efforts to advance green and smart

[8] State Council. (2021, December 28). The Comprehensive Work Plan for Energy Conservation and Emission Reduction for the 14th Five-Year Plan Period (2021-2025). https://www.gov.cn/zhengce/content/2022-01/24/content_5670202.htm; Ministry of Transportation. (2021, October 29). The 14th Five-Year Plan for Green Transportation. https://www.gov.cn/zhengce/zhengceku/2022-01/21/content_5669662.htm.
[9] Ministry of Transportation, Ministry of Finance, National Development and Reform Commission, & State Grid of China. (2021, July 14). Notice on Further Promoting the Use of Shore Power by Ships Docking in the Yangtze River Economic Belt. https://www.mot.gov.cn/2021zhengcejd/cjjjdchuanbokaogang/.
[10] China Energy News. (2020, December 7). Basic shore power coverage along the Yangtze River ports. http://paper.people.com.cn/zgnyb/html/2020-12/07/content_2022614.htm.

ships.[11] The country plans to establish a comprehensive green shipbuilding system by 2030 that encompasses ship design, green ship development and manufacturing, and the green supply chain.[12] China's shipbuilding industry, aided by cost advantages and strong policy support, has grown since the 1980s to encompass a large share of the global market. Production, as measured by share of global gross tonnage (GT), grew by 17.5% between 2014 and 2021, when China accounted for 44% of the gross tonnage of ships built globally.[13] In 2023, China achieved a significant milestone, where new orders for green ships captured 57% of the global green ship market share. [14]

Policy recommendations to advance maritime decarbonization across China should emphasize collaborative approaches to accelerate progress. Supporting bilateral agreements for technical sharing in green shipbuilding could foster innovation and enhance capacity among nations with varying levels of technological development. International cooperation on the commercial deployment of green fuels and vessels may also help address shared challenges such as infrastructure investment and operational scalability. Additionally, experience sharing on carbon pricing mechanisms and emission reduction policy design in the shipping sector would enable countries to build on successful strategies and refine approaches to suit their unique circumstances.

[11] Ministry of Industry and Information Technology, National Development and Reform Commission, Ministry of Finance, Ministry of Ecology and Environment, & Ministry of Transportation. (2022, September 27). Implementation Opinions on Accelerating the Green and Intelligent Development of Inland Waterway Vessels. https://www.gov.cn/gongbao/content/2022/content_5729426.htm.

[12] Ministry of Industry and Information Technology, National Development and Reform Commission, Ministry of Finance, Ministry of Ecology and Environment, & Ministry of Transportation. (2023, December 26). Action Plan for the Green Development of the Shipbuilding Industry (2024–2030). https://www.gov.cn/zhengce/zhengceku/202312/content_6923175.htm.

[13] United Nations Conference on Trade and Development, 2023

[14] Xinhua News. (2024, April 4). China's "Green Ships" Set Sail Globally. http://www.xinhuanet.com/fortune/20240404/73b20cb7ff3e4bd88560bc36342660de/c.html.

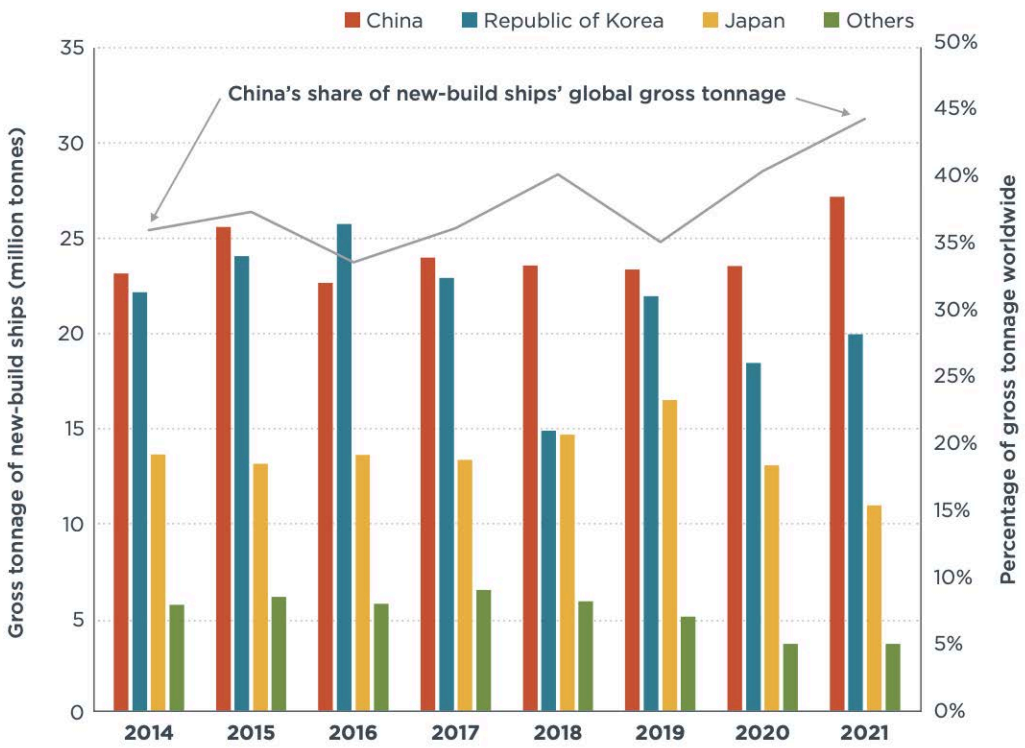

Figure 4. Shipbuilding by country and China's share of the global market, 2014-2021. United Nations Conference on Trade and Development (2023)
https://unctad.org/publication/trade-and-development-report-2023

California-Level Maritime Decarbonization Policy

California has been a leader in cleaning the air and the fight against climate change for decades. Most recently, California passed Assembly Bill (AB) 1279 (Muratsuchi, Chapter 337, Statutes of 2022). This bill establishes the State's science-based policy to achieve carbon neutrality no later than 2045 and to reduce anthropogenic GHG emissions 85% below 1990 levels also by 2045. Reaching these goals requires a whole of government approach, and the California Air Resources Board (CARB) plays a lead role in developing, and updating every five years, the statewide Scoping Plan to meet them. CARB is also responsible for regulating emissions from statewide mobile sources, including equipment at ports. CARB's Low Carbon Fuel Standard (LCFS), which regulates the carbon intensity of on-road and aviation transportation fuels by promoting cleaner, low-carbon alternatives, also offers incentives to power Ocean-Going Vessels (OGV) with electricity while docked at ports, in place of burning fossil fuels. CARB's most recent update to the LCFS in 2024 includes targets to cut the

carbon intensity of transportation fuels by 30% by 2030 and 90% by 2045.[15] As a result of the rigorous research and stakeholder engagement of the 2024 update to the LCFS, CARB is also looking to include marine fuels into the next Scoping Plan update and future LCFS rulemakings as appropriate.[16]

Three principal CARB regulations currently control air pollutant emissions from OGVs and commercial harbor crafts (CHC) with the co-benefit of reducing GHG emissions: the California OGV Fuel Regulation, the OGVs At Berth Regulation, and the CHC Regulation. These regulations, and others for cargo-handling equipment and trucks that service ports, target GHG and air pollution emission sources that are critical to meeting State climate targets and federal air quality standards. These standards are outlined in the 2022 Strategy for the State Implementation Plan and protect public health in port communities, as residents currently breathe some of the most polluted air in the country.[17]

The California OGV Fuel Regulation requires the use of marine gas oil or marine diesel oil with a maximum of 0.1% sulfur by weight within Regulated California Waters.[18] The At Berth Regulation requires certain vessel types to plug into shore power or use an equally effective CARB approved emission control strategy while at berth.[19] CARB is considering a regulation to control emissions from OGVs in transit.[20] Expanding the scope of the At Berth Regulation to bulk and general cargo vessels and regulating emissions at anchor have been discussed as potential future measures as well.[21] CARB could also consider implementing incentive measures together with ports and air

[15] All documents related to the 2024 update to the LCFS can be found here: https://ww2.arb.ca.gov/rulemaking/2024/lcfs2024.
[16] Public Hearing to Consider Amendments to the Low Carbon Fuel Standard. Final Statement of Reasons for Rulemaking, Appendix B Summary of Comments and Agency Responses, pages 103 – 123: https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2024/lcfs2024/fsor_appb.pdf.
[17] California Air Resources Board, *2022 State Strategy for the State Implementation Plan* (Sacramento, CA: California Air Resources Board, 2022), https://ww2.arb.ca.gov/sites/default/files/2022-08/2022_State_SIP_Strategy.pdf.
[18] California Air Resources Board. Final Regulation Order: Fuel Sulfur and Other Operational Requirements for Ocean-Going Vessels Within California Waters and 24 Nautical Miles of the California Baseline, 13, 17 California Code of Regulations (CCR) § 2299.2, 93118.2 (2011). https://ww2.arb.ca.gov/sites/default/files/2019-11/fuelogv17_ADA.pdf.
[19] California Air Resources Board. Final Regulation Order: Control Measure for Ocean-going Vessels at Berth, 13, 17 California Code of Regulations (CCR) § 2299.3, 93118.3, 93130- 93130.22 (2020). https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2019/ogvatberth2019/fro.pdf.
[20] California Air Resources Board. "Ocean-Going Vessel In-Transit Rulemaking Kickoff & Emissions Inventory Workshop." December 5, 2024. https://ww2.arb.ca.gov/sites/default/files/2024-12/2024%20December%205%20OGV%20In-Transit%20Workshop%20Presentation.pdf.
[21] California Air Resources Board. "Interim Evaluation Report: Control Measure For Ocean-Going Vessels At Berth," December 1, 2022. https://ww2.arb.ca.gov/sites/default/files/2022-12/At%20Berth%20Interim%20Evaluation%20Report_Final_Remediated.pdf.

districts to encourage just-in-time arrival and visits of ships using low- and zero-emission fuels.

Shanghai Municipality-Level Maritime Decarbonization Policy

As China's economic powerhouse for decades, Shanghai is now taking the lead in advancing decarbonization actions. The city aims to peak its carbon emission before 2025, a timeline that surpasses the national goal by half a decade.[22] To achieve this climate goal, Shanghai adopts a holistic approach aiming to deliver co-benefits. In its latest Clean Air Action Plan, Shanghai emphasizes the coordinated control of particulate matter 2.5 and ozone, joint reduction of volatile organic compounds and nitrogen oxides, and enhanced regional cooperation with the Yangtze River Delta to align pollution and carbon reduction efforts.[23] In addition, to implement the 2015 national emission control policy that designated certain areas in the Yangtze River Delta as emission control areas,[24] Shanghai has introduced a series of measures and regulations to curb shipping-related pollution. These include stricter emission standards for sulfur oxides, particulate matter and nitrogen oxides, application of new fuel standards,[25] and enhanced oversight of shore power.[26]

Furthermore, Shanghai is advancing shipping decarbonization across multiple fronts. It plans to develop a shipping-specific carbon inventory, integrate the shipping sector into Shanghai's carbon trading system,[27] and establish a green supply chain for the shipbuilding industry, one of Shanghai's key manufacturing industries.[28] Public-private partnerships are being formed to promote green vessels. For instance, Shanghai has

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[22] Shanghai's 14th FYP of economic and social development. (n.d.). Retrieved November 7, 2023, from https://www.shanghai.gov.cn/nw12344/20210129/ced9958c16294feab926754394d9db91.html.
[23] Shanghai government. (2023, July 15). Shanghai Clean Air Action Plan 2023-2025. https://www.shanghai.gov.cn/nw12344/20230807/495e682c56924cfb96c34b88022a071e.html.
[24] Ministry of Transportation. (2015, December 4). Implementation Plan for Emission Control Areas in the Waters of the Pearl River Delta, Yangtze River Delta, and Bohai Rim (Beijing-Tianjin-Hebei). https://www.gov.cn/xinwen/2015-12/04/content_5019932.htm.
[25] Shanghai Municipal Commission of Economy and Informatization. (2018, December 28). Notice on Ensuring the Supply of the Refined Oil Market in the Near Term. https://www.shanghai.gov.cn/nw12344/20200813/0001-12344_57768.html.
[26] Shanghai Municipal Transportation Bureau. (2019, June 4). Shanghai Port Shore Power Development Plan. https://www.shanghai.gov.cn/cmsres/f1/f12acea11f73401ebf282614909a2437/44580f5299a16fb46c77765343399a4b.pdf
[27] Shanghai government. (2023, June 29). Action Plan for Enhancing Shanghai's Shipping Services to Support the Development of an International Shipping Center. https://www.shanghai.gov.cn/nw12344/20230721/85cde799f0d4499e803f648c0ab14b5f.html.
[28] Shanghai government. (2024, March 16). Action Plan for Accelerating the Establishment of a Product Carbon Footprint Management System and Building a Green, Low-Carbon Supply Chain. https://www.shanghai.gov.cn/nw12344/20240325/9ddcd99b89f14cb2a3c301ab8fc8c859.html.

collaborated with China COSCO SHIPPING Corporation to develop electric vessels, which were put into operation in April 2024.[29]

Advancing maritime decarbonization in Shanghai and the surrounding region requires targeted strategies that address emissions at multiple levels. Localized approaches, such as sharing experiences on setting shipping emission standards, building carbon inventories, and integrating the sector into cap-and-trade systems, can help regions design effective policies. Supporting greater use of shore power through incentives and non-monetary programs offers an opportunity to reduce emissions from docked vessels by shifting to cleaner energy sources. Furthermore, deploying low or zero-emission heavy-duty trucks at ports through policy innovation and technological advancements can significantly reduce on-site emissions, contributing to cleaner port operations.

Port of Los Angeles and Long Beach

The Port of Los Angeles and the Port of Long Beach have each pioneered measures to reduce air emissions from port operations in an effort to improve air quality in the southern California region. In 2006, the ports released the joint San Pedro Bay Ports Clean Air Action Plan (CAAP), focused on criteria pollutants like nitrous oxides (NOx), sulfur oxides (SOx), and diesel particulate matter (DPM), that included goals for significant reduction of these pollutants by 2023 as well as specific control measures the ports committed to implement to achieve these goals. Many of the measures included in the CAAP were later adopted by CARB in state-wide rules. By 2023, the ports had achieved DPM reductions of 91% for Los Angeles and 92% for Long Beach, NOx reductions of 74% for Los Angeles and 71% for Long Beach, and SOx reductions of 98% for both Los Angeles and Long Beach when compared to 2005 levels. The 2017 CAAP Update expanded its focus to include carbon emissions alongside criteria pollutants. In this update, the ports set targets to reduce GHG emissions by 40% below 1990 levels by 2030 and 80% by 2050, while also committing to a full transition to zero-emission terminal equipment by 2030 and zero-emission on-road trucks by 2035.[30] To reach these goals, they are employing a range of programs related to drayage trucks (Clean Trucks Program), terminal equipment, and vessels. As part of the CAAP, the ports offer several incentive programs to support clean trucks and greener vessels. One example is the Clean Truck Fund to support the transition of drayage trucks to

[29] Shanghai government. (2024, April 23). The world's largest and first-ever Jiangsu-to-Haiwan 10,000-ton pure electric container ship embarks on its maiden voyage. https://www.coscoshipping.com/col/col6865/art/2024/art_ba3d26a036844b519cb7cbe768e77890.html.

[30] San Pedro Bay Ports, "2017 Clean Air Action Plan Update," *Clean Air Action Plan*, https://cleanairactionplan.org/2017-clean-air-action-plan-update/.

zero emission through collecting a fee from non exempt trucks. The Clean Trucks Program at the Port of Long Beach provided a progressive ban on older heavy pollution diesel drayage trucks and has led to a 90% reduction in port truck emissions.

Building on the success of the Ports of Los Angeles and Long Beach in decarbonizing port operations, scaling proven policies across other major ports could amplify global emission reduction efforts. Programs like the Clean Truck Fund and the Clean Trucks Program, which have significantly reduced port truck emissions, offer replicable models for transitioning to zero-emission terminal equipment and vehicles. Establishing joint initiatives between the Ports of Los Angeles/Long Beach and the Port of Shanghai could further advance global decarbonization by sharing expertise and resources, particularly in green fuel bunkering and zero-emission technology deployment. These collaborative efforts would help align international sustainability goals while fostering innovation and operational efficiencies in port decarbonization.

Port of Shanghai

The Port of Shanghai has been the world's top port for annual container throughput for 14 consecutive years,[31] reaching a new milestone in 2024 by surpassing 50 million twenty-foot equivalent units (TEUs) for the first time.[32] Aiming to establish itself as an international shipping center, Shanghai is emphasizing port electrification, green fuel bunkering, and clean port operations.[33] By 2025, the city aims for 100% shore power coverage, a 30% shore power utilization rate at container terminals, and 100% utilization rate at cruise terminals and for port vessels.[34] As of 2023, the port has reached 90% shore power coverage.[35]

The Port of Shanghai is advancing its initiatives to reduce emissions by adopting renewable energy technologies and implementing systems to optimize port operations and logistics. Shanghai prioritizes clean trucks at the port. For instance, 60 of its 1,394 trucks are pure electric container trucks and a pilot program for intelligent hydrogen

[31] People's Daily. (2024, January 3). Shanghai Port has maintained the highest container throughput globally for 14 consecutive years. http://paper.people.com.cn/rmrbhwb/html/2024-01/03/content_26034863.htm.
[32] Shanghai International Port Group. (2024, December 22). 50 Million TEU+ Shanghai Port Sets a World Record for Annual Container Throughput. https://www.portshanghai.com.cn/jtxw/4288.jhtml.
[33] Shanghai government. (2023, June 29). Action Plan for Enhancing Shanghai's Shipping Services to Support the Development of an International Shipping Center. https://www.shanghai.gov.cn/nw12344/20230721/85cde799f0d4499e803f648c0ab14b5f.html.
[34] Shanghai government. (2021, June 23). The 14th Five-Year Plan for Developing Shanghai as an International Shipping Center. https://www.shanghai.gov.cn/nw12344/20210708/17c981e16c96444abb0c73b590d39fc5.html; Shanghai government. (2022, August 8). Shanghai Carbon Peaking Implementation Plan. https://sisi.shmtu.edu.cn/2022/1024/c8825a192237/page.htm.
[35] China Transportation News Network. (2023, May 26). Shanghai Port's shore power coverage at container berths exceeds 90% within the year. https://www.mot.gov.cn/jiaotongyaowen/202305/t20230526_3834222.html.

heavy-duty trucks is being conducted.[36] Since 2016, the port has enforced a port-specific emission standard, requiring ships to use fuel with a sulfur content ≤0.5% by mass while docked, and will soon be subject to a stricter emission control policy.[37] Furthermore, the Port of Shanghai is making strides on advancing liquified natural gas (LNG) and green methanol bunkering. By 2024, it had completed 125 LNG bunkering operations for international vessels, totaling 730,000 cubic meters of fuel. It also aims to boost LNG bunkering capacity to 1 million cubic meters and increase green methanol and green ammonia bunkering to 1 million tons by 2030. In addition, the port also completed a "ship-to-ship" green methanol fueling operation for a large container ship in 2024, the first of its kind in China.[38]

Collaborative efforts between the Port of Shanghai and other leading ports, such as the Ports of Los Angeles and Long Beach, could drive significant advancements in maritime decarbonization. Facilitating technical exchanges on green port operations would enable these ports to share best practices, such as electrification of port equipment, shore power adoption, and emissions monitoring technologies, fostering innovation and operational efficiency. Establishing joint initiatives focused on green fuel bunkering infrastructure would further support the transition to low- and zero-emission fuels by creating a network of ports capable of accommodating alternative fuel demands. These partnerships can accelerate progress toward global decarbonization goals while reinforcing the role of major ports as leaders in sustainable maritime practices.

Fuels in the Maritime Space

Transitioning to low- and zero-emission fuels is critical to decarbonizing the global shipping industry. Presently, low-emission alternative fuels such as methanol, hydrogen, and ammonia are at various stages of development and have yet to be widely adopted. Fuel used in maritime applications is predominantly distillate fuels or residual fuels accompanied by an exhaust gas treatment system, because both are cost-effective and readily available. Another current maritime fuel, LNG, while offering immediate reductions in criteria pollutant emissions (e.g., NOx, SOx , PM), provides limited GHG benefits especially with risks of methane leakage and locking the industry into fossil fuel reliance. Biofuels, which can be drop-in fuels for short term adoptions,

[36] Shanghai government. (2023, July 14). Shanghai Hydrogen Energy Promotion and Application Plan for the Transportation Sector (2023-2025). https://www.shanghai.gov.cn/hqzxsj2/20240729/2505aba0dcdc4e3c986eda39c4fdc05b.html.
[37] Shanghai government. (2023, July 15). Shanghai Clean Air Action Plan 2023-2025. https://www.shanghai.gov.cn/nw12344/20230807/495e682c56924cfb96c34b88022a071e.html.
[38] Shanghai International Port Group. (2024, December 22). 50 Million TEU+ Shanghai Port Sets a World Record for Annual Container Throughput. https://www.portshanghai.com.cn/jtxw/4288.jhtml.

can offer emission reduction benefits, but are varying in the life cycle benefits depending on the carbon source and upstream practices.

For the next generation of maritime fuels, it is an increasingly-common practice to consider fuels on a fuel life cycle basis. This means, to account for their upstream emissions in production, rather than just the exhaust emissions when considering their environmental benefit. Methanol, particularly when derived from renewable sources, has lower carbon intensity than current traditional fuels and can leverage existing infrastructure for easier adoption. Renewable-produced hydrogen and ammonia hold potential for near-zero emissions but face significant barriers, including high production costs, safety concerns, and non-existent bunkering infrastructure. These challenges highlight the need for a collaborative movement in engine design, portside infrastructure development, and transparent emissions reporting to accelerate the transition to cleaner maritime fuels. In the recently published Maritime Decarbonization Action Plan, the US DOE proposes the creation of a new initiative, the "Sustainable Maritime Fuel Grand Challenge", which would be modeled after its aviation equivalent. This program would establish specific targets for alternative fuel production and infrastructure development to guide government agencies in achieving these goals. This challenge will depend on the definition of 'sustainable maritime fuel', which is currently in a public commenting stage through a Request For Information and is set to be developed in later 2025.[39]

To close the gap between traditional fossil based fuels and the emerging alternative fuels, policies should prioritize research and development in green fuel infrastructure and production to improve efficiency and scalability. Governments and industry stakeholders will need to bridge the current cost gap of expensive next generation fuels by incentivizing or rewarding uptake and use. Additionally, establishing clear and enforceable safety protocols is essential to address the operational risks associated with handling these fuels.

[39] U.S. Department of Energy, "Maritime Energy Emissions Innovation Action Plan," *Office of Energy Efficiency and Renewable Energy*, December 2024, https://www.energy.gov/sites/default/files/2024-12/doe-eere-modal-reports_maritime-energy-emissions-innovation-action-plan.pdf.

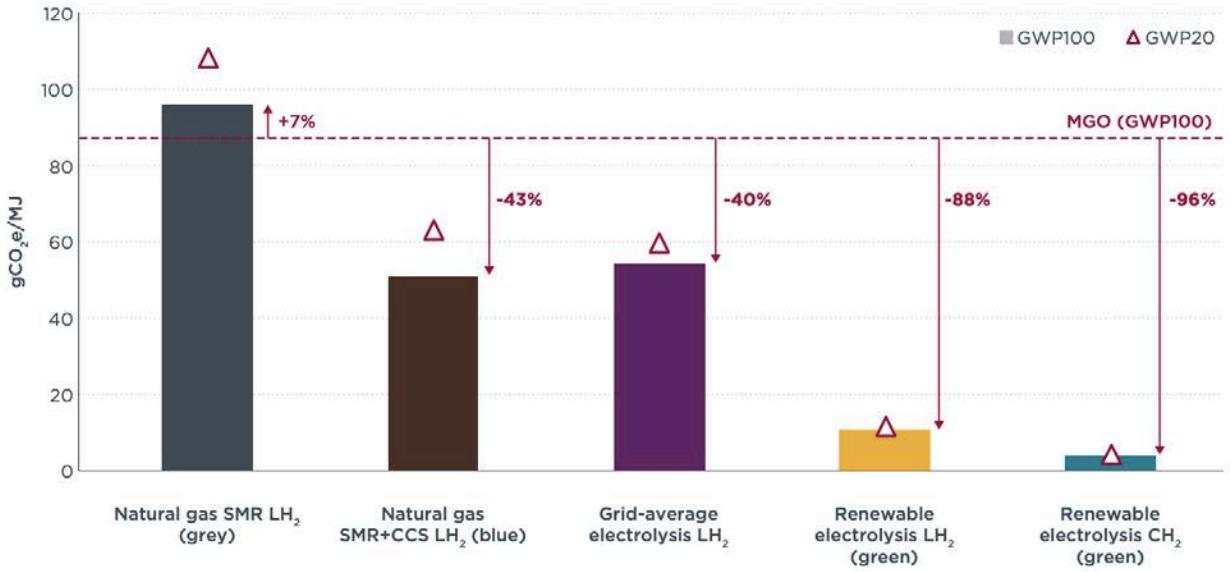

Figure 5. Hydrogen Pathway Life-cycle GHG Emissions. Carvahlo, Osipova, and Zhou (2023) International Council on Clean Transportation. https://theicct.org/publication/maritime-brazil-hydrogen-costs-mar23/