CEAP | CLEAN ENERGY ACCOUNTING PROJECT

CLEAN FUELS IN THE MARITIME SHIPPING SECTOR

Background Report | August 2024

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Key Takeaways

- Under a global convention, the international maritime shipping sector is to reduce GHG emissions 50% and GHG intensity 70% by 2050, primarily through shifting to biogenic fuels.
- Most ship operators achieve reductions in GHG emissions intensity by blending some amount of “clean” fuel into conventional fuel supplies.
- Fuels in this sector tend to be delivered via dedicated supply lines from fuel-specific bunker tankers. Documentation of delivery is based on chemical testing of fuels, not purely based on contractual ownership.
- The EU has adopted aggressive new regulations to spur demand for cleaner maritime fuels that include market-based mechanisms to facilitate compliance, but which may complicate efforts to expand market-based accounting for fuel use.

1. Introduction

Global maritime shipping accounted for 2.89% of global warming in 2018 (up from 2.76% in 2012).[1] More recent data from the Organization for Economic Cooperation and Development (OECD) shows that by 2022 global shipping emitted slightly more than 858 million tons of CO_2, which would represent a 7.3% decrease from 2018.[2] More than half of these emissions came from large container ships and bulk carriers, and one-fifth were attributable to tankers primarily hauling fossil fuels. In fact, OECD's estimates show that bulk cargo ships and fossil fuel tankers accounted for more CO_2 emissions than all other maritime shipping vessels combined.

Maritime shipping vessels consume vast amounts of fuel. A single large cargo ship traversing the Atlantic may consume one gallon of fuel every 15 feet at a cost of $300,000 or more for a single crossing.[3]

The 1973 International Convention on the Prevention of Pollution from Ships (MARPOL) has 105 signatories representing over 97% of global shipping by tonnage. Since 1997, in addition to binding limitations on nitrous oxide and sulfur emissions, the convention has also regulated the carbon intensity of direct emissions from ships. Enforcement of MARPOL falls mainly to the International Maritime Organization (IMO), the multilateral authority governing global maritime shipping.

This document includes a summary of the shipping sector's key fuel consuming scale and scope, production and distribution characteristics of the clean fuel types available, and examples of relevant regulations and initiatives.

2. Maritime Shipping Sector Overview

The maritime shipping sector includes all ships, ports, personnel, and infrastructure involved in the transport of goods via ocean waterways, which includes more than 80% of all goods worldwide.

It is common for maritime shipping vessels to consume several different types of fuel in their operations. For example, to operate the main engines, a ship might take two fuels with different sulfur content depending on the different regulations of sulfur emissions at different ports. It might consume a third type of fuel for smaller engines, lifeboats, and tenders, and yet a different type of fuel for running gas turbines to produce the electrical power required for on-board operations.

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[1] International Maritime Organization (IMO), *Fourth Greenhouse Gas Study*, 2020. https://www.imo.org/en/ourwork/Environment/Pages/Fourth-IMO-Greenhouse-Gas-Study-2020.aspx

[2] Clarke, D., et.al. "New estimates provide insights on CO2 emissions from global shipping," *OECD Statistics Blog*, June 15, 2023. https://oecdstatistics.blog/2023/06/15/new-estimates-provide-insights-on-co2-emissions-from-global-shipping/#footnote_1_3881.

[3] Kym, "Where do ships get their fuel?" *Casual Navigation*, May 28, 2021. https://www.youtube.com/watch?app=desktop&v=-A-SavHMHNs.

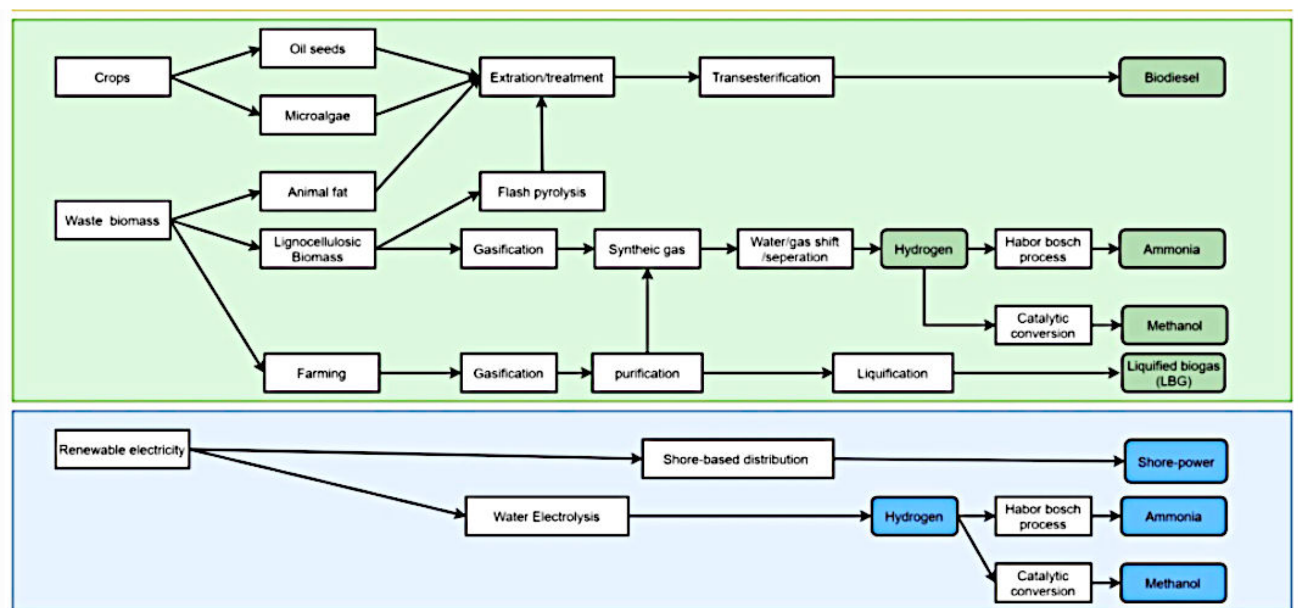
Several sustainable low-carbon fuels also require a highly combustible "pilot fuel' to ignite the main fuel, which is usually less combustible. Methanol and LNG-fueled ships, for example, use a diesel-like distillate to ignite the main fuel. Pilot fuels can comprise between 5-10% of the total fuel consumed by a ship in a year. Clean fuel can therefore require a fossil-based pilot fuel, though some biogenic clean fuels may also prove useful as pilot fuels.

3. Clean Maritime Shipping Fuels

Several alternative fuels are being used to decarbonize the global shipping sector. These include liquified biogas (LBG), biomethane, biodiesel, methanol, and ammonia. Liquified hydrogen may also be used in smaller maritime vessels, which may better support the necessary cryogenic storage tanks than larger ships, where hydrogen storage would be cost prohibitive.[4]

Figure 1 highlights common production pathways for some clean shipping fuels and demonstrates some of the complexities associated with tracing how clean shipping fuels are produced and distributed. To add to this complexity, fuels may be further blended or undergo critical molecular transformations along their distribution routes. These complex transformations often create additional challenges for accurately tracking the environmental attributes of clean shipping fuels.

Figure 1. Production Pathways of Various Alternative Shipping Fuels



(Source: *Wang, Y., 2021*)

[4] Blomerus, Paul. "Decarbonizing Marine Shipping: Clean Fuels for a Greener Future?" [Blog post.], *Clear Seas Centre for Responsible Shipping Blog*, November 27, 2023. https://clearseas.org/en/blog/decarbonizing-marine-shipping-clean-fuels-for-a-greener-future/

3.1 Liquified Biogas (LBG) and Biomethane

Production Process and Feedstocks

Whereas LNG is composed of roughly 95% methane, liquified biogas (LBG, or Bio-LNG) contains about 99.8% methane as well as significant amounts of CO_2 and trace amounts of other gases, primarily ethanes. Biomethane contains even higher concentrations of methane and is generally derived by 'upgrading' biogas to remove the CO_2, hydrogen sulfide, and water. This process is energy intensive and costly, preventing biomethane from playing a bigger role as a clean shipping fuel.

Both LBG and biomethane are produced mainly through anaerobic digestion (AD) or biomass gasification. Various biological feedstocks can be used for AD and biomass gasification, although there is a trend to recover energy from agricultural wastes, food wastes, manure, and sewage sludge.

Distribution Networks

Both LBG and Bio-LNG are considered 'drop in' fuels since they can be used interchangeably in LNG-fueled engines, which have grown in popularity after the IMO adopted stricter limits on sulfur dioxide (SO_x) emissions in 2019. As of January 2022, vessels fueled by LNG represented 4% of the existing global fleet, but nearly 30% of newly built ships (in gross tonnage).[5] Moreover, for over 40 years, many LNG tankers have used gas boiled off from their cargo to reduce fuel costs because it has a similar chemical composition as biogas, but the practice has grown more widespread after stricter SO_X limitations were adopted.

3.2 Biodiesel

Production Process and Feedstocks

Biodiesel can be produced from a wide variety of feedstock resources from vegetable oils, waste cooking oils, factory sludge, to animal fats and other oleaginous sources. Biodiesel is in a liquid state at room temperature and has similar chemical characteristics to conventional diesel fuels. However, it contains almost no sulfur and has more free oxygen than conventional petrol diesel, resulting in more complete combustion and less carbon monoxide, hydrocarbon, and particular matter emissions.

The main feedstocks for biodiesel production vary between regions depending on availability. For example, biodiesel is mainly produced from canola oil in the U.S., rapeseed oil in Europe, and palm oil in Malaysia. The first and second-generation biofuels derived from these feedstocks often compete with agricultural lands and, directly and indirectly, impact biodiversity. Biodiesels obtained from different feedstocks, moreover, have observable variations in the purity and composition of the generated fuel, which causes similar variation in production costs.

Distribution Networks

Biodiesel is one of the few clean maritime fuels that can utilize most of the existing maritime fuel distribution infrastructure and can also be safely combusted in engines made to burn conventional shipping fuel. However, because of its higher lubricity and narrower temperature tolerances, biodiesel cannot be stored in the same tanks as diesel oil, nor can it remain for long periods of time in conventional diesel engines without the higher lubricity generating deposits that can clog pipes and fuel valves.

3.3: Methanol

Production Pathways and Feedstocks

Methanol is the simplest alcohol, also known as methyl alcohol or wood alcohol. It is a toxic, light, volatile, and flammable liquid at standard temperature and pressure. In comparison with marine diesel, methanol has a higher hydrocarbon ratio, higher octane, and contains more oxygen. The high oxygen content assists in producing more efficient combustion in the engine systems, generating almost no sulfur oxides and less CO_2 and particulate matter emissions. One of the key advantages of methanol is lower NO_x forming potential from its relatively low combustion temperature. Ships using methanol as fuel, therefore, could more easily comply with stricter NO_x emission regulations.

Currently, most methanol worldwide is produced from catalytic conversion of synthetic gas (carbon monoxide and hydrogen) generated from natural gas reforming or from the gasification of coal. However, much of the current research into scalable methanol production focuses on the use of agricultural waste, forest biomass, municipal solid waste, and captured CO_2 as potential 'green' feedstocks.[6]

Under current regulations, ships consuming methanol are required to report the composition of the fuel they consume, but there are no requirements to collect data on the processes used to produce it, calling into question whether the production pathways for methanol can be traced accurately enough to characterize it as a 'clean' fuel for GHG emissions accounting purposes.

Distribution Networks

Maritime shipping faces an essential infrastructure problem in making a wholesale shift to methanol. Today, only about 120 ports globally can deliver methanol, which requires specific storage and handling and is largely incompatible with existing shipping fuel distribution infrastructure. In most cases, distribution is arranged via bilateral contracts, a choice available only to the largest and most profitable operations.

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[6] See, for example, the Methanol Institute online database tracking 'renewable methanol', 'bio-methanol' and 'e-methanol' production projects worldwide at https://www.methanol.org/renewable/

3.4 Ammonia

Production Pathways and Feedstocks

Globally, nearly 90% of ammonia is produced from fossil fuels using the Haber-Bosch process, which requires high temperatures and pressures and generates significant GHG emissions.[7] The Haber-Bosch process also requires hydrogen as a precursor, the generation of which can utilize clean or fossil resources.

Roughly 72% of hydrogen generated for ammonia production derives from natural gas using steam methane reforming (SMR). About 26% is produced from coal gasification, primarily in China, where coal has been the primary feedstock.[8]

Creating sufficient hydrogen feedstock to support ammonia production at the scale needed to support the maritime shipping sector would consume vast amounts of precious potable water. The most widely adopted process for generating hydrogen to produce 'clean' ammonia is electrolysis, cracking water into its component parts using electricity from renewable resources, such as wind and solar. In general, electrolysis requires a large and continuous supply of highly pure water. To produce 1 ton of hydrogen through electrolysis typically requires approximately 9 tons of water pre-treated to 'ultrapure' standards.[9] But purification to the necessary standards is itself an energy intensive process involving reverse osmosis, which sucks the water through very fine membranes to remove impurities that could disrupt efficient electrolysis.

Under current guidelines, the electricity used to purify water in the production of green hydrogen used as a feedstock to produce ammonia need not be generated from renewable resources. However, because many green hydrogen producers treat purified water on-site, they would report emissions associated with purification of water for electrolysis as Scope 2 emissions under the GHG Protocol Corporate Standard.[10]

Distribution Networks

Like hydrogen, ammonia is seen by many as a promising clean shipping fuel if it can be produced from renewable sources and consumed in an environmentally benign way. Ammonia solves the problem that hampers widespread use of hydrogen as a shipping fuel: it is easier to store and transport. Ammonia requires a vapor pressure of

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[7] Gavham, S. et. al. "Sustainable Ammonia Production Processes," *Front. Energy Res. (*9), March 29, 2021. https://www.frontiersin.org/articles/10.3389/fenrg.2021.580808/full

[8] *Ibid.*

[9] Taekker Madsen, Henrik. "Water treatment for green hydrogen: what you need to know," *Hydrogen Tech Worl*d, October 27, 2022. https://hydrogentechworld.com/water-treatment-for-green-hydrogen-what-you-need-to-know.

[10] Whether emissions associated with the purification of water to create hydrogen precursor are attributed to the ammonia that is produced from it is unclear. Under 2022 revisions to the DOE's GREET model for calculating the lifecycle emissions of various production pathways, hydrogen is considered a direct feedstock, but the emissions resulting from the methods used to produce the hydrogen appear to be considered upstream and not included in the calculation of emissions from direct inputs to the fuel's production pathway. Even though ammonia producers often purify water to create the hydrogen precursor on-site, in the GREET Model, the energy used for purification would factor into the scope 2 emissions reported by the facility, but would not count toward the lifecycle emissions associated with the ammonia produced.

about 8.6 bar at standard temperature to maintain liquid form (typical to propane), which would require far less energy than the cryogenic storage needed to transport liquid hydrogen.[11]

Other Critical Issues

3.5 Transactional Transparency

Transitioning to cleaner maritime shipping fuels is challenging given the lack of transparency by fuel suppliers in this sector. Tight profit margins and fierce competition between companies that operate bunker tankers has discouraged open sharing of fueling data. Moreover, because of the vast quantities of fuel involved, many shipping fuel transactions are measured volumetrically, with their mass-equivalent value calculated indirectly. This creates a layer of uncertainty about the transaction that often leads to differing interpretations between suppliers and buyers on the precise quantities and characteristics of the fuel consumed.[12] These disputes would complicate efforts to verify the biogenic attributes of marine biofuels whose use is claimed to reduce Scope 1 emissions.

There is some momentum toward migrating the industry to a mass-flow system based on fuel delivery. Calibrated mass flow meters (MFMs) measure mass directly and can provide transactional transparency, with data available to all parties and in real time.

MFMs measure a wide range of fuel characteristics—including aggregate state, conductivity, and density—with an accuracy up to 0.1% when measured directly. Other measurement values—volumetric flow rate and percent concentration, for example—can be inferred from the fluid density, mass flow rate, and temperatures recorded by the MSM.[13] The greater accuracy and granularity of data provided through flow meters would therefore help verify the biogenic content in clean shipping fuels and introduce greater transparency in fuel transactions.

To date the adoption of MFMs has been uneven, however, with some ports, like Singapore, Hong Kong, and Amsterdam, requiring their use among bunker suppliers, while the technology remains entirely foreign in other ports.

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[11] As both a potential fuel and the key ingredient for other clean fuels, green hydrogen will need large investments as it must be stored in special containers at temperatures around -253 degrees Celsius.

[12] See Shelton, Darren. "Maritime Fuel Market Fraud Could be Costing $5 Billion Each Year," Port Bureau News, April 28, 2023. https://www.txgulf.org/news/maritime-fuel-market-fraud-could-be-costing-5-billion-each-year-.

[13] Tolson, A., Modernizing Marine Fuel Delivery: Transparency, digitalization and decarbonization, TFG Marine White Paper, January 18, 2024. https://www.tfgmarine.com/media/eadbu1de/20240118-tfg-marine-the-case-for-standards-compliant-mfm-white-paper-pdf.pdf

4. Regulatory Context

4.1 International

The 1997 Kyoto Protocol gave the IMO authority to regulate the air emissions of maritime vessels, and the Maritime Environment Protection Committee (MEPC) is the IMO administrative body that issues regulations enforcing MARPOL.[14]

In 2011, parties to MARPOL began regulating carbon emission indirectly as part of a mandated Energy Efficiency Design Index (EEDI), which requires newly built ships to meet a minimum energy efficiency per capacity mile by ship type. The EEDI is based on a complex formula that considers the ship's size, installed shaft power, average speed, specific fuel consumption, and the amount of CO_2 released by the fuel consumed.[15]

Starting in 2019, MEPC required that all ships with a gross tonnage of 5,000 or more collect consumption data for each type of fuel consumed, in addition to disaggregated data characterizing the ship, its travels, and its daily operations. Governments annually verify the disaggregated data of ships operating under their flags and issue compliance certificates to each qualifying ship.

MEPC also requires ship operators to reduce the carbon intensity of ship operations in grams of CO_2 equivalent per cargo-carrying capacity and nautical mile. Each ship is given a target intensity based upon its size, classification, travel distances, and other factors.

4.2 Europe

The EU has adopted binding targets to reduce the volume of GHG emissions from European ships by 20% by 2025 (compared to 1990 levels), with interim targets of a 40% reduction by 2030, and a 60% reduction by 2040. While these are sector-wide targets, meeting them generally requires a greater decarbonization of maritime fuel consumption then those needed to achieve targets under MARPOL.

5. Regulations and Initiatives

5.1 EU Monitoring, Reporting, and Verification (EU-MRV)

Under current EU regulations, much of the data to support market-based accounting of maritime shipping fuels is already collected. Notably, since 2018, the mandatory EU Monitoring, Reporting, and Verification (EU-MRV) protocol requires that every ship of 5,000 gross tons or more (and which carries out an EU-related voyage) develop an emissions monitoring plan that accurately accounts for fuel consumption and

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[14] See Mendes Vianna, Kinkaid. *MARPOL at 50 – our commitment goes on: IMO releases the world maritime theme for 2023*, International Bar Association, October 18, 2022. https://www.ibanet.org/marpol-imo-maritime-theme.
[15] International Council on Clean Transportation (ICCT), "The Energy Efficiency Design Index for New Ships," *ICCT Policy Update* 15, October 3, 2011. https://theicct.org/sites/default/files/publications/ICCTpolicyupdate15_EEDI_final.pdf.

related air pollutants. Moreover, the MRV plans must be independently verified by an accredited third-party verifier.

Monitoring plans must include the CO_2 emission sources on board, including fuels for the main engines, auxiliary engines, gas turbines, boilers and inert gas generators along with the fuel types used; a description of the procedures for monitoring the fuel consumption of the ship, including the method used to calculate the fuel consumption of each CO_2 emission, source, the procedures for the measurement of fuel loaded into on-board tanks , a description of the measuring equipment used and the method used to determine density, where applicable.

The monitoring plan must also include emission factors used for each fuel type or the methodologies for determining the emission factors for alternative fuels, including details of sampling, methods, fuel analysis and the laboratories used along with the ISO 17025 accreditation of those laboratories, if any.

While the IMO-DCS collects annual aggregated data from ship operators, EU-MRV collects per-voyage data, often from automated systems installed on each ship. As a result, granular data required to track fuel transportation and consumption is made publicly available.

5.3 FuelEU Maritime Law

In 2021, the European Commission (EC) presented new laws restricting aggregate direct and indirect carbon emissions of ship operations for ships trading in the EU or the European Economic Area, which includes the EU states plus Iceland, Norway and Lichtenstein. The regulation requires that yearly average GHG emissions intensity[16] of energy consumed (measured as grams of CO_2-e/megajoule) must be below a threshold that is reduced every five years culminating in an 80% reduction in carbon intensity by 2050.

Annex 1 of the regulation lists default emissions factors to be used for determining the GHG intensity of voyages and establishes specific methods for calculating the intensity of energy consumed in ship operations, including complex formulas for fossil fuels and fuels derived from biological and non-biological feedstocks. For fuel blends, the regulations require that a ship report the calculation for each component product. Any fuel that does not meet the sustainability criteria set forth in the regulation is deemed to have the emissions factor of “the least favorable fossil fuel pathway” for that type of fuel.

Fleet owners may demonstrate compliance at a fleet-wide level or even between different companies subject to the regulation to incentivize investments in new, innovative ships designed to use the alternative fuels at optimal efficiency.

[16] GHG intensity is targeted as a certain percentage reduction relative to a reference value of 91.16 gCO_2e/MJ.

FuelEU Maritime also allows owners to bank the volume of alternative shipping fuel exceeding the volume necessary to meet the GHG intensity target and apply it for future use or to borrow ‘over-compliance’ projected in future reporting cycles and either apply it a current cycle where it faces a deficit or to sell it to another owner who may be struggling to meet the targets. The banking of overcompliance credit utilizes aspects of market-based accounting, but it is unclear yet how the system will work and what standards may apply for certifying transactions or verifying use claims.

6. Summary

To ameliorate the sector’s contribution to global climate change and comply with new GHG intensity regulations, ship owners are pursuing several cleaner alternatives to conventional fossil-based shipping fuels, though no consensus has emerged around a fuel of choice. The global fleet of shipping vessels, moreover, is aging, which presents both an opportunity to invest in new ships designed to run on a specific clean fuel and a risk that whatever choice is made will lock the owner into a particular alternative for the next 20 to 30 years.

While efforts are underway to improve data collection and more accurately track the consumption of maritime shipping fuels, the sector has not embraced any widely accepted market-based accounting methods, and no voluntary market for environmental attributes of clean shipping fuels has emerged. However, some of the flexible compliance mechanisms adopted under the EU’s new international shipping regulations could generate a compliance market for tradeable attributes among ship owners and could spur widespread demand for more guidance on how the sector should apply market-based accounting to transactions involving the attributes of clean fuels.