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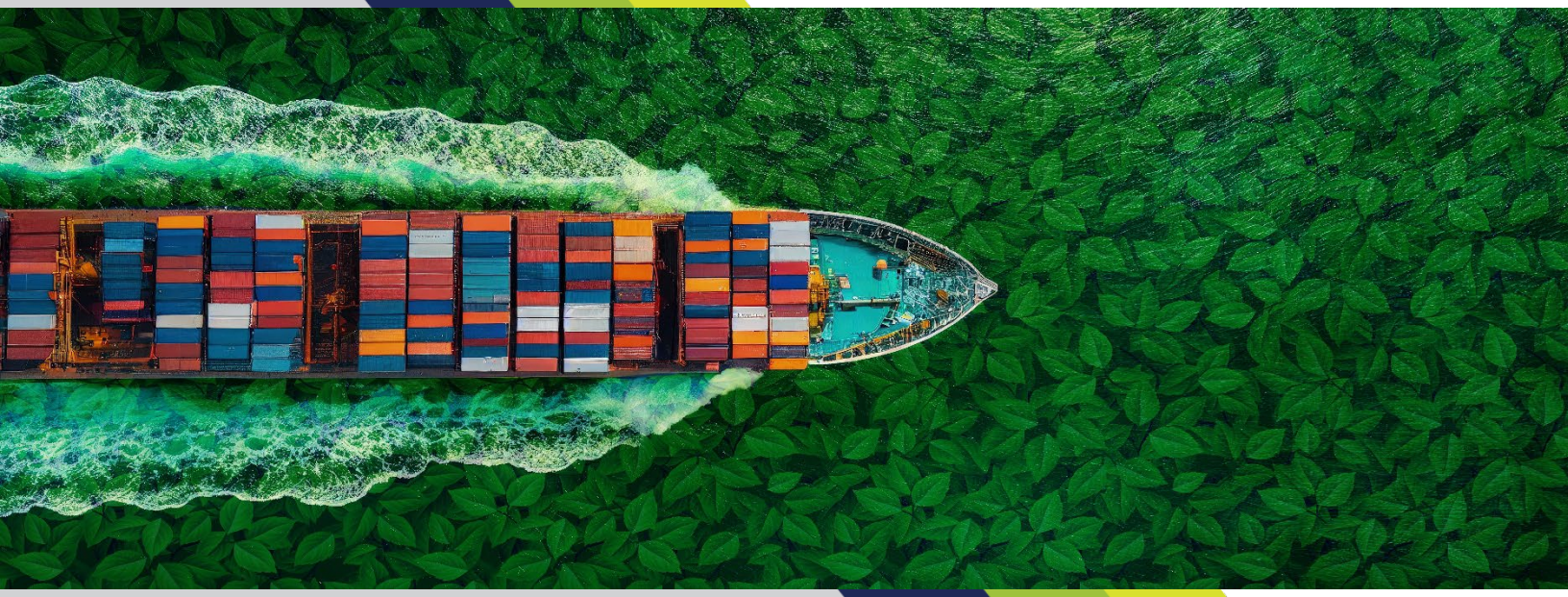

# DECARBONIZING THE MARITIME SHIPPING INDUSTRY

## Starter Guide to Reducing Greenhouse Gas Emissions from Maritime Shipping

MOMENTUM

U.S. Department of Transportation, Office of the Secretary
www.transportation.gov/Momentum

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**About this Toolkit**

The U.S. Department of Transportation's (U.S. DOT) Office of International Transportation and Trade developed this document as part of its *Momentum* initiative.

Through *Momentum*, U.S. DOT aims to assist global partners in sharing knowledge and best practices in key areas, including economic development, sustainability, and equity.

To learn more about U.S. DOT's *Momentum* resources, please visit www.transportation.gov/momentum

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This toolkit provides a suite of strategies and approaches to reduce greenhouse gas (GHG) emissions from maritime shipping (moving cargo along inland waterways, coastal, or sea routes). It aims to help government agency decision-makers:

- ✓ Better understand what maritime shipping is and why decarbonization of this sector is important;
- ✓ Identify stakeholders (players) and their roles in maritime shipping;
- ✓ Identify key maritime shipping-related decarbonization policies and why they matter; and
- ✓ Better understand strategies that agencies can take (in collaboration with others) to support decarbonizing the maritime shipping sector.

This toolkit uses the term "government agency" broadly to refer to a public entity that focuses on transportation or is involved in transportation decision-making at any level. Examples might include Federal transportation departments or sub-departments, ministries or sub-ministries, local or regional government entities, or port authorities.

This toolkit provides a starting point of information. For additional information on reducing GHG emissions from transportation, government agency decision-makers may want to view U.S. DOT's *Addressing Transportation's Impact: A Starter Guide to Reducing Transportation GHG Emissions.*

Please contact U.S. DOT's *Momentum* initiative to explore specific topics in more depth.

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# WHAT IS MARITIME SHIPPING?

Maritime shipping refers to the transport of goods via coastal, oceanic, or inland waterways. Maritime shipping is crucial to the global economy as well as many regional or domestic economies. Globally, ocean-going transportation provides the backbone for much of the world's trade: ships carry over 80 percent of internationally traded goods by volume, and over the next 25-30 years, substantial growth in maritime shipping is expected.[1]

Waterborne vessels carry everything from packaged consumer goods to livestock, chemicals, produce, vehicles, project cargo (such as wind turbine blades and cranes), and petroleum products.[2] Globally, Asia has the highest share of total international maritime trade by loaded tonnage, followed by the Americas, Europe, Oceania, and Africa. The Asia Pacific region is also the largest player in the global inland waterways market (32% market share), while Western Europe is the second largest player.[3]

Solar panels at Port of Seattle (Image source: Port of Seattle)

[1] https://theicct.org/sector/maritime-shipping/
[2] https://www.oneocean.com/news/vessel-types-explained/
[3] https://www.businesswire.com/news/home/20210226005455/en/Global-Inland-Water-Transport-Market-Report-2021---ResearchAndMarkets.com

# WHY CONSIDER CLIMATE IN MARITIME SHIPPING DECISION-MAKING?

Heavy fuel oil (HFO), also known as bunker fuel, is the most widely used fuel source for maritime shipping today.[4] When burned, HFO emits large amounts of carbon dioxide ($CO_2$), adding to global carbon emissions that contribute to climate change. Bunker fuel also contains large amounts of sulfur, which, when burned, produces fine particulates that are a concern for human health.[5] Burning HFO can also generate black carbon, which can absorb a million times the incoming solar energy as $CO_2$ and is a particular challenge near the Arctic.[6] According to the U.S. Department of Energy (U.S. DOE), if the maritime shipping industry was a country, it would be the sixth-highest global emitter of GHGs.[7]

**Small Island Developing States (SIDS)**

SIDS are particularly vulnerable to the impacts of climate change due to their geographies as low-lying island countries, economic reliance on maritime trade, developing economies, and other socioeconomic factors. Due to these and other factors, SIDS present special opportunities for maritime decarbonization efforts.

Regulators first began discussing the environmental impacts of burning HFO in the early 1970s, at the first International Convention for the Prevention of Pollution from Ships (MARPOL) conference. In 1997, the International Maritime Organization (IMO) established limits on international maritime ship emissions, which entered into force in 2005.[8] The IMO has also introduced guidelines for more energy efficient ship design (see page 40 for additional details) and recently revised its maritime GHG strategy to include increased ambitions for reducing GHG emissions from ships by or around 2050 (see page 13 for additional details).

In 2021, at the 26th United Nations Climate Change Conference (COP26), a multi-country coalition launched the Clydebank Declaration. This calls for signatories to establish and develop Green Shipping Corridors (GSCs). As of March 2022, there were 22 signatories to the Clydebank Declaration. GSCs aim to take a holistic approach to port-to-port decarbonization by incorporating strategies to reduce maritime fuel emissions as well technology, infrastructure, coordination, and regulatory actions (see page 25 for additional information on GSCs). The U.S. Department of State (U.S. DOS) released a GSC Framework in April 2022 to outline specific building blocks and action steps for countries interested in pursuing GSCs.

[4] https://www.marineinsight.com/tech/marine-heavy-fuel-oil-hfo-for-ships-properties-challenges-and-treatment-methods/
[5] https://e360.yale.edu/features/at-last-the-shipping-industry-begins-cleaning-up-its-dirty-fuels
[6] Black carbon accounts for 21 percent of $CO_2$-equivalent emissions from ships, making it the second most important driver of the shipping industry's climate impacts after $CO_2$. https://www.congress.gov/117/chrg/CHRG-117hhrg44944/CHRG-117hhrg44944.pdf
[7] https://www.energy.gov/eere/maritime-decarbonization#:~:text=Maritime%20decarbonization%20is%20the%20process,rise%20to%201.5%2Ddegrees%20Celsius.
[8] https://e360.yale.edu/features/at-last-the-shipping-industry-begins-cleaning-up-its-dirty-fuels

# MARITIME SHIPPING IMPACTS ON CLIMATE CHANGE

The transportation sector is responsible for more than a third of global GHG emissions.[9] The maritime shipping industry contributes about 3 percent to overall global GHG emissions.[10] As compared to some other modes of transportation such as trucking, maritime shipping produces lower GHG emissions on a per-ton-mile basis.[11] However, emissions from maritime shipping are expected to increase as freight demand grows.[12] For example, the IMO estimated that international maritime shipping emissions will increase by 90 to 130 percent of 2008 emissions by 2050. The International Council on Clean Transportation (ICCT) estimated that ocean-going ships could contribute 17 percent to total human-caused carbon emissions by 2050.[13,14]

**Air Pollutants**

In addition to carbon emissions, activity associated with maritime shipping (such as the use of fossil fuel-based cargo-handling equipment in ports) also introduces air pollutants, such as particulate matter (PM) and nitrogen oxides ($NO_x$), into the atmosphere. These pollutants have negative environmental impacts (such as reduced air quality) as well as negative impacts on human health, especially in communities located in close geographic proximity to shipping activities, such as ports.

Source: Ports at the Forefront

[9] https://www.iea.org/topics/transport
[10] The IMO reported that in 2018, maritime shipping was responsible for about 2.89 percent of all human-caused GHG emissions. https://www.imo.org/en/OurWork/Environment/Pages/Fourth-IMO-Greenhouse-Gas-Study-2020.aspx
[11] https://www.wsp.com/en-in/insights/designing-net-zero-ports
[12] www.oecd.org/ocean/topics/ocean-shipping/
[13] https://theicct.org/sector/maritime-shipping/#:~:text=Ocean%2Dgoing%20ships%2C%20which%20carry,caused%20carbon%20emissions%20by%202050.
[14] Another study conducted by Transport & Environment, a European Union NGO, found that under a business-as-usual scenario where other sectors reduce emissions to below 2 degrees Celsius, shipping could represent about 10 percent of overall global GHG emissions by 2050. www.transportenvironment.org/challenges/ships/greenhouse-gases/

# CLIMATE CHANGE IMPACTS ON MARITIME SHIPPING

While maritime shipping contributes GHG emissions, this sector is also impacted by climate change. Many of the same strategies that reduce shipping's GHG emissions will in turn help mitigate the climate change-induced impacts experienced by the sector.

Impacts include increased risks to infrastructure, vessels in operation,[15] and logistics due to sea level rise, inland flooding, droughts, and heat waves. Climate change can increase the severity of these types of severe weather events as well as the frequency of these events. In turn, severe weather impacts can lead to trade disruptions, operational delays, and increased costs likely to be passed to consumers in the longer-term.[16] According to one research study, climate change-induced impacts to the maritime shipping industry could cost more than $9 billion per year by 2050 and $25 billion per year by 2100.[17] Climate change-induced disruptions at a single terminal or port can have significant ripple effects on the global economy. Countries can experience general economic downturns due to a disruption at one port.

Severe weather may also impact routing choices; for example, ocean-going vessels may need to adjust planned routes to bypass storms. While rerouting may reduce some risk to vessel loss or damage, it could also increase fuel needs and costs, leading to more GHG emissions from maritime shipping.

Climate change could also change shipping patterns due to reduction of ice cover along certain waterways or increased variations in some inland waterways water levels.[18]

[15] A research study sponsored by the Environmental Defense fund found that severe weather was responsible for more than 20% of the roughly 400 total worldwide vessel losses that occurred between 2015 and 2019. See https://www.edf.org/sites/default/files/press-releases/RTI-EDF%20Act%20Now%20or%20Pay%20Later%20Climate%20Impact%20Shipping.pdf

[16] https://www.edf.org/sites/default/files/press-releases/RTI-EDF%20Act%20Now%20or%20Pay%20Later%20Climate%20Impact%20Shipping.pdf

[17] This statistic reflects cost estimates associated with port damages and disruptions due to sea level rise and stronger storms. The research study notes that "future costs overall could be far higher than estimated here." https://www.edf.org/sites/default/files/press-releases/RTI-EDF%20Act%20Now%20or%20Pay%20Later%20Climate%20Impact%20Shipping.pdf

[18] https://www.sciencedirect.com/science/article/pii/S136192090800165X#sec1

**Severe Weather Disruption to Port Activity**

One of the most significant examples of economic disruption due to severe weather occurred as a result of Typhoon Maemi in 2003. The Port of Busan in South Korea, the 6th busiest container port in the world (as of 2020), was left inoperable for 91 days due to the storm. The typhoon caused over $1 billion in damage to the port. Storm-related losses from export slowdowns, disruptions, and lost business operations were estimated to be multiple millions of dollars. Typhoon Maemi was an example of a "super-typhoon" that scientists believe will be more likely to occur as a result of warmer ocean temperatures due to global climate change.

Content Source: The Top 50 Container Ports, Global Warming Could Spawn Super Typhoons, Port disruptions due to natural disasters: Insights into port and logistics resilience

Image source: https://www.researchgate.net/figure/Container-cranes-in-Pusan-port-destroyed-by-strong-wind-during-Typhoon-Maemi_fig2_32175853

# WHO ARE MARITIME SHIPPING STAKEHOLDERS? HOW CAN STAKEHOLDERS ADVANCE DECARBONIZATION?

Government agencies play an important role in the maritime shipping ecosystem, but there are many stakeholders involved that form a highly complex, interconnected web. Examples of stakeholders include policymakers, regulators, ports, shippers and shipping agents, ship owners and operators, ship builders, fuel providers, researchers, and many others (see below figure).

**Examples of Stakeholders Involved in the Maritime Shipping Ecosystem**

The maritime shipping ecosystem is complex and will look different in each country. It is not possible to apply a "one size fits all" approach for sector decarbonization. All stakeholders involved in the ecosystem have roles to play, although the specifics of each role depend on many factors. Stakeholders' roles may shift and evolve; stakeholders may also play multiple roles at once. While roles may change, there are six general strategy areas where stakeholders can take action (see below table). Government agencies can consider implementing strategies from one area or multiple areas in parallel.

| Strategy Area | What is Involved |
|---|---|
| **Planning and Policymaking** | Developing decarbonization goals and objectives; developing plans, programs, guidelines, and other policy initiatives to support reaching these objectives |
| **Regulating and Enforcing** | Developing decarbonization standards and targets; monitoring, overseeing, and tracking responses to standards and targets; developing and applying penalties for non-compliance |
| **Funding and Financing** | Providing funding to stakeholders (e.g., grant programs, incentives, or tax subsidies) to support specific projects aimed at decarbonization or to incentivize behaviors aligned with decarbonization goals |
| **Capacity Building** | Convening stakeholders to discuss decarbonization needs, gaps, and opportunities; ensuring alignment in activities and goals; developing training/education materials to communicate and reinforce information; recruiting and retaining a diverse workforce; creating a green workforce |
| **Research, Development, and Technology (RD&T)** | Investigating, analyzing, and assessing decarbonization through data collection and analysis; advancing novel and cutting-edge ideas; supporting commercialization of key technologies (e.g., tech transfer); supporting stakeholders in uptake of selected technologies (e.g., technical assistance) |
| **Building, Producing/ Manufacturing, Maintaining, and Operating** | Constructing maritime shipping infrastructure (e.g., terminals, vessels); maintaining infrastructure (e.g., dredging ship channels); producing resources or infrastructure (e.g., fuel, vessels) needed to move maritime freight; utilizing equipment and infrastructure to move or carry maritime freight |

# HOW CAN GOVERNMENT AGENCIES SUPPORT MARITIME DECARBONIZATION GOALS?

Maritime shipping is difficult to decarbonize due to the global nature of international maritime transport, the types of stakeholders involved across different sectors, the spectrum of vessel types and sizes used, the physical variability of waterways, and other factors. Government agencies and other stakeholders have already begun implementing strategies to help catalyze decarbonization of the maritime sector. Nonetheless, agencies need to implement a broad set of strategies, in coordination with other stakeholders in public and private sectors, to provide redundancy and increase the potential for successful outcomes.

Electric shore power at the Port of Los Angeles (Image source: Maritime Executive)

# PLANNING AND POLICY STRATEGIES

Planning strategies outline a roadmap for realizing a desired goal, such as "net zero emissions by 2050." Policy strategies develop specific rules, or guidelines, for what needs to be done to achieve this goal. Both policy and planning strategies develop a common framework for understanding key issues involved in decarbonization. Involving relevant stakeholders is critical to ensure buy-in.

As the regulatory body for international maritime shipping, the IMO has led most planning and policy efforts for international maritime sector decarbonization. The IMO's Initial Strategy on Reduction of GHG Emissions from Ships (2018) laid out a broad aim to reduce the carbon intensity of international shipping by at least 40 percent by 2030 as compared to 2008. In July 2023, the IMO reached agreement to revise and strengthen this initial strategy to set a "goal of net-zero emissions from ships by or around, i.e. close to, 2050."[19] The IMO also agreed to set "indicative checkpoints" to track progress towards this goal, which include reducing GHG emissions from ships by at least 20 percent (striving for 30 percent) in 2030 and at least 70 percent (striving for 80 percent) in 2040, both in comparison to 2008 levels.[20] Some government agency and NGO stakeholders, such as the European Commission and the ICCT, have responded positively to the IMO's recently increased ambitions.[21] In parallel with (and prior to) this revision, many government agencies have taken actions or expressed aims to strengthen the IMO's decarbonization policies through planning and policy initiatives.

Examples of planning and policy strategies include:

- Evaluating needs, gaps, and opportunities through feasibility studies, white papers, etc.
- Identifying evaluation criteria for decarbonization readiness (e.g., to identify candidate ports with a high degree of readiness for decarbonization or assess the viability of investment in particular alternative marine fuels).
- Developing frameworks to help align policies, standards, initiatives, investments, etc. to ensure a holistic approach and regime.
- Developing blueprints, roadmaps, action plans, and related materials to guide next steps. These articulate goals and objectives; strategies to address goals; barriers for implementation; timelines and strategies for implementation; and identify how success will be measured, evaluated, and monitored. Many materials also identify specific resources needed to carry out the highest-priority strategies.

[19] https://ec.europa.eu/commission/presscorner/detail/en/ip_23_3745
[20] https://ec.europa.eu/commission/presscorner/detail/en/ip_23_3745
[21] For example, see https://ec.europa.eu/commission/presscorner/detail/en/ip_23_3745 and https://theicct.org/marine-imo-updated-ghg-strategy-jul23/

**Application of Strategies for Inland Waterways**

Government agency decision-makers can consider applying any of the strategies detailed in the following sections to coastal/trans-oceanic or inland waterways shipping (i.e., shipping on rivers and inland lakes). However, decision-makers should be aware that inland waterways decarbonization will involve addressing unique challenges not faced by coastal/trans-oceanic shipping. For example, river depth, width, and lock sizes may vary greatly and have implications for the physical design of towboats and barges that move along inland waterways. A 2021 study found that electrifying large river boats with current technology may be more challenging due to the size of batteries that would be required. To make inland shipping decarbonization economically viable, government agencies will need to take special note of funding/financing and regulatory/enforcement strategies, along with other strategies described in this section.

Source: Decarbonization of the Inland Waterway Sector in the United States

# REGULATORY AND ENFORCEMENT STRATEGIES

Through regulatory strategies, agencies can incentivize or require behaviors that help reach goals articulated in plans and policies. Enforcement strategies track and monitor how stakeholders are meeting these goals, and in some cases, implement penalties for non-compliance.

Government agencies can support international or domestic regulatory and enforcement actions through stakeholder engagement, advocacy, and research and development efforts. For example, the U.S. has worked with the IMO to help develop energy efficiency standards for ships.[22]

Agencies can also develop their own regulatory programs for maritime shipping that occurs within their jurisdiction. This might involve identifying targets for GHG (or air pollutant) emissions reduction for ships traveling through areas within an agency's jurisdiction as well as restrictions to be imposed if targets are not reached. Government agencies can also assist in identifying reporting requirements and collecting information to help evaluate whether targets are reached.

**Regulatory Program Examples**

- MARPOL signatory states may request the designation of Emission Control Areas (ECAs) that impose more stringent limits on fuel sulfur levels and $NO_x$ emissions on ships operating within these ECAs. Currently, there are ECAs off the coasts of North America and the Hawaiian Islands, as well as in the Baltic Sea, the North Sea, and U.S. regions of the Caribbean Sea.

- In July 2021, the European Union announced a provisional agreement to extend its Emissions Trading System (ETS) to maritime transport. This action aims to include maritime transport emissions as part of the EU's overall ETS cap, creating incentives to foster the reduction of GHG emissions and spur the transition to cleaner technologies.

Container ship docked at a port. (Image source: Adobe stock)

[22] https://www.epa.gov/international-cooperation/epas-role-international-maritime-organization-imo

**Pacific Blue Shipping Partnership**

The Pacific Blue Shipping Partnership (PBSP) is a coalition of Pacific Island nations that have voluntarily agreed to work together at a country-to-country level to invest in low-carbon shipping infrastructure. Launched in April 2019 by Fiji and the Marshall Islands, in partnership with Kiribati, Samoa, Solomon Islands, Tonga, Tuvalu, and Vanuatu, the PBSP is working on several policy and planning initiatives (as well as financing initiatives) such as developing a roadmap, drafting, and discussing white papers developed by PBSP sub-committees, and finalizing member countries' commitments and ambitions. In 2021, the PBSP published a Concept Note (designed as a living document to be updated over time) that detailed its 2020-2030 work plan. This work plan included the following priority activities:

- Investment in retrofits and purchase of low-carbon cargo and passenger ferries;
- Securement of loans for longer-term projects to implement renewable energy infrastructure;
- Launch of a revolving loan facility to support commercial activity aligned with the PBSP's objectives; and
- Development of a partnership, research, and collaboration hub to support information-sharing, RD&T activities, training, and capacity building.

Children playing in the foreground as ships are on the horizon off the coast of Vanuatu. (Image source: Sean Gallagher/The Guardian)

# FUNDING AND FINANCING STRATEGIES

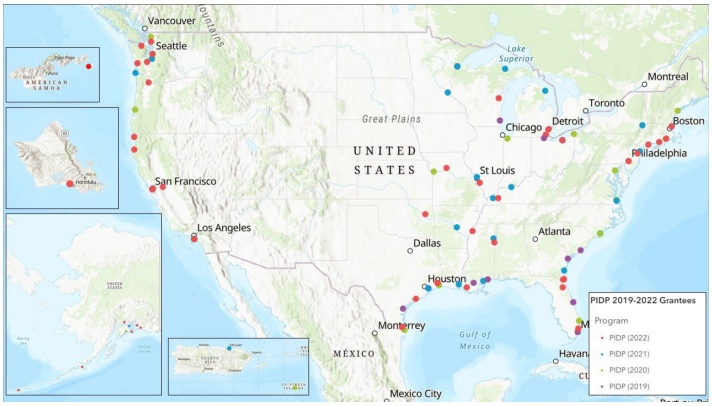
Funding and financing strategies include direct investments to address maritime decarbonization, such as financing infrastructure projects with zero emission goals. Funding and financing strategies could also include indirect investments through the development of grant programs, incentive programs, or tax subsidies. Through incentives and tax subsidies, government agencies can spur the industry's broader adoption of decarbonization practices by minimizing or removing cost-related barriers to uptake.

Other examples of government funding and financing strategies for decarbonization include developing incentive programs to catalyze production and the uptake of zero- or near-zero-emission maritime fuels or considering subsidies to industry to convert vessels to more modern or efficient designs. Agencies could also consider incorporating decarbonization goals into selection criteria for existing grant programs or establishing new grant programs focused on maritime decarbonization.

**U.S. Investment in Maritime Decarbonization (examples)**

In October 2022, U.S. DOT announced more than $703 million to fund 41 projects that will improve port facilities through the Port Infrastructure Development Program (PIDP). The funding will benefit coastal seaports, Great Lakes ports, and inland river ports, helping to improve operational efficiencies and reduce port emissions, among other goals. PIDP funds are awarded on a competitive basis to projects that improve the safety, efficiency, or reliability of the movement of goods into, out of, around, or within a port. For instance, a port could use PIDP funds for establishing cold-ironing infrastructure or charging facilities.

As of 2022, the EPA is offering $3 billion under the Clean Ports Program to fund zero-emission port equipment or technology, along with providing technical assistance for electrification and emissions reduction planning and port climate action plan development.




Map of PIDP grantees, 2019-2022. (Image source: Maritime Administration)

**Maritime Singapore Green Initiative**

In 2011, the Maritime and Port Authority of Singapore (MPA) launched its Maritime Singapore Green Initiative and pledged to invest up to $100 million through 2024 to promote shipping decarbonization through several initiatives that include a green ship, green port, green energy/technology, and green awareness programs. The purpose of these programs is to provide financial incentives to companies that adopt clean and green shipping practices over and above the minimum required by IMO regulations. For example, from May 2022 to December 2024, the Port of Singapore will reduce fees for vessels calling at the port, if they meet certain criteria such as the use of low- or zero-carbon fuels or if their EEDI standards exceed the IMO requirement by 10 percent or more.

Solar panels at the Jurong Port, Singapore. (Image source: Maritime and Port Authority of Singapore)

# CAPACITY BUILDING STRATEGIES

Through capacity building, government agencies identify stakeholders to bring to the table, provide opportunities for stakeholder collaboration and learning, and support workforce development, among other types of efforts. Through these activities, agencies can foster dialogue, spur innovation, and create or strengthen partnerships to build consensus, leverage resources and expertise, and drive collective action towards meeting decarbonization goals.

Examples of capacity building strategies include hosting working groups, workshops, roundtables, or similar opportunities; reaching out to organizations or individuals to obtain feedback on specific questions; or engaging specific groups (e.g., trade associations, non-governmental organizations) through ongoing initiatives. These strategies can involve stakeholders and partners from across local, regional, national, and global organizations.

Capacity building strategies also include identifying champions to provide leadership for decarbonization efforts, as well as cultivating partnerships between policy-makers and financial decision-makers. Examples of financial decision-makers include finance ministries, which may exert a great deal of influence over national development policies and may be able to help direct or shape the flow of external funds to support decarbonization goals.

Decarbonization will provide opportunities to create a green workforce. Agencies can identify and implement trainings to help individuals develop new skillsets; they can also implement recruitment and retainment strategies to ensure a diverse transportation workforce. This will bring new perspectives to consider decarbonization needs and solutions. Decision-makers should proactively seek perspectives from stakeholders with more limited resources, those who have not historically had deep interactions with government, or those who are under-represented in transportation fields.[23,24] Given that the private sector owns, manages, and operates a great deal of maritime shipping physical infrastructure, decision-makers should also target the private sector as a key stakeholder to engage in capacity building efforts.[25]

Government agencies interested in capacity building strategies do not have to "start from scratch." There are many existing initiatives that offer resources that agencies can leverage. For example, the IMO's GHG Trust Fund makes financial resources available to IMO members and others to implement technical assistance and capacity building efforts that seek to reduce GHG emissions from ships.

[23] https://unctad.org/rmt2022
[24] https://unctad.org/news/positioning-partnerships-shipping-decarbonization
[25] https://www.epa.gov/statelocalenergy/webinar-electrifying-americas-ports https://www.epa.gov/statelocalenergy/webinar-electrifying-americas-ports

**C40 Network**

C40 is an international network of city mayors representing nearly 100 cities across the globe. C40 aims to engage its members in collaborative efforts to halve the emissions of member cities. C40 provides its members with support to implement coordinating and collaborating strategies for decarbonization across many different economic sectors, including ports and shipping. C40's shipping-focused initiatives include the Zero Emissions Areas Program, which facilitates peer-city collaboration and incentivizes cities to develop meaningful public-private partnerships within the shipping industry.

C40's Green Ports Forum includes 20 of the world's leading port cities from every region and is focused on connecting port cities and ports around the world to implement policies and programs that mitigate air pollution and greenhouse gas emissions from ports, shipping, and logistics.

# RESEARCH, DEVELOPMENT, AND TECHNOLOGY (RD&T) STRATEGIES

RD&T strategies refer to the complete set of activities involved in creating and sharing knowledge and commercializing innovations. Government agencies can support RD&T activities by setting research agendas; conducting research and development; testing and evaluating emerging technologies, practices, and processes; and supporting the deployment of market-ready technologies and innovations. The maritime decarbonization space is well suited for RD&T-focused government involvement, as it involves activities that are high-risk, long-term, and highly complex—a suite that non-governmental research sponsors may not be able or willing to fully address. Government RD&T activities play an important role in de-risking industry investment in alternative fuels and improved vessel and propulsion technologies.

Government agencies should cultivate and leverage strong partnerships and collaborations across agencies and with academic institutions and private industry organizations. These partnerships are important to coordinate RD&T efforts, avoid duplication, respond to stakeholder needs, and benefit from the unique capabilities of various stakeholders to advance shared goals for advancing RD&T. Working within this partnership framework, governments can strategically identify opportunities for collaboration, coordination, and independent research that advance the goals of maritime decarbonization.

Government agencies can also support technology transfer (T2) efforts to accelerate the implementation, delivery, and commercialization of new innovations and technologies with broad applicability that result from RD&T and benefit maritime decarbonization. T2 can include identification and rapid deployment of proven, yet underutilized innovations that support maritime decarbonization goals. For example, the US Maritime Administration (MARAD) Maritime Environmental and Technical Assistance (META) Program-funded Energy Efficiency and Decarbonization Technical Guide (2022) identifies several technologies that are ready for commercialization such as anti-fouling coatings, hull form optimization, rotor sails, and polymer electrolyte membrane fuel cells.

Governments should communicate maritime decarbonization RD&T outcomes with relevant stakeholders to facilitate better policy decisions, inform updates to regulations and standards, and translate research into practice. This work includes sharing of noteworthy practices and lessons learned from the application of innovations in the field to ensure technologies are adopted effectively. For example, the U.S. DOE Office of Energy Efficiency and Renewable Energy (EERE) compiles and catalogues information on decarbonization such as programs, reports, tools, and workshops related to energy efficiency and optimization, exhaust treatment and carbon capture, hybridization and all-electric power, and low-carbon fuels.[26]

[26] https://www.energy.gov/eere/maritime-decarbonization

**MARAD's Maritime Environmental and Technical Assistance (META) Program**

MARAD provides leadership in U.S. maritime decarbonization efforts through several initiatives, including the META Program. The META Program promotes RD&T on emerging technologies, practices, and processes that improve maritime industrial environmental sustainability, including significant work related to decarbonization in the following topic areas:

- Vessel and port air emissions
- Port electrification and energy efficiency
- Alternative fuels and fuel cells
- Shipboard carbon capture and storage
- Methane slip and fugitive emissions
- Emission reduction technologies
- Modeling
- Hybridization and batteries
- Autonomous systems
- Reduction of vessel-generated underwater noise

Solar film installed on rooftops in Barcelona (Image source: Optics.org)

**Panama Canal Authority RD&T Efforts**

Canals and other chokepoints can play an important role in maritime decarbonization. Improvements in operational efficiency at canals (e.g., by reducing vessel speeds and waiting times) can reduce GHG emissions.

The Panama Canal Authority (ACP) is implementing a new Green Vessel Classification System, which establishes requirements for certain vessels transiting the Panama Canal to provide information related to fuels, energy efficiency, and engines. ACP will use this information to develop a database and analyze trends related to the technological and environmental attributes of ships using the canal.

ACP is also developing a calculator that compares the GHG emissions of ships using the Panama Canal versus those using alternative routes. The tool is intended to inform recognition of environmental excellence and encourage lower-emission itineraries.

Content Source: Greenhouse gas mitigation at maritime chokepoints: The case of the Panama Canal

(Image source: Adobe Stock)

# BUILDING, PRODUCING/MANUFACTURING, MAINTAINING, AND OPERATING STRATEGIES

These strategies are typically—but not exclusively—implemented by non-governmental stakeholders in the maritime shipping ecosystem (for example, the U.S. Army Corps of Engineers, a government agency, maintains and operates much of the inland waterway lock and dam systems in the United States). These strategies broadly cover creating maritime shipping infrastructure (e.g., port terminals, vessels); maintaining this infrastructure; manufacturing and transporting resources needed to support this infrastructure (e.g., maritime fuels); and managing or performing activities involving this infrastructure (e.g., loading and unloading cargo).

While not all governments directly execute all of these strategies, governments can influence and shape the building, manufacturing, and operating actions of private organizations through the strategies described in the previous sections. For example:

- ***Planning and policy***: Several ports in the North Sea and Baltic Sea performed a feasibility study of green shipping corridors in the region. The analysis identified segments that are good candidates for green corridor projects and assessed the development of alternative fuel infrastructure in the region. The report concludes with recommended actions for ports, shipping companies, fuel producers, and others to advance maritime decarbonization in the region.
- ***Funding and financing***: The U.S. EPA's Clean Ports Program will provide funding for grants and rebates for the private sector to purchase or install zero-emission port equipment or technology. As another example, the Port of Prince Rupert in British Columbia, Canada, is using reduced port fee discounts to incentivize customers to invest in emissions reduction technology, zero and near-zero carbon fuels, and other sustainable practices.[27]
- ***Regulatory and enforcement***: The North American Emissions Control Area (ECA) limits $SO_x$ and $NO_x$ pollution from ships in compliance with IMO requirements.
- ***Capacity building***: The Green Shipping Challenge, spearheaded by Norway and the United States, encourages countries, ports, companies, and others in the shipping value chain to announce initiatives that will advance maritime decarbonization such as production and bunkering of alternative fuels and demonstration and deployment of low- and no- emission vessels.
- ***RD&T***: The U.S. DOE's Bioenergy Technologies Office (BETO) invests in RD&T on low- and net-zero-carbon sustainable marine fuels, focusing on near-term and emerging biofuels with the potential for negative or near-negative life-cycle GHG emissions. BETO provide analyses and data to help industry better understand regulatory requirements, alternative fuel performance, and commercialization challenges. BETO conducts cost and emissions analyses, combustion/engine testing, and fuel quality assessments. In partnership with the Pacific Northwest National Laboratory and the National Renewable Energy Laboratory, BETO is piloting demonstrations of alternative fuel production technologies.[28,29]

[27] https://www.oceansnorth.org/wp-content/uploads/2023/06/Canadian-Green-Shipping-Corridors-Preliminary-Assessment-Final-Report.pdf
[28] https://www.pnnl.gov/process-development-units
[29] https://www.nrel.gov/bioenergy/tcpdu.html

Container ships docked at a port. (Image source: Adobe Stock)

**For more information:**

- A Pathway to Decarbonizing the Shipping Sector by 2050, International Renewable Energy Agency
- Charting a Course for Decarbonizing Maritime Transport, World Bank
- Decarbonizing Shipping: All Hands on Deck, Deloitte
- Energy Efficiency and Decarbonization Technical Guide, U.S. Maritime Administration
- Frequently Asked Questions on the Energy Efficiency Existing Ship Index (EEXI) and Annual Operational Carbon Intensity Indicator (CII) and CII Rating, International Maritime Organization
- GSC Framework, U.S. DOS
- Maritime Decarbonization Strategy 2022: A decade of change, Maersk McKinney MØller Center for Zero Carbon Shipping
- National Blueprint for Transportation Decarbonization, U.S. DOE, U.S. DOT, HUD, and U.S. EPA
- IMO's Work to Cut GHG Emissions, IMO
- Initial IMO Strategy on Reduction of GHG Emissions, IMO
- Roadmap to decarbonize the shipping sector: Technology development, consistent policies, and investment in research, development and innovation,
- Supporting Financing for Maritime Decarbonisation, International Maritime Organization
- What We Do, Blue Sky Maritime

# WHAT ARE EXAMPLES OF MARITIME DECARBONIZATION OPPORTUNITIES FOR GOVERNMENT AGENCIES?

Government agencies can apply all or some of the strategies described above to reach their specific goals. The following sections highlight examples of cross-cutting opportunity areas where agencies could apply multiple strategies to progress maritime decarbonization. Each of these opportunities involves different combinations of the strategies described above. Agencies interested in these opportunities will need to assess what combination of strategies may be appropriate for their own countries or regions given their goals, available resources, and other factors.

Wind turbines on shore at a port. (Image source: Adobe Stock)

# GREEN SHIPPING CORRIDORS (GSCS)

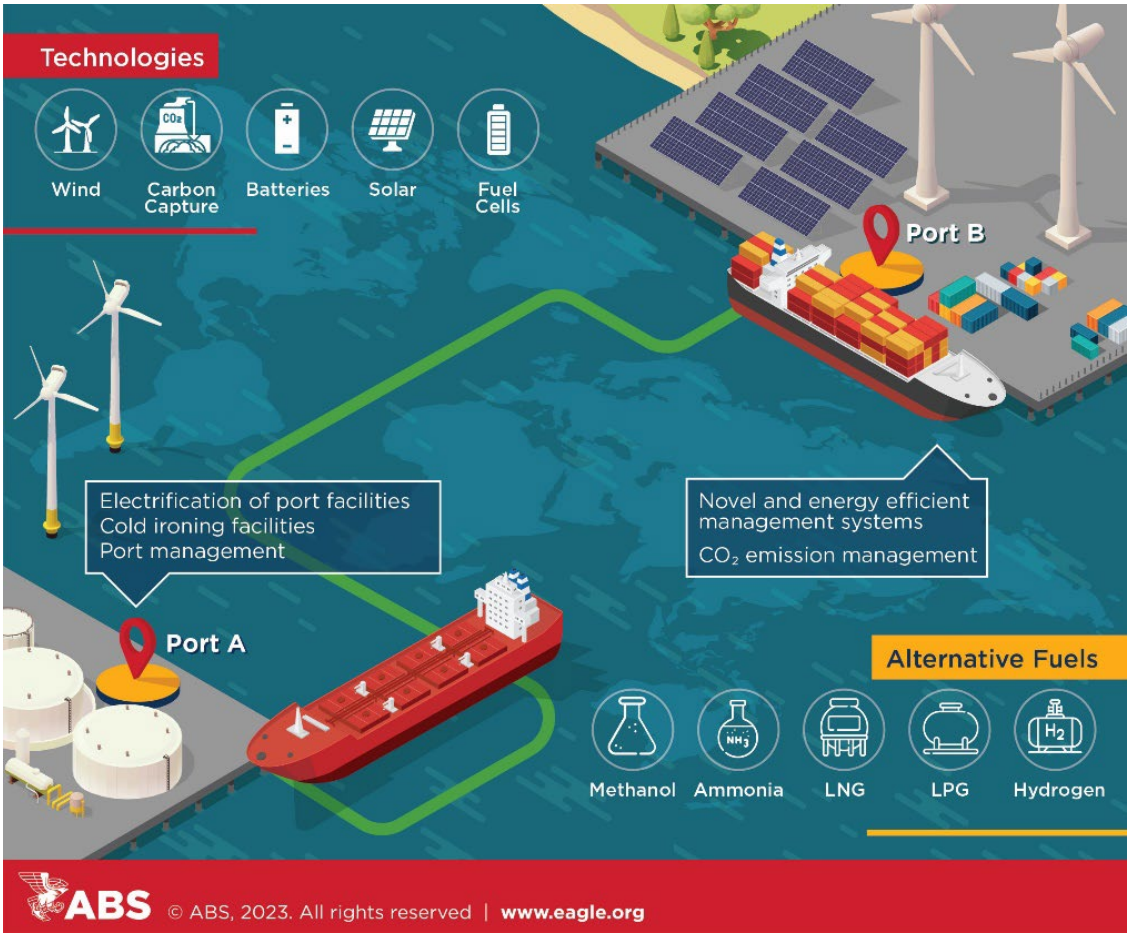
The United States envisions GSCs as "maritime routes that showcase low- and zero-emission lifecycle fuels and technologies with the ambition to achieve zero GHG emissions across all aspects of the corridor in support of sector-wide decarbonization no later than 2050."[30] There are "multiple pathways through which a fully decarbonized corridor can be achieved" but GSCs are a framework that "provides maritime stakeholders the flexibility to choose the path that best suits their needs."[31] GSC participants work together to accelerate the decarbonization of the shipping sector and its fuel supply through demonstration projects, technology implementation, and other innovations. GSCs should feature concrete implementation plans along with measures to analyze progress and achievement reports.

In 2022, U.S. DOS published a GSC Framework that identifies "building blocks" for planning and delivering GSCs. For example, GSC decision-makers should outline anticipated timelines, targets, and achievements (while continuously engaging stakeholders). GSC decision-makers should also demonstrate progress, while transparently sharing relevant information on a regular basis. The image below illustrates key GSC Framework building blocks. As described in the GSC Framework, these building blocks are neither prescriptive nor exhaustive.


(Image source: USDOT)

[30] https://www.state.gov/green-shipping-corridors-framework/
[31] https://www.state.gov/green-shipping-corridors-framework/

In 2022, the Global Maritime Forum identified 21 announced GSC initiatives that involved over 113 stakeholder agencies (49 of these were port authorities and vessel owners/operators; government regulators made up 15 of the stakeholder agencies).[32,33] The image below illustrates an idealized vision for a GSC where two ports use technologies and alternative fuels to reduce $CO_2$ emissions.




Note: "Alternative fuels" can include biofuels as well.
(Image source: ABS, reprinted with permission)

GSCs are evolving quickly and are at different stages of implementation, though none had formally begun operations as of the writing of this toolkit (July 2023). The Port of Los Angeles-Port of Shanghai GSC, the first announced GSC along one of the world's busiest trade routes, was due to deliver an implementation plan by end of calendar year 2022, but the plan was not publicly available as of this writing. It is likely that GSCs will continue to evolve as stakeholders begin to operate GSCs and share lessons learned. While no GSC are yet operational, they continue to facilitate the exchange of best practices and help to further publicize maritime decarbonization efforts.

[32] https://www.globalmaritimeforum.org/content/2022/11/The-2022-Annual-Progress-Report-on-Green-Shipping-Corridors.pdf
[33] Since the Global Maritime Forum's research, additional GSCs have been announced. For example, in November 2022, the U.S. Department of State and the U.S. Department of Energy, along with several agencies representing the Republic of Korea, announced they would undertake a feasibility study to explore the potential of developing a GSC between the U.S. and the Republic of Korea. For more information see https://kr.usembassy.gov/110722-u-s-republic-of-korea-joint-statement-announcing-collaboration-on-green-shipping-corridors/

**For more information:**

- National Blueprint for Transportation Decarbonization, U.S. DOE, U.S. DOT, HUD, and U.S. EPA
- Green Shipping Corridors: Leveraging Synergies, American Bureau of Shipping
- Annual Progress Report on Green Shipping Corridors, Global Maritime Forum
- Green Shipping Corridor Hub, Mission Innovation

# PORT, TERMINAL, & LANDSIDE DECARBONIZATION

Maritime shipping activity at ports and terminals contributes to carbon emissions through shore-side activities that include the use of diesel-powered infrastructure like cranes to move cargo, and the use of non-renewable electricity to power berthed vessels as well as port facilities like buildings, lighting, and machinery.[34,35] Port construction activities can also have significant impacts; one study estimated that 40 percent of a port's life-cycle carbon emissions can be attributed to port construction activities.[36]

Freight logistics activities also create GHG emissions. These activities include warehousing and transporting cargo to and from ports via trucks, rail, barges, or intermodal transfers. By one estimate, moving containerized cargo to a port represented about 20 to 30 percent of the port's total GHG emissions.[37]

Ports are critical nodes in the maritime shipping supply chain and have important roles to play in reducing GHG impacts.[38] Major opportunity areas for port decarbonization include planning, construction, design, energy use, and information technology systems (ITS) (see below table). Some of the outlined decarbonization strategies, especially the energy use strategies, might require enhancement to the power grid to accommodate additional electricity demand. "Greening of the grid" is another opportunity area for government agencies to work with regulators, electricity providers, and other stakeholders to support a consolidated approach to decarbonization.

| Decarbonization Opportunity Area for Ports | Strategy Example(s) |
|---|---|
| **Planning** | • Re-use existing port infrastructure for other uses, versus building new infrastructure. For example, decision-makers can evaluate the feasibility of constructing ports close to channels that already offer deep-water access to minimize dredging activities.[39]<br>• Identify and plan for opportunities to make better use of rail or barge facilities accessible from the port; relative to trucking, use of rail or barges to transport cargo can be more energy efficient and result in lower GHG emissions.[40] |
| **Capacity Building** | • Identify specific recruitment and retainment strategies to build a more diverse workforce, which can bring new and innovative perspectives to advance the decarbonization conversation.<br>• Develop targeted trainings and/or educational and communications materials (e.g., web content, fact sheets, brochures, case studies) to assist port stakeholders in better understanding key opportunities for decarbonization (building a "green workforce") or to help market port initiatives to a broader audience. |

[34] https://eit.europa.eu/sites/default/files/decarbonising_ports-catalogue_of_innovative_solutions_f.pdf
[35] According to one study, comparatively little GHGs (1 to 2 percent) are emitted by in-port activities themselves such as powering cargo-moving machinery. https://www.itf-oecd.org/sites/default/files/docs/dp201319.pdf
[36] https://www.wsp.com/en-gl/insights/designing-net-zero-ports
[37] https://www.itf-oecd.org/sites/default/files/docs/dp201319.pdf
[38] https://www.aceee.org/sites/default/files/pdfs/Ports%20Smart%20Freight%2011-18-21.pdf
[39] https://www.wsp.com/en-gl/insights/designing-net-zero-ports
[40] https://www.eesi.org/papers/view/issue-brief-climate-change-mitigation-and-adaptation-at-u.s-ports-2022

| | |
|---|---|
| **Construction** | • Minimize the use of carbon-intense building materials (e.g., concrete, steel) through the use of lower-carbon materials (e.g., cement with large quantities of recycled content) or alternative materials (e.g., timber).[41]<br>• Install energy-efficient buildings on port property.<br>• Consider nature-based resiliency approaches (e.g., wetlands restoration near coasts around ports). |
| **Design** | • Consider optimizing terminal layouts to facilitate more efficient cargo flows and reduce congestion on the water and on land.[42] For example, container storage yards could be consolidated or moved to ensure optimal proximity to intermodal transport facilities like rail terminals. On-dock rail and yard planning can improve the efficiency of truck operations by reducing wait and turn times. Many of the same design strategies used to improve port efficiencies will also lead to reduced GHG emissions. |
| **Energy use** | • Utilize cold ironing, where shoreside electrical sources power docked vessels. These vessels can then shut off their engines while at port.<br>• Use electricity to power equipment used in port construction, such as dredgers, or equipment used to handle cargo, such as cranes; encourage port users like drayage operators to utilize electric zero-emission vehicles. (Note that some of these strategies may require enhancing the grid or power production to support additional electricity demand.)<br>• Modernize vehicles and equipment used in port operations to increase energy efficiency and lower GHG emissions (as well as local air pollutants). For example, through truck replacement programs, older drayage trucks are replaced with newer, lower-emission models and zero-emission vehicles in the near future. Programs to address drayage truck idling can also help reduce GHG emissions (as well as local air pollutants).[43]<br>• Implement alternative energy projects such as installing solar panels on buildings located in ports.<br>• Install charging/refueling stations on port property for electric vessels used in port operations. |
| **ITS and data** | • Make use of real-time information, data, and dynamic analytics to improve operations and communications efficiencies. For example, dynamic ITS can facilitate terminal management, berth planning, remote machinery monitoring, container control, etc. to improve efficiencies and reduce costs,[44] while supporting decarbonization goals. |

**For more information:**

- Clean Heavy-Duty Vehicle Program, U.S. Environmental Protection Agency
- Action Plan for the Zero-Emission Shipping Mission, Zero-Emission Shipping Mission
- Clean Air Guide for Ports & Terminals, Environmental Defense Fund
- Ports – Green gateways to Europe: 10 transitions to turn ports into decarbonization hubs, Euroelectric
- A Practical Guide to Decarbonizing Ports: Catalogue of Innovative Solutions, European Institute of Innovation & Technology

[41] https://www.wsp.com/en-gl/insights/designing-net-zero-ports
[42] https://www.mdpi.com/2071-1050/14/20/13517 .
[43] https://theicct.org/wp-content/uploads/2023/02/Ports-electrification-US_final.pdf
[44] https://www.wsp.com/en-gl/insights/designing-net-zero-ports

- Ports Playbook for Zero Emission Shipping, Pacific Environment
- Practical Steps Towards a Carbon-Free Maritime Industry: Updates on Fuels, Ports, and Technology, U.S. Congress

**Green Port Policy (Kenya)**

At the Mombasa port, the Kenya Ports Authority (KPA) has implemented a Green Port Policy to reach environmental sustainability goals. Ships calling at the Port of Mombasa will be compelled to switch off their diesel engines and power their vessels using electric power. In February 2023, KPA announced plans to develop a new solar plant within the port to provide shore power generated by renewable energy sources. This was identified as a technology to cut emissions by at least 90 percent in harbor areas.

Source: KPA shifts to solar power plant in green port plans, tunahusika: A Corporate Social Investment (CSI) programme by Kenya Ports Authority

# ALTERNATIVE, ZERO, AND NEAR-ZERO CARBON MARINE FUELS

Depending on their feedstock and production process, alternative marine fuels may produce less GHG emissions than conventional maritime fuel, such as HFO.[45] Because burning fuels is a major driver of GHG emissions in the maritime shipping sector, uptake of alternative, zero and near-zero fuels is critical to achieving sector decarbonization. There are several marine fuels being considered today to reach decarbonization goals. Each is produced through different pathways that involve different feedstocks and production processes (see below table).[46]

| Zero and Near-Zero Carbon Fuel Option* | Feedstock | Production Process | Resulting Fuel |
|---|---|---|---|
| **Biofuel** | Biomass, biowaste | Biofuel synthesis | Bio-methane, bio-methanol, bio-oils |
| **Blue fuel** | Natural gas | Conventional energy paired with carbon capture and either liquefaction or ammonia synthesis | Blue hydrogen, blue ammonia |
| **Electro-fuel (e-fuel)**** | Low-carbon electricity | Electrolysis of water paired with carbon capture, synthesis, and liquefaction; ammonia synthesis; or liquefaction | E-hydrogen, e-ammonia, e-methane, e-methanol, e-diesel |

*Note that there are other aspects of sustainability (e.g., environmental, social, and economic factors) that should be considered when developing or deploying a low-carbon fuel.
**E-fuels are only low- or no-carbon to the extent that they are produced with low-carbon generated electricity.

Fuel pathways are at different maturity levels. At present, biofuels (particularly bio-methane) are the most mature (bio-methane and renewable diesel are currently commercially available). Emerging alternative, zero, and near-zero carbon fuels include hydrogen, ammonia, and methanol.

Transitioning the maritime shipping sector to using alternative maritime fuels requires involving the entire shipping logistics chain—from identifying feedstocks to developing and scaling production processes; to advancing storage, logistics, and bunkering solutions that can accommodate alternative fuels; to managing the safe storage and use of fuels onboard vessels; and managing vessel emissions.[47]

Technology, policy, logistics, economics, and infrastructure challenges affect the use and uptake of alternative, zero, and near-zero carbon marine fuels. Some challenges could limit the extent of GHG

[45] In addition to decarbonization benefits, these fuels have potential to support the IMO's low-sulfur fuel requirement, which entered into force in 2020.
[46] https://cms.zerocarbonshipping.com/media/uploads/publications/Maritime-Decarbonization-Strategy-2022.pdf
[47] https://cms.zerocarbonshipping.com/media/uploads/publications/Maritime-Decarbonization-Strategy-2022.pdf

reductions seen from these fuels. For example, the release of "fugitive" methane during production and use of some alternative fuels can limit GHG reduction benefits.[48, 49, 50]

Evaluating and balancing these challenges along with alternative fuels' potential benefits will require a full life-cycle perspective. This should account for the direct and indirect environmental impacts of emissions across the fuel supply chain.[51] Government agencies can develop, host, and advocate for more robust tools that can support stakeholders in evaluating marine fuel options using this full life-cycle perspective.[52] Agencies can also help identify or clarify potential barriers to the use of alternative marine fuels and work with relevant partners to produce alternative fuel quality standards which are important to ensure safety and increase attractiveness to industry buyers.[53]

**Emission Methodologies**

Maritime fuel pathway GHG emissions can be estimated using different methodologies. The IMO is developing life-cycle assessment GHG guidelines for maritime fuels. The guidelines, once complete, will include methodologies that allow for the calculation of well-to-wake GHG emissions default values for both conventional and alternative marine fuel pathways.

Source: IMO Marine Environment Protection Committee (MEPC) – 79th session, 12-16 December 2022, CORSIA Eligible Fuels

Further, agencies can support identifying areas with high renewable energy production potential and understanding the production costs of renewable fuels in the short and long term.[54]

***Considering alternative fuel tradeoffs.*** Drivers influencing the uptake of alternative marine fuels include meeting international regulations/targets and may include considerations of life-cycle GHG intensity, technical feasibility, or other factors. Additionally, there are several practical considerations regarding commercial fuel maturity/readiness that are likely to influence decision-making about specific fuel usage and the timeline for uptake:[55, 56]

- ***Economic competitiveness*** addresses cost differences between alternative and traditional fuels, as well as the costs of necessary retrofits to use alternative fuels.
- ***Fuel/powertrain compatibility*** considers fuel fungibility; that is, whether the fuel can be used in the engines of existing and planned vessels or in dual-fuel engines. Fuel attributes such as cold weather performance, abrasiveness, and corrosiveness affect engine compatibility.
- ***Scalable supply*** asks whether fuel production levels are sufficient to meet current and future demand.
- ***Infrastructure availability*** assesses whether there is storage, transport, and bunkering infrastructure in place to get fuel where it needs to be. Existing infrastructure for traditional

48 https://onlinelibrary.wiley.com/doi/full/10.1002/ese3.956#:~:text=Far%20from%20being%20low%20carbon,the%20release%20of%20fugitive%20methane.

49 https://www.transportenvironment.org/discover/methane-escaping-from-green-gas-powered-ships-fuelling-climate-crisis-investigation/

50 https://theicct.org/wp-content/uploads/2022/09/Renewable-LNG-Europe_report_FINAL.pdf

51 https://www.nrel.gov/docs/fy21osti/78747.pdf

52 Some have argued that the IMO's EEDI, for example, underestimates carbon intensity because it focuses on vessels and does not take a full lifecycle approach. https://www.nrel.gov/docs/fy21osti/78747.pdf

53 https://www.nrel.gov/docs/fy21osti/78747.pdf

54 https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2021/Oct/IRENA_Decarbonising_Shipping_2021.pdf

55 Marine Environmental Protection Committee (MEPC) 79/7/12, Reduction of GHG Emissions from Ships: Interim report of the Correspondence Group on Marine Fuel Life Cycle GHG Analysis (7 October 2022). Anticipated finalization, adoption, and publication of the guidelines by July 2023.

56 https://www.nrel.gov/docs/fy21osti/78747.pdf.

fuels may require modification to be compatible with alternative fuels. Alternative fuels with lower energy densities require larger storage tanks. Fuel stability also varies across types.

- ***Safety*** addresses whether the fuel is safe to store, transport, bunker, and manage onboard vessels. Fuel characteristics impacting safety include carcinogenicity/toxicity, flammability, and explosion risk.
- ***Sustainability*** considers environmental, social, and economic factors relating to a fuel's production and use. For example, environmental factors include emissions from air pollutants of concern like $SO_x$, $NO_x$, and PM2.5, as well as the ecological impacts of potential fuel spills.

In a 2021 analysis by the National Renewable Energy Laboratory (NREL) and Argonne National Lab (Argonne), researchers rated select alternative fuels favorably (green), neutral (yellow), or unfavorably (red); grey indicates insufficient data for the specified fuel characteristics.[57] See below table for details. The terms "favorable" and "unfavorable" refer to *current* technical and economic feasibility of particular fuels. As alternative fuel technologies develop, these ratings are expected to change.

**Ratings for Selected Alternative Fuels**

| | Abrasiveness | Bunkering | Cold Weather Performance | Corrosiveness | Current Fuel Cost | Engine Compatibility | Flammability Limit | Explosion Risk | Fuel Stability | Fuel Standards | Lifecycle NOx | Lifecycle PM2. | Lifecycle SOx | Production | Retrofit Cost | Spill Risk | Storage Convenience | Toxicity | Volumetric Energy Density |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ammonia | | | | | | | | | | | | | | | | | | | |
| Biocrude | | | | | | | | | | | | | | | | | | | |
| Biodiesel | | | | | | | | | | | | | | | | | | | |
| Methanol | | | | | | | | | | | | | | | | | | | |

**For more information:**

- Alternative Fuels, International Maritime Organization, GreenVoyage 2050
- Sustainable Shipping: Alternative Sources of Power, European Maritime Safety Agency
- Techno-economic assessment of zero-carbon fuels, Lloyd's Register and University Maritime Advisory Services
- Sustainable Marine Fuels , U.S. EPA
- Charting a Course for Decarbonizing Maritime Transport: Summary for Policymakers and Industry, World Bank

[57] Adapted from Anthony Foretich; George G. Zaimes; Troy R. Hawkins; Emily Newes. (2021). Challenges and opportunities for alternative fuels in the maritime sector. Maritime Transport Research. Available at https://www.nrel.gov/docs/fy21osti/78747.pdf.

## Passenger Vessel Sustainable Practices

Passenger waterborne transportation industries (cruises and passenger ferries) are implementing different practices and technologies to meet decarbonization goals. The cruise industry has been particularly vocal about its commitment to reach a goal of net zero carbon cruising by 2050.[58] Strategies deployed by the cruise industry have special relevance for consideration in international or inland maritime shipping, given parallels in vessel physical characteristics and routes. Ferry decarbonization practices, such as electrification, may be useful as demonstrations for future scale-up or adoption to international shipping. However, the types of vessels and routes typically used in ferry transportation are very different from international shipping.

### *Cruise ships*

Cruise ships utilize many of the technologies described in this toolkit. Cruise Lines International Association (CLIA), the global cruise ship trade association, reported that the industry is making substantial investments in innovations and engineering solutions for decarbonization. For example, CLIA reported that by 2028, 90 percent of new build cruise ships will have cold ironing abilities or will commit to adding these capabilities.[59] In 2019, the MS Roald Amundsen became the first hybrid cruise ship in operation. This vessel utilizes both electric engines (powered by a mix of batteries and high-efficiency diesel generators), amounting to a reduction of up to 20 percent in fuel consumption annually.[60] As of 2023, major cruise companies recently announced plans to retrofit existing ships to accommodate methanol fuel or the construction of methanol-fueled new builds.[61] Other companies have announced plans to develop strategy frameworks, partnerships, measurable goals, and technology investments to assist in moving to a net zero cruise industry by 2050.[62]

### *Passenger ferries*

To date, most passenger ferry decarbonization practices have focused on electrification. For example: in March 2023, the first all-electric ferry in the US, a 75-passenger catamaran, was positioned in California to begin operations along the San Francisco waterfront in late spring 2023. This ferry, which was developed using $3 million of State funding, is powered entirely by hydrogen fuel cell technology and can operate for 16 hours before refueling.[63] A new electric ferry that can carry 30 passengers and runs on a battery will launch trial operations in Sweden within the next few months. This ferry also has autonomous sailing capabilities and is being marketed as the "world's fastest electric ship."[64]

[58] https://porthole.com/cruise-industry-commits-to-pursue-net-zero-carbon-for-global-cruising-by-2050/
[59] https://porthole.com/cruise-industry-commits-to-pursue-net-zero-carbon-for-global-cruising-by-2050/
[60] https://www.cntraveler.com/ships/hurtigruten/ms-roald-amundsen
[61] https://www.cruisehive.com/cruise-lines-move-on-decarbonisation-of-the-cruise-industry/94485
[62] https://www.seatrade-cruise.com/environmental-health/net-zero-cruise-ship-2035-among-royal-caribbean-decarbonization-aims
[63] https://www.govtech.com/fs/san-francisco-sees-delivery-of-3m-all-electric-ferry
[64] https://www.hellenicshippingnews.com/from-electric-ferries-to-wind-powered-boats-heres-how-the-shipping-industry-can-decarbonize/

Washington State Ferries (WSF) operates the largest passenger ferry system in the United States. WSF is electrifying its fleet by building 16 new plug-in hybrid electric ferries, retrofitting 6 existing diesel ferries to hybrid-electric designs, and retiring 13 diesel vessels.[65] Each plug-in hybrid ferry will be equipped with a diesel generator, lithium-ion batteries, a rapid charging system with a robotic arm to connect with shore power, as well as supporting systems for power and battery management, battery cooling and ventilation, and fire and gas detection and suppression. When complete in 2040, the transition will reduce GHG emissions by up to 76 percent, assuming a green electricity portfolio. By using hybrid electric technology, the ferry system will be more resilient to energy price fluctuations and will be able to achieve earlier emissions reductions while WSF works to electrify its terminals as well. WSF's long-range planning for this effort is documented in the System Electrification Plan.[66]

**Northwest to Alaska Green Corridor for Cruise**

The Port of Seattle, City and Borough of Juneau, Vancouver Port Authority, Carnival Corporation, Norwegian Cruise Line Holdings, Royal Caribbean Group, Cruise Lines International Association, the Global Maritime Forum, Blue Sky Maritime Coalition, and Washington Maritime Blue launched the first green corridor for cruise in an effort to launch the first zero-emission cruise ships and operations. The green cruise corridor is called the Pacific Northwest to Alaska Green Corridor project and is a collaborative effort led by ports, industry, governments, and decarbonization subject matter experts. Project partners are committed to working together to further define and scope out the green corridor concept, enhance and support emission-reduction efforts, and work collaboratively to define governance structures, terms, and frameworks. The project builds on a history of environmental leadership in the Pacific Northwest region and has long been a diversified hub for maritime research and development. A maritime corridor already exists between Puget Sound and Alaska with regularly scheduled vessel calls by the cruise, commercial fishing, cargo, and tug industries.

Source: Exploring the World's First Green Corridor for Cruise

[65] https://wsdot.wa.gov/construction-planning/major-projects/ferry-system-electrification
[66] https://wsdot.wa.gov/sites/default/files/2021-11/WSF-SystemElectrificationPlan-December2020.pdf

Ferry pulling into terminal. (Image source: Washington State Ferries)

**Green Methanol Partnerships**

Maersk, one of the world's largest shipping and maritime logistics companies, is expanding its capacity to use methanol in its fleet. The company plans to add 19 dual-fuel container ships capable of running on traditional fuel oil or methanol between 2023-2025.[67] To provide fuel for these vessels, Maersk is developing partnerships to source methanol from providers in North and South America, Europe, and other locations.[68,69] The 19 vessels, when deployed and operating on green methanol, will reduce $CO_2$ emissions by 2.3 million tons per year.[70] Governments play an important role in promoting transitions to alternative fuels; for example, Spain and Maersk signed a General Protocol for Collaboration to identify opportunities to increase production of e-methanol in Spain, in alignment with the Spanish government's goals of reindustrialization, just transition, and decarbonization.[71]

Green methanol is an attractive low-carbon marine fuel because it can be stored as a liquid, is less toxic than other alternative fuels like ammonia, and can be used in dual-fuel engines that also burn standard marine fuels. However, methanol is only a low-carbon fuel when produced from waste biomass (bio-methanol) or from hydrogen created with renewable energy (e-methanol). Maersk's partners will produce bio-methanol using feedstock from agricultural residues, forestry residues, municipal solid waste, as well as e-methanol.

Beyond production, a transition to methanol will require retrofits to refueling infrastructure including barges, pumps, and hoses to accommodate the alternative fuel.[72]

[67] https://www.reuters.com/business/sustainable-business/maersk-agrees-project-with-spain-make-e-methanol-its-fleet-2022-11-03/
[68] https://www.maersk.com/news/articles/2022/03/10/maersk-engages-in-strategic-partnerships-to-scale-green-methanol-production
[69] https://www.maersk.com/news/articles/2022/12/15/maersk-and-sungas-renewables-sign-strategic-green-methanol-partnership
[70] https://www.maersk.com/news/articles/2022/10/05/maersk-continues-green-transformation
[71] https://www.reuters.com/business/sustainable-business/maersk-agrees-project-with-spain-make-e-methanol-its-fleet-2022-11-03/
[72] https://www.wsj.com/articles/methanol-shipping-green-fuel-11675445221

# SHIP-BASED OPERATIONAL PRACTICES AND TECHNOLOGIES

Energy efficient, ship-based operational practices and energy-efficient technologies (EETs) aim to improve the efficiency of a vessel itself or the way a vessel is handled and run. Currently, most of these practices and EETs are implemented by the industry, with support from other stakeholders, either voluntarily or to meet requirements established by regulatory agencies such as the IMO.

Solutions vary in terms of their maturity level for broad implementation. Many are feasible with today's technology and have been proven in commercial operations. For example, slow steaming, where ships intentionally reduce their speed to realize fuel savings, involves few technical constraints and offers a high GHG emission reduction potential, as compared to other operational/technological solutions.[73,74,75] Some may require upfront costs to deploy but ultimately result in cost-savings over time.

The table below outlines different types of operational practices and EETs along with examples, expected benefits for reducing GHG emissions, and considerations in implementation.

| Type | | Example(s)[76] | Expected Benefits | Considerations |
|---|---|---|---|---|
| **Operational practice** | | Slow steaming, route optimization | Nearly a 2 percent reduction in fuel consumption per ton mile is feasible. | May be "low-hanging fruit" due to technical feasibility, but market forces may create disincentives to widespread adoption. For example, slow steaming may require additional ships to carry the same cargo loads to meet customer demand, which could partially negate the overall GHG emission reductions achieved. |
| **EET** | Hull improvements & propulsion | Low-friction coatings, propeller polishing, energy-saving devices | Better hull condition can translate to better fuel consumption and reduced GHG emissions. | Certain types of applications or devices may only be suitable for certain types of ships and hull forms. |
| **EET** | Machinery & energy systems | Engine retrofits, waste heat recovery systems | Improved flows behind the engine significantly reduce the propeller hub vortex. Retrofits could help ships potentially accommodate multiple | May only be suitable for certain types of ships. Retrofits may require significant upfront investment and upstream planning time. |

[73] https://reader.elsevier.com/reader/sd/pii/S002980182200960X?token=6FE22F141F7F69EDDB9794B70305317AFAF777AD82195E580BF0EA6CF346E1766EE32745716148F13E8AFA206E574470&originRegion=us-east-1&originCreation=20230321020114

[74] https://mfame.guru/performance-of-energy-efficiency-technologies-for-ships/

[75] Reducing ship speed by 10 percent could lead to a 27 percent reduction in ship emissions.

[76] Compiled from https://mfame.guru/performance-of-energy-efficiency-technologies-for-ships/ and https://www.marinelog.com/views/op-eds/op-ed-how-technology-can-help-you-sail-through-eexi-and-cii-and-beyond/

| | | | | |
|---|---|---|---|---|
| | | | alternative fuel technologies as they evolve while realizing significant efficiencies and GHG emission reductions. | |
| **EET** | Renewable energy | Wind-harnessing technologies (e.g., rotor sails, kites, soft sails) | New innovations in development that will make wind power more commercially viable. | Largely still in demonstration status (first cargo ship partially powered by a hard sail wind propulsion system sailed in 2022[77]). Not suitable for all ship types. Fuel savings and emission reduction values vary widely depending on weather conditions and other factors. May require new ship builds versus retrofitting. |
| **EET** | Operations | Trim and draft optimization, autopilot adjustment and use | Applicable to all vessel types and ages. Trim influences ship fuel consumption significantly, with evidence showing up to 4 percent savings in fuel consumption. | May lead to smaller GHG emission reductions as compared to other EET solutions.[78] |

While some operational practices and EETs are easily implemented, there are still barriers that challenge the industry's widespread adoption of these solutions for reduced GHG emissions. Market forces create incentives for the industry to retain maximum flexibility in operational practices; the industry may be reluctant to commit to practices that they perceive will limit their ability to adapt to changing supply chain needs. Industry may also be reluctant to absorb upfront costs. Additionally, there are structural issues within the maritime shipping ecosystem that can create disincentives for implementation. For example, often the party responsible for investing in EET implementation (e.g., a ship owner) may not be the party whose operations benefits most (e.g., a ship charterer).[79]

Government agencies can support the industry in adopting energy efficient operational practices and EETs by helping to identify and address barriers such as offering incentives. Agencies can also advocate for stronger enforcement of existing international energy efficiency measures designed to spur industry action (see text box). They can assist in identifying suitable mechanisms to monitor energy efficiency; encourage research and development efforts focused on efficiency practices; support knowledge-sharing; and advocate for industry to adhere to design and operation standards.[80]

[77] https://ajot.com/news/article/delivery-of-shofu-maru-worlds-first-cargo-vessel-equipped-with-wind-challenger-hard-sail
[78] https://glomeep.imo.org/technology/autopilot-adjustment-and-use/
[79] https://reader.elsevier.com/reader/sd/pii/S002980182200960X?token=6FE22F141F7F69EDDB9794B70305317AFAF777AD82195E580BF0EA6CF346E1766EE32745716148F13E8AFA206E574470&originRegion=us-east-1&originCreation=20230321020114
[80] https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2021/Oct/IRENA_Decarbonising_Shipping_2021.pdf

**IMO Maritime Shipping Energy Efficiency Measures**

The IMO has established several mechanisms to assist the maritime industry in reducing ship-related carbon emissions through more efficient ship design and operations:

- The **Energy Efficiency Design Index** (EEDI), introduced in 2011 (made effective in 2013), is a performance-based mechanism that provides a minimum energy efficiency level per capacity mile (e.g., ton mile) for different ship types and size segments (specific technologies to achieve EEDI targets are left up to the industry to determine). The EEDI aims to promote the use of more energy-efficient (less polluting) ship equipment and engines. The requirements are expected to tighten every five years. Current guidelines require a $CO_2$ reduction level of 10 percent while after 2025 a 30 percent reduction level will be required. New ships built after 2013 are required to meet ship design-specific EEDI minimum standards.

  The **Energy Efficiency Existing Ship Index (EEXI),** which entered into force in 2022, is an energy efficiency measurement tool. Beginning January 1, 2023, all ships are required to use the EEXI to measure their energy efficiency and annually report a carbon intensity indicator (CII). On the basis of the CII, ships receive a CII rating that indicates their overall efficiency; ratings will become increasingly stringent. A ship that receives a D rating for 3 consecutive years will need to develop a corrective action plan. The EEXI stems from the IMO's 2018 Initial Strategy on Reduction of GHG Emissions from Ships, which aims to reduce ship carbon intensity by 40 percent (compared to 2008 levels) by 2030.

- The **Ship Energy Efficiency Management Plan (SEEMP)**, introduced in 2011 (made effective 2013), is a practical, operational tool to assist ship owners in improving a ship's operational efficiency. SEEMPs consist of three parts: 1) a ship management plan, 2) an oil consumption data collection plan, and 3) a carbon intensity plan. Through developing SEEMPs, the industry must consider energy-efficient technologies and practices to optimize a ship's fuel use, reduce energy needs, and decrease GHG emissions. SEEMPs are mandatory for new ships built after 2013. SEEMPs will need to be revised to account for the EEXI and CII requirements that came into force in 2023.

  Source: EEXI and CII - ship carbon intensity and rating system, New EEXCI, CII requirements effective from 2023: How to revise SEEMP

**Technology Seminars to Support Local Air Emission Reductions**

Through work with the U.S EPA, the Mexican government has explored ways to reduce emissions and set policies to reduce air pollution from ships near local communities. This led to the establishment of a Mexican Emissions Control Area as well as the adoption of MARPOL Annex VI (an international air pollution agreement). In 2012, a ship technologies seminar was held to provide Mexican stakeholders with information about some of the ship technologies needed to meet policy requirements set forth by the county. The seminar educated public and private stakeholders about the benefits of an ECA, including learning more about the technologies required to reduce pollution from shipping.

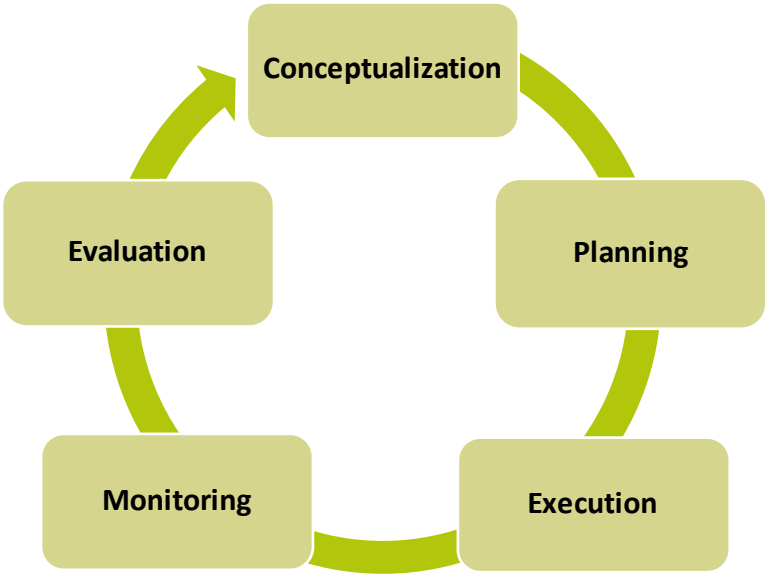
Source: Ship Technology Workshop Materials from Collaboration with Mexico to Reduce Emissions from Ships | International Cooperation | US EPA

**For more information:**

- Introductory Course on Energy Efficient Ship Operation, United Nations Climate Change Learning Partnership
- Energy Efficiency Technologies Information Portal, IMO

# PUTTING STRATEGIES INTO ACTION

Government agencies should work with all stakeholders in the maritime shipping ecosystem to address decarbonization through the strategies described throughout this document. Broadly speaking, implementing any strategy will involve conceptualization and planning, followed by execution, monitoring, and evaluation. The details, timeline, and resources needed for implementation can vary greatly depending on many factors.




## SHORT-TERM ACTION ITEMS

Many actions can be undertaken within a shorter time period, using resources likely already in hand. Agencies can consider the following:

- **Build a customized maritime shipping ecosystem web** specific to your country, area, or region. This web could include specific names of agencies, organizations, firms, companies, individuals, etc. This web helps assess where an agency already has partnerships or where there are opportunities to develop new partnerships to help implement decarbonization strategies of mutual interest.
- **Identify political and technical champions** – a combination of sustained political will and technical expertise are needed for decarbonization efforts. Political champions can help to cultivate leadership-level buy-in. Technical champions can assist to provide expertise, leadership, and other resources to see efforts through.
- **Identify opportunities for coordination among policy and financial stakeholders**. For example, government agencies should consider coordination with finance ministries, which tend to have a lot of influence on national development policy and may interface with donors. Finance ministries may be able to help shape and direct external financial flows towards port decarbonization efforts.

- Look for opportunities to bring **diverse perspectives into discussions about transportation sustainability generally and maritime shipping decarbonization specifically.** For example, identify recruitment strategies to target hiring of populations who have been historically under-represented in the transportation/maritime industry. Agencies can also convene stakeholders who represent different sectors, disciplines, and skill sets; agencies can facilitate discussions among diverse stakeholders to identify and understand varying viewpoints.
- **Collect inventory available data to assess needs and gaps**. Clarify what methodologies are being used to assess maritime emissions and ensure that methodologies are transparent to partners and stakeholders.
- **Identify existing funding and financing resources**, such as grant programs, that could be leveraged to support specific investments in maritime shipping decarbonization.
- **Review planned transportation projects** to identify where there are indirect or direct benefits to the maritime sector. For example, projects that address truck bottlenecks may facilitate transportation movements to and from a port, leading to a more efficient transportation system and reduced GHG emissions.
- **Highlight, celebrate, and publicize initiatives or programs** that have led to environmental successes, such as improved air quality, even if these successes have been relatively small or benefit areas outside of the maritime sector. Agencies can build on these successes to reach specific decarbonization goals for maritime shipping.
- **Help stakeholders review existing in-port energy use practices and policies.** Assist stakeholders to identify opportunities to implement new practices or policies aimed at reducing energy use and increasing efficiencies. For example, ports can discourage vehicle idling within the port or issue warnings to ships that emit excessive amounts of smoke.
- Make industry aware of **transportation practices and technologies** that have been successfully utilized to achieve environmental sustainability goals. Often these practices can be adapted for decarbonization goals within the maritime sector.
- Create **training, communications, or educational materials** (such as case studies or fact sheets).
- **Promote funding and financing resources** (such as tax credit programs) to industry that can be utilized for specific technology adoptions that improve transportation environmental sustainability or reduce GHG emissions. Even if these are not directly aimed towards maritime transportation, adoption could assist in moving the transportation industry towards decarbonization goals generally.
- **Reach out to a variety of organizations working on maritime decarbonization**—including regulatory bodies (e.g., IMO), non-governmental organizations (e.g., Global Maritime Forum), or other government agencies in your country or region—to explore what resources are available to support your agency in reaching its decarbonization goals.

# GLOSSARY

**Drayage:** the short-haul transport of cargo, goods, or containers from an ocean port to a destination.

**Energy efficient technologies (EETs):** energy-saving devices, resources, or systems, such as engine retrofits and waste heat recovery systems.

**Green shipping:** the movement of goods using vessels that operate with zero-emission or near-zero-emission fuels and using infrastructure powered by energy produced from low- or zero-emission sources.

**Green shipping corridors (GSCs):** maritime routes that showcase low- and zero-emission lifecycle fuels and technologies with the ambition to achieve zero GHG emissions across all aspects of the corridor in support of sector-wide decarbonization no later than 2050.

**Heavy fuel oil (HFO):** fuel oil with >2.0% sulfur, corresponding to ISO 8217:2017 residual grades. Also known as bunker fuel and is the most widely used fuel source for maritime shipping today.

**Information technology systems (ITS):** the sharing of real-time information, data, and dynamic analytics to improve operations and communications efficiencies.

**Maritime decarbonization:** the process of reducing greenhouse gas (GHG) emissions from the global maritime sector, with an overall goal of placing the sector on a pathway that limits global temperature rise to 1.5-degrees Celsius.

**Maritime shipping/transport:** the movement of cargo by sea or along inland waterways between ports.

**Zero-emission or near-zero-emission marine fuels:** alternative fuels produced using a variety of materials, methods, and technologies that convert domestic fuel resources—called "feedstocks"—into energy-dense fuels with the correct properties and characteristics to be safely used in marine engine. Zero and near-zero carbon fuels include biodiesel and bio-methanol.

# SELF-ASSESSMENT QUESTIONS

This Appendix presents a series of questions that will help you and your agency think through how to conceptualize, coordinate, plan for, execute, and monitor decarbonization strategies for maritime shipping. Consider the following questions:

- **What roles and responsibilities do government agencies in your country/region have in overseeing, regulating, or managing maritime shipping?**
- **What are your government's short-term and long-term goals for maritime shipping decarbonization? Does your government have any specific targets associated with these goals?**
  - If yes, how is your government monitoring/tracking progress towards these targets?
- **Does your government already know who is part of the maritime shipping ecosystem in your country/region? How does your government currently engage or partner with maritime shipping stakeholders?**
- **How are maritime shipping stakeholders in your country/region reducing GHG emissions?**
- **How is your government promoting, incentivizing, or regulating adoption of these GHG emissions strategies by stakeholders?**
- **How does your government assess and mitigate the impacts of maritime shipping on the environment and climate change?**
- **Does your government use any data for these assessments? Are there opportunities to improve data or address data gaps? What resources are available to assist in data improvement?**
- **What are the financial opportunities for maritime sector decarbonization investments in your country/region such as emissions reduction schemes?**
- **What strategies has your government implemented to help achieve your country's/region's goals for maritime shipping decarbonization? Or, what strategies has your government implemented to achieve environmental goals for transportation that could be adapted for maritime shipping decarbonization?**
- **Is your government experiencing any challenges in implementing maritime shipping decarbonization strategies?**
  - If so, has your government determined how these challenges could be addressed?
- **Are there any particular maritime decarbonization strategies that your government is interested to learn more about? Are there any questions that your government has related to maritime shipping emissions, maritime decarbonization opportunities, or related topics?**

For more information about maritime decarbonization, or to learn more about partnering with MOMENTUM, please contact us at momentum@dot.gov