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BIOFUELS COMPARED TO FOSSIL FUELS IN THE SHIPPING SUPPLY CHAIN

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Dedication / Αφιέρωση

Dedicated to my family.

Αφιερωμένο στην οικογένειά μου.

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ACRONYMS & ABBREVIATIONS

ARA: Amsterdam-Rotterdam-Antwerp (Bunkering Hub)
BDN: Bunker Delivery Note
CFPP: Cold Filter Plugging Point
CII: Carbon Intensity Indicator
CO_2: Carbon Dioxide
CoQ: Certificate of Quality
CP: Cloud Point
DMA: Distillate Marine Category A (commonly used for **MGO**)
DMB: Distillate Marine Category B (commonly used for **MDO**)
ECA: Emission Control Area
EEDI: Energy Efficiency Design Index
EEXI: Energy Efficiency Existing Ship Index
EU ETS: European Union Emissions Trading System
EU RED: European Union Renewable Energy Directive
FAME: Fatty Acid Methyl Esters (Biodiesel)
FONAR: Fuel Oil Non-Availability Report
FuelEU: FuelEU Maritime Regulation
GHG: Greenhouse Gas
HFO: Heavy Fuel Oil
HVO: Hydrotreated Vegetable Oil (Renewable Diesel)
iLUC: Indirect Land Use Change
IMO DCS: International Maritime Organization Data Collection System
IMO: International Maritime Organization
ISCC: International Sustainability and Carbon Certification
ISO: International Organization for Standardization
LCA: Lifecycle Assessment
LHV: Lower Heating Value
MARPOL: International Convention for the Prevention of Pollution from Ships
MDO: Marine Diesel Oil
MGO: Marine Gas Oil
MJ/kg: Megajoules per kilogram
mt: metric tonne

NOx: Nitrogen Oxides

OPEC: Organization of the Petroleum Exporting Countries

PP: Pour Point

PSC: Port State Control

RSB: Roundtable on Sustainable Biomaterials

SDGs: Sustainable Development Goals

SOx: Sulphur Oxides

Tonne-km: Tonne-kilometre (unit of freight transport)

TtW: Tank-to-Wake

UCO: Used Cooking Oil

ULSFO: Ultra Low Sulphur Fuel Oil

USD: United States Dollar

VLSFO: Very Low Sulphur Fuel Oil

WtW: Well-to-Wake

GLOSSARY

Advanced Biofuels: Sustainable fuels produced from non-food feedstocks, such as agricultural waste or Used Cooking Oil (UCO), which offer significantly higher GHG savings compared to first generation biofuels [Mizik, 2025].

Bio-blend: A mixture of a conventional fossil fuel (like VLSFO or MGO) with a specific percentage of biofuel (e.g., B30 contains 30% biofuel and 70% fossil fuel) [Stamatopoulos & Stamatopoulos, 2021].

Blending mandates: Government rules that require fuel suppliers to mix a specific percentage of biofuels into traditional fossil fuels. These mandates ensure minimum biofuel shares in fuel supply, creating stable demand conditions for producers [Ebadian et al., 2020]

Bunker Delivery Note (BDN): The statutory commercial document required by MARPOL Annex VI that provides details of the fuel delivered to a vessel, serving as the primary record for regulatory compliance [IMO, 2025].

Carbon Intensity Indicator (CII): An IMO operational measure that grades ships (A to E) based on their efficiency in terms of grams of CO_2 emitted per cargo-carrying capacity and distance travelled [IMO, 2025].

Carbon Lock-in: The tendency for existing fossil fuel infrastructure and market rules to inhibit the transition to low-carbon alternatives by making them appear more expensive or complex [Urban et al., 2024].

Cetane Number: A measure of the ignition quality of a diesel fuel; a higher cetane number indicates a shorter ignition delay, which is critical for efficient combustion in marine engines [Stamatopoulos & Stamatopoulos, 2021].

Cloud Point (CP): The temperature at which wax crystals first begin to form in a fuel, giving it a cloudy appearance and potentially clogging filters [Stamatopoulos & Stamatopoulos, 2021].

Cold Filter Plugging Point (CFPP): The lowest temperature at which a fuel can still pass through a standardized filtration device without clogging [Stamatopoulos & Stamatopoulos, 2021].

Compliance Deficit: A status under **FuelEU Maritime** where a vessel's greenhouse gas intensity exceeds the permitted regulatory limit. This results in financial penalties unless the deficit is covered by a **Compliance Surplus** from another vessel in the pool [Stamatopoulos, 2026].

Compliance Pooling: A regulatory mechanism (under FuelEU Maritime) allowing multiple vessels to share their emission balances to meet a fleet-wide average [Stamatopoulos, 2026].

Compliance Surplus: A regulatory balance achieved under FuelEU Maritime when a ship's carbon intensity is lower than the required limit. This surplus can be "pooled" to offset deficits in other vessels within the same fleet [Stamatopoulos, 2026].

Crop Switching: The agricultural practice where farmers shift from producing food crops to energy crops (biofuel feedstocks) in response to market demand. This transition can lead to food price instability and supply shortages [Morone et al., 2020]**.**

Drop-in Fuel: A renewable fuel that is chemically compatible with existing marine engines and bunkering infrastructure, requiring no significant technical modifications [Mohammadpour & Salehi, 2025].

Feedstock: The raw biological or waste material (e.g., Used Cooking Oil, algae, animal fats) used as the basis for biofuel production [DNV, 2025].

Flash Point: The lowest temperature at which a fuel emits enough vapor to form an ignitable mixture in the air; for marine fuels, this must be above 60°C to ensure safety on board [Stamatopoulos & Stamatopoulos, 2021].

FuelEU Maritime: A key EU regulation designed to increase the demand for and use of renewable and low-carbon fuels by setting binding greenhouse gas intensity targets for energy used on board ships [European Parliament, 2017].

Green Premium: The additional cost paid for a sustainable fuel (biofuel) compared to its conventional fossil fuel equivalent (e.g., VLSFO) [DNV, 2025].

Hygroscopicity (Hygroscopic Nature): The physical property of a substance (like FAME) to absorb moisture from the air, which can lead to fuel degradation and microbial growth in fuel tanks [Stamatopoulos & Stamatopoulos, 2021].

IMO (International Maritime Organization): The agency of the United Nations which is responsible for measures to improve the safety of international shipping and to prevent marine pollution from ships [Wartsila, 2026].

Indirect Land-Use Change (iLUC): the displacement of agricultural production (food, feed) or forest production (fibre, timber) to previously uncultivated areas, such as peatland, grasslands or forested lands, induced by the cultivation of biomass feedstocks [European Parliament, 2017].

Life Cycle Assessment (LCA): A methodology for assessing environmental impacts associated with all the stages of a fuel's life, from raw material extraction through materials processing, manufacture, distribution, and use [Li et al., 2025].

Lubricity: The ability of a fuel to reduce friction and wear between moving engine parts (like fuel pumps). Biofuels generally offer superior lubricity compared to ultra-low sulphur fossil fuels [Stamatopoulos & Stamatopoulos, 2021].

MARPOL 73/78 Annex VI, Prevention of Air Pollution from Ships: Came into force on 19/05/2005 and dictates the control of the discharge of noxious substances from ship diesels. It is applicable to ship diesels with a power larger than 130kW built and installed since 1 st January 2000 [Wartsila, 2026].

MGO Baseline (94 gCO_2eq/MJ): The specific reference value set by the EU to represent the average carbon intensity of Marine Gas Oil; biofuels must significantly outperform this baseline to be considered green [DNV, 2025].

MJ/kg (Megajoules per kilogram): The unit of measurement for the energy content **(Lower Heating Value, LHV)** of a fuel; it determines how much power a ship gets from each kilo of fuel [Stamatopoulos & Stamatopoulos, 2021].

Oxidation Stability: The resistance of a fuel to chemical breakdown during storage. Low stability in biofuels can lead to the formation of sludge and gums that clog filters [Stamatopoulos & Stamatopoulos, 2021].

Pooling Mechanism: A strategic compliance tool under FuelEU Maritime that allows ships with high GHG savings to pool their surplus with non-compliant vessels to avoid fleet-wide penalties [Stamatopoulos, 2026].

Pour Point: The lowest temperature at which a fuel remains liquid and capable of flowing. For biofuels, high pour points can lead to gelling in cold weather [Stamatopoulos & Stamatopoulos, 2021].

Second-Generation Biofuels: Fuels produced from non-food biomass, such as waste oils or agricultural residues, which do not compete with food crops [Mizik, 2025].

Sustainability Certification (ISCC/RSB): Third-party auditing systems (like the International Sustainability and Carbon Certification) used to prove that a biofuel meets strict environmental and social criteria throughout its supply chain [Global Fuels Director Interview, 2026].

Tank-to-Wake (TtW): An emissions accounting method that only considers the greenhouse gases released during the combustion of fuel on board the ship.

Viscosity: A measure of a fluid's resistance to flow; correct viscosity is essential for the proper atomization of fuel in the engine's combustion chamber [Stamatopoulos & Stamatopoulos, 2021].

Voluntary Scope 3: Reporting of indirect emissions that occur in a company's value chain. In shipping, this market is driven by cargo owners who are willing to pay an additional fee for ocean freight in exchange for reduced GHG emissions. This mechanism is currently most common in the container and car carrier segments, where cargo owners actively pursue specific sustainability goals [DNV, 2025]**.**

Well-to-Wake (WtW): A lifecycle emissions accounting method that evaluates the total environmental impact of a fuel, from its production and transport (Well-to-Tank) to its final combustion on board (Tank-to-Wake) [European Parliament, 2017].

ABSTRACT

This thesis provides a comparative analysis of biofuels versus conventional fossil fuels within the maritime supply chain, focusing on the Greek shipping cluster. Utilizing a mixed research study, the research combines a review of scientific and industry papers with primary data from 30 industry stakeholders and three high-level experts. The findings reveal a significant reliability gap, with fossil fuels scoring 4.23 versus 3.37 for biofuels. Economically, a USD 172/mt **Green Premium** remains a major barrier in hubs like Rotterdam, especially for the tanker and bulk sectors where green freights are absent. However, regulatory mandates such as **FuelEU Maritime** and the EU ETS are transforming biofuels into a vital compliance asset. The study concludes that while biofuels are the only immediate drop-in bridge to the 2030 targets, their success depends on **feedstock** scalability and the strategic use of **compliance pooling** to manage high operational costs.

Keywords: Biofuels, Maritime Decarbonization, Greek Shipping, Green Premium, FuelEU Maritime.

Περίληψη

Η παρούσα διπλωματική εργασία παρέχει μια συγκριτική ανάλυση των βιοκαυσίμων έναντι των συμβατικών ορυκτών καυσίμων στη ναυτιλιακή εφοδιαστική αλυσίδα, εστιάζοντας στην ελληνική ναυτιλία. Χρησιμοποιώντας μια μεικτή ερευνητική μεθοδολογία, η μελέτη συνδυάζει την ανασκόπηση επιστημονικών άρθρων με πρωτογενή δεδομένα από 30 στελέχη του κλάδου και τρεις εμπειρογνώμονες υψηλού επιπέδου. Τα ευρήματα αποκαλύπτουν ένα σημαντικό χάσμα αξιοπιστίας, με τα ορυκτά καύσιμα να συγκεντρώνουν βαθμολογία 4,23 έναντι 3,37 για τα βιοκαύσιμα. Οικονομικά, το πρόσθετο κόστος (Green Premium) των 172$/mt παραμένει κύριο εμπόδιο σε κόμβους όπως το Ρότερνταμ, ειδικά για τους τομείς των δεξαμενοπλοίων και φορτηγών πλοίων όπου απουσιάζουν οι πράσινοι ναύλοι. Ωστόσο, κανονισμοί όπως το FuelEU Maritime και το EU ETS μετατρέπουν τα βιοκαύσιμα σε ζωτικό εργαλείο συμμόρφωσης. Η μελέτη καταλήγει ότι, αν και τα βιοκαύσιμα αποτελούν τη μόνη άμεση και έτοιμη λύση για τους στόχους του 2030, η επιτυχία τους εξαρτάται από τη διαθεσιμότητα των πρώτων υλών και τη στρατηγική της ομαδοποίησης (pooling) για τη διαχείριση του υψηλού λειτουργικού κόστους.

Λέξεις-Κλειδιά: Βιοκαύσιμα, Απανθρακοποίηση Ναυτιλίας, Ελληνική Ναυτιλία, Green Premium, FuelEU Maritime.

CHAPTER 1: INTRODUCTION

1.1 SHIPPING EMISSIONS AND THE GLOBAL CONTEXT

International shipping is the backbone of global trade, but it is also a major source of atmospheric pollution. Currently, the maritime sector accounts for approximately 2-3% of global Greenhouse Gas (GHG) emissions only [Halpe et al., 2025; van Leeuwen & Monios, 2022]. Every year, the industry burns roughly 300 million mt of fossil fuels, releasing about 980 million mt of CO_2 [Fridell, 2019; Gucma, 2025]. Combined with aviation, these hard-to-abate transport sectors represent nearly 10% of global emissions [Urban et al., 2024]. Projections suggest these emissions could increase without immediate intervention. Therefore, there is an urgent need for technological and regulatory solutions to support the industry's transition toward a greener future [Halpe et al., 2025; van Leeuwen & Monios, 2022].

1.2 THE DECARBONIZATION PROBLEM

While the need to transition is clear, shipping faces a unique energy intensity challenge. Unlike land-based transport, deep-sea vessels require high-density fuels to maintain global and long-distance supply chains. Biofuels are a vital transition tool, but their environmental value is not always equal. This value depends heavily on how the feedstock is grown, the energy used in processing, and the efficiency of the logistics [Li et al., 2025].

For example, while algae-based fuels show potential, the extreme energy needed for cultivation and extraction currently blocks their ability to scale [Gollakota & Shu, 2023; Manikandan et al., 2025]. Furthermore, expanding biofuel production can create land-use risks, damage biodiversity, and compete with food and water resources [Li et al., 2025; DNV, 2025]. This creates a bottleneck where policymakers categorize biofuels into different generations. Nevertheless, the industry still lacks a clear and practical comparison of how these fuels actually perform against the established fossil baseline [Suali & Suali, 2023].

1.3 RESEARCH AIM AND OBJECTIVES

The aim of this thesis is to provide a comprehensive comparison of biofuels versus conventional fossil fuels within the maritime supply chain, focusing on the Greek shipping cluster.

- Objective 1: To evaluate the technical performance of bio-marine fuels compared to Marine Gas Oil (MGO) or Very Low Sulphur Fuel Oil (VLSFO).
- Objective 2: To analyze the economic and regulatory impact of the Green Premium and EU mandates, FuelEU Maritime (FuelEU) and European Union Emissions Trading System (EU ETS).
- Objective 3: To identify the operational barriers and supply chain constraints reported by Greek industry experts.

CHAPTER 2: LITERATURE REVIEW AND REGULATORY FRAMEWORK

2.1 TYPES AND TECHNICAL TRAITS OF BIOFUELS

2.1.1 MARINE BIOFUEL GENERATIONS

Biofuels are currently the most technically ready low-carbon option for ships [Harahap et al., 2023]. In academic literature, these fuels are categorized into generations based on their source and technological maturity. First-generation biofuels are produced via transesterification of feedstocks such as food crops (e.g. corn and vegetable oils, animal fats and waste cooking oils) into Fatty Acid Methyl Esters (FAME). The biofuels produced with this process are usually biodiesel or bioethanol. This generation is the most common, but face major sustainability hurdles [Zhang et al., 2025] [Padder et al.,2024]. Because they compete with food security, rules like the EU Renewable Energy Directive (RED) now limit their share to just 7% of transport energy [Morone et al., 2020; Azadi et al., 2017]. From an operational standpoint, first-generation biofuels also have higher thickness **(viscosity)** and lower energy density than fossil fuels, which can lead to higher fuel consumption during long trips [Manikandan et al., 2025].

To solve these land-use problems, the industry is moving toward **second-generation** and third-generation biofuels. Advanced second-generation fuels Hydrotreated Vegetable Oils (HVO) use waste oils, Used Cooking Oils (UCO), forestry inputs, and agricultural residues. In this way, the biomass origin of this kind of biofuel avoids the food versus fuel conflict and can cut lifecycle Carbon Dioxide (CO_2) emissions by up to 70% [Padder et al.,2024; Manikandan et al., 2025]. Third-generation fuels, made from algae, are the most land-efficient and do not compete with any arable land. However, they are still too expensive to produce at scale [Carneiro et al., 2017]. While newer fourth and fifth generation fuels look into carbon capture and synthetic biology, they are still in the experimental phase [Padder et al., 2024].

In practice, this means these advanced fuels are simply not ready for large-scale use in time for the 2030 climate goals. Despite the clear environmental benefits of these newer generations, the shipping industry’s transition is just beginning. In 2023, biofuels made up only 0.3% of total marine energy demand, showing that the biofuel revolution is still in its very early stages [DNV, 2025].

2.1.2 FUEL CHARACTERISTICS AND ENERGY DENSITY

In order biofuels to be used as bunkers in the maritime supply chain, their properties must align with the engine's needs, specifically in terms of viscosity, ignition quality, and energy density [Damian et al., 2025]. The most important metric is specific energy **(Megajoules per kilogram, MJ/kg)**, which determines how much heat the fuel releases during combustion. Because biofuels generally have a lower energy density than fossil MGO, they lead to higher fuel consumption. This energy gap forces shipowners to reconsider their voyage planning and fuel storage strategies [Stamatopoulos & Stamatopoulos, 2021, pp. 78-79; Global Fuels Director Interview, 2026]. While standard fuels like MGO or VLSFO usually range between 40-43 MJ/kg, biofuels often stand lower, at 37-40 MJ/kg [Stamatopoulos & Stamatopoulos, 2021, pp. 78-79].

In practice, this means a vessel must carry and burn more fuel to travel the same distance as it would on fossil fuel [Manikandan et al., 2025]. This creates a fuel penalty that increases the ship's weight and raises the total cost of every voyage. However, biofuels, especially FAME, do offer a benefit: they provide better **lubricity**. This can actually extend the life of fuel injection parts compared to the "drier" low-sulphur fossil fuels used today [Stamatopoulos & Stamatopoulos, 2021, p. 96, pp. 105-107].

Combustion efficiency is also tied to the **Cetane Number**. Higher cetane values in second-generation fuels like HVO actually help the engine start and burn more smoothly than fossil fuels [Manikandan et al., 2025]. This shorter ignition delay improves efficiency and keeps the engine's performance similar to conventional fuels [Bilgili, 2023]. On the other hand, if a biofuel is too thick (high viscosity), it can struggle to break into droplets (atomization), leading to poor burning unless it is pre-heated [Mohammadpour & Salehi, 2025]. Fuel safety is also a priority. **Flash point** and **oxidation stability** ensure the fuel stays stable under the high-pressure and intense heat conditions of a modern engine room [Nagamani & Kasture, 2022; Chen et al., 2025].

To manage these differences, the industry uses strict qualification standards. Biofuel parts must follow EN 14214 (for FAME) or EN 15940 (for HVO). Most importantly, the latest ISO 8217:2024 standard (International Organization for Standardization) now provides the global rulebook for these blends [Stamatopoulos, 2026] [Global Fuels Director Interview, 2026]. This ensures that biofuels can finally be used under clear quality rules. Therefore, such a universal standard is vital because biofuel quality traits can change depending on where the feedstock comes from. Also, ships need operational consistency no matter where they trade [Stamatopoulos, 2026].

2.1.3 DROP-IN POTENTIAL AND SUSTAINABILITY CRITERIA

The main strategic advantage of marine biofuels is their drop-in compatibility. This allows for immediate decarbonization without the need to retrofit entire fleets or invest in unproven propulsion technologies [Robalo-Cabrera et al., 2025; Amdi et al., 2024]. Fuels like FAME and HVO mix and burn very much like standard marine diesel, meaning they can be integrated into current supply network with almost no extra investment in new equipment [Zhang et al., 2025; Bach et al., 2021]. In particular, B20 blends and advanced HVO work seamlessly with existing engines, maintaining operational stability without major engine modifications [Manikandan et al., 2025; Selvam et al., 2025]. This readiness makes biofuels a much more accessible transition tool than alternative fuels that require expensive and complex engine changes [Mohammadpour & Salehi, 2025].

However, this technical ease is balanced by strict sustainability rules. To qualify for regulatory benefits, biofuels must prove they can achieve large lifecycle emission reductions. These reductions have a minimum limit of 60% for new installations under EU criteria [Morone et al., 2020; DNV, 2025]. To avoid taking land away from food crops **(Indirect Land Use Change, iLUC)**, modern policies prioritize waste-based and non-competitive feedstocks, such as UCO and non-food HVO [Cherwoo et al., 2023; Cabrera-Jiménez et al., 2022]. For a fuel to be considered green and be legally valid to apply for lifecycle reduction benefits, it must have a proven origin through certification schemes like International Sustainability and Carbon Certification (ISCC) or Roundtable on Sustainable Biomaterials (RSB) [DNV, 2025].

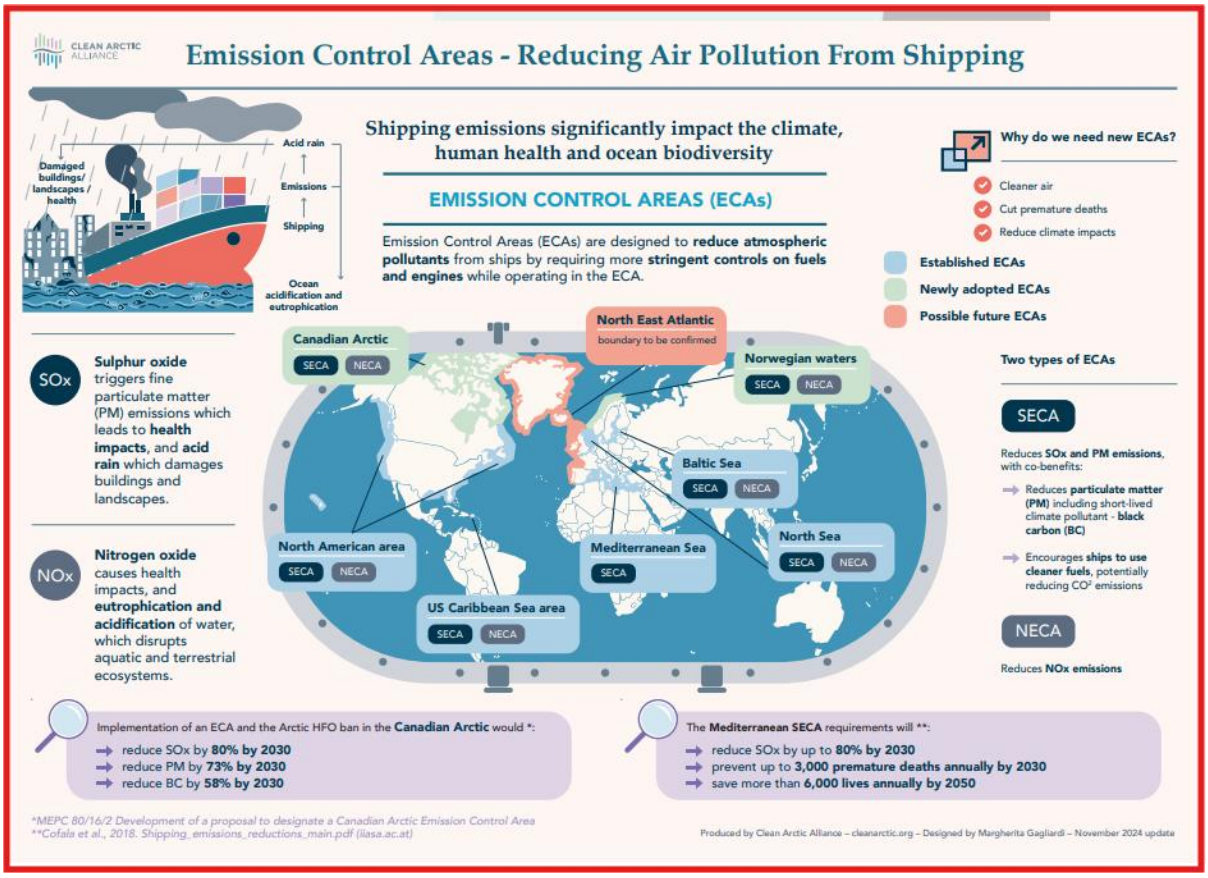
A major managerial risk is the delay in receiving these certificates. If the paperwork arrives after the fuel is consumed, the shipowner may lose all the expected cost reductions or carbon credits [Energy Manager Interview, 2026]. To conclude, while biofuels are a drop-in solution that saves shipowners from spending millions on new equipment investments, the administrative requirements must be perfect. If the availability of fuel certification is delayed and cannot be legally proven at the time of use, then the financial benefits of the transition will simply disappear [Robalo-Cabrera et al., 2025; Energy Manager Interview, 2026].

2.2 GLOBAL AND REGIONAL SHIPPING RULES

2.2.1 MARPOL AND THE SO_X/NO_X BASELINE

The main set of global rules governing ship pollution is **MARPOL Annex VI (International Convention for the Prevention of Pollution from Ships)**, which sets strict limits on Sulphur Oxides (SO_x) and Nitrogen Oxides (NO_x) [Tadros et al., 2023; IMO, 2025]. Until recently, the shipping industry relied exclusively on High-Sulphur Heavy Fuel Oil (HFO). The **IMO 2020 (International Maritime Organization)** gradually reduced the global sulphur cap from 4.5% to the current 0.5% in 2020, with an even tighter 0.1% limit inside Emission Control Areas (ECAs) [IMO, 2025; Stamatopoulos & Stamatopoulos, 2021, p. 83]. As shown in **Figure 2.1**, these designated areas, which include the North Sea, the Baltic Sea, the Mediterranean Sea, the US Caribbean Sea area and the North American area, as of 2025, require the most stringent controls on fuels and engine performance to protect human health and ocean biodiversity [Clean Arctic Alliance, 2023]. Biofuels have emerged as a practical drop-in answer to these rules because they are naturally low in sulphur, allowing vessels to stay compliant without needing expensive exhaust scrubbers [Sagin et al., 2024; Schulz et al., 2025].

The rules for NO_x create a different operational hurdle. Using biodiesel can sometimes increase NO_x emissions because it burns at higher temperatures [EL-Seesy et al., 2022; Liu et al., 2024]. Under MARPOL Annex VI Regulation 13, the IMO currently classifies biofuel blends up to B30 just like regular petroleum hydrocarbons. From a shipowner's perspective, this makes B30 the easiest choice for existing fleets. Using B30 allows them to cut emissions without the headache of re-certifying engines or changing their official legal papers [Global Fuels Director Interview, 2026].



Shipping emissions significantly impact the climate, human health and ocean biodiversity

EMISSION CONTROL AREAS (ECAs)

Emission Control Areas (ECAs) are designed to **reduce atmospheric pollutants** from ships by requiring more **stringent controls on fuels and engines** while operating in the ECA.

Sulphur oxide triggers fine particulate matter (PM) emissions which leads to **health impacts**, and **acid rain** which damages buildings and landscapes.

Nitrogen oxide causes health impacts, and **eutrophication and acidification** of water, which disrupts aquatic and terrestrial ecosystems.

Reduces **SOx and PM emissions**, with co-benefits:

- Reduces **particulate matter (PM)** including short-lived climate pollutant - **black carbon (BC)**
- Encourages **ships to use cleaner fuels**, potentially reducing CO^2 emissions

Implementation of an ECA and the Arctic HFO ban in the **Canadian Arctic** would *:

- reduce SOx by **80% by 2030**
- reduce PM by **73% by 2030**
- reduce BC by **58% by 2030**

The **Mediterranean SECA** requirements will **:

- reduce SOx by up to **80% by 2030**
- prevent up to **3,000 premature deaths annually by 2030**
- save more than **6,000 lives annually by 2050**

*MEPC 80/16/2 Development of a proposal to designate a Canadian Arctic Emission Control Area
**Cofala et al., 2018. Shipping_emissions_reductions_main.pdf (iiasa.ac.at)

Produced by Clean Arctic Alliance – cleanarctic.org – Designed by Margherita Gagliardi – November 2024 update

Figure 2.1: Global Emission Control Areas (ECAs) and their role in reducing shipping pollutants

Source: Adapted from Clean Arctic Alliance (2023).

In contrast, if an owner uses a blend higher than B30, they must prove that the engine's settings haven't changed, which adds a heavy technical and administrative burden [Global Fuels Director Interview, 2026]. This regulatory split reinforces the role of biofuels as a transitional bridge fuel. Lower blends (B20-B30) provide immediate CO_2 and SO_x reductions while avoiding the expensive complexity of re-certifying engine performance [Kim & Choi, 2023; DNV, 2025].

2.2.2 EU ETS AND FUELEU MARITIME

Two main sets of measures drive the shift toward biofuels in Europe. These regional rules are designed to bridge the huge price gap between fossil and renewable fuels. First, the EU

ETS works as a carbon tax. It allows owners to use certified biofuels to report lower emissions, which directly cuts the number of carbon allowances they have to buy [DNV, 2025]. This offers a direct saving, especially as carbon allowances become more expensive [Stamatopoulos, 2026]. For many Greek shipowners, the adoption of biofuels is still limited and hard to justify without this specific regulatory support. The high Green Premium simply makes biofuels much more expensive than standard fossil fuels [Solakivi et al., 2022; Energy Manager Interview, 2026].

Alongside this carbon tax is the FuelEU regulation, which targets an 80% reduction in GHG intensity by 2050 [Kanchiralla et al., 2024]. Unlike old standards, FuelEU looks at emissions from the field to the funnel **(Well-to-Wake, WtW)**, rewarding **advanced biofuels** with a **compliance surplus** [DNV, 2025]. The most important part for a fleet manager is the **pooling mechanism**. This allows one ship burning a high blend, like B100, to create enough extra credit to cover the deficits of other vessels in the same fleet [Stamatopoulos, 2026]. A case study, included in CIMAC's presentation about B100, show how powerful this is: a single ship on B25 can save five others, while a B50 scenario can cover twelve vessels. Theoretically, one ship on B100 could offset the entire compliance debt of a large fleet [Stamatopoulos, 2026]. However, a disclaimer should be included acknowledging that price fluctuations can significantly impact the findings in this area, ensuring that any conclusions drawn are appropriately contextualized and remain defensible given that inherent variability.

Even with these tricks, the initial cost of compliance is still a major hurdle. While the total cost might be lower under a B100 plan if the surpluses are sold or traded, the initial fuel bill is massive [Stamatopoulos, 2026]. Furthermore, getting these carbon discounts is not automatic. Shipowners must provide strict third-party certificates, like ISCC or RSB, to prove the fuel is truly sustainable [Global Fuels Director Interview, 2026]. In practice, if the paperwork is missing or wrong, the shipowner faces a heavy fine, even if they have already paid the high price for the biofuel [Global Fuels Director Interview, 2026]. This complexity, combined with new **blending mandates**, creates a tough market where charterers often care more about the paperwork and compliance than the technical quality of the fuel [Mizik, 2025; Ebadian et al., 2020; Stamatopoulos & Stamatopoulos, 2021, p. 41].

2.2.3 CII RATINGS AND OPERATIONAL METRICS

A major hurdle for shipowners is that current Energy Efficiency Design Index (EEDI) and Energy Efficiency Existing Ship Index (EEXI) design ratings do not actually reward the use of biofuels [DNV, 2025]. In practice, this means even if a vessel burns 100% bio-marine fuel, its technical birth certificate remains the same. This is because these IMO rules only care about the ship’s hardware and engine design [DNV, 2025]. This leaves older vessels in a difficult position. They cannot simply fuel-switch their way into a better EEXI score.

However, the **Carbon Intensity Indicator (CII)** and the IMO Data Collection System (DCS) work differently. These mechanisms focus on how a ship is actually operated throughout the year. This allows certified biofuels to improve the vessel's annual grade (from A to E) by applying specific lifecycle emission factors [DNV, 2025]. While this provides a clear way for owners to keep existing ships commercially viable, the legal credit for these fuels is not yet set in stone. The constant changes in WtW GHG accounting mean that shipowners face a level of commercial uncertainty. The latter will continue until the IMO finalizes these global monitoring rules [Global Fuels Director Interview, 2026].

CHAPTER 3: RESEARCH METHODOLOGY

3.1 RESEARCH DESIGN AND DATA SOURCES

This research is built as a mixed research study to compare biofuels and fossil fuels. Despite the growing literature on alternative marine fuels, limited research has comparatively analysed fossil and biofuel supply chains while incorporating market and stakeholder perspectives within the Greek shipping context.

To address this gap, the study combines a review of scientific and industry papers with primary data from maritime professionals. This approach allows this research to compare established literature against the practical realities of the industry. The study is supported by a series of Appendices (A-F) to ensure the process is transparent and easy to follow.

3.2 THE STAKEHOLDER SURVEY AND DATA COLLECTION

The primary data comes from a 10-question survey targeting Piraeus-based shipowners, technical managers, and bunker suppliers. This questionnaire (see Appendix A) was designed to measure specific metrics like fuel reliability and the operational requirements of different fuel types. All raw data and feedback from the 30 respondents are recorded in Appendices B and C.

To add a deeper layer of professional insight, the study also includes direct input from three high-level experts. These include a Bunker Broker, an Energy Performance Manager, and a Global Marine Fuels Business Development Director. Each expert answered three targeted questions about fuel price premiums and operational risks. Additionally, the Bunker Broker provided a marine fuel price list for the periods before and after the Middle East oil crisis. These interviews and price datasets (documented in Appendices D and E) provide a real-world perspective that balances the broader survey data.

3.3 DATA ANALYSIS AND RESEARCH LIMITS

The analysis uses two main methods. First, it uses simple statistics to identify clear trends in the survey responses. The survey utilizes a 5-point Likert Scale to measure the perceived operational reliability of different fuel types. This allows for a direct mathematical comparison between the established fossil baseline and the emerging biofuel market.

Second, the study uses an economic comparison for fuel costs. This logic looks at the price gaps in Rotterdam and Singapore against the cost of EU ETS carbon taxes. While the study provides deep insight into the Greek shipping sector, the results reflect the specific Tramp shipping nature of the local fleet. This framework, i.e. the combination of statistical and economic analysis, ensures that the conclusions are grounded in both scientific fact and maritime commercial reality.

CHAPTER 4: MARINE FUEL SUPPLY CHAINS

4.1 THE GLOBAL FOSSIL FUEL SYSTEM

4.1.1 REFINERY CAPACITY AND SCALE

The global maritime fuel supply chain relies on an industrial-scale refining infrastructure. Modern facilities process between 100,000 and over one million barrels of crude oil every day. This massive capacity ensures the long-term availability of MGO and VLSFO. These fuels are optimized through specific refinery procedures that adapt to changing energy demands.

The choice of crude oil feedstocks ranges from complex "sour" crudes to simpler "sweet" low-sulphur varieties. This selection determines which marine products are economically viable for the market [Stamatopoulos & Stamatopoulos, 2021, pp. 32-34, p. 43, p. 44, p. 46]. This maturity is clearly reflected in the 100% usage rate of MGO and VLSFO reported by the Greek shipping stakeholders in this study. Such a high percentage confirms the solid dominance of fossil fuels within current operational frameworks [Author's Survey Results, 2026].

4.1.2 ISO 8217 AND QUALITY CONTROL

The reliability of the fossil fuel supply is built on ISO 8217 quality standards. These standards provide the global rules for fuel safety, compatibility, and emissions compliance [Gucma, 2025]. By setting strict limits for viscosity, acidity, and flash point (which must be at least 60°C), they ensure that engines perform reliably across different vessel types.

For example, ISO 8217 defines the minimum viscosity for distillate grades like DMA (Distillate Marine Category A, commonly used for MGO) and DMB (Distillate Marine Category B, commonly used for Marine Diesel Oil, MDO). This is crucial for protecting the integrity of a ship's injection system. In 2017, these standards were updated to include low-sulphur and blended fuels, reflecting the industry's changing needs [Stamatopoulos & Stamatopoulos, 2021, pp. 61-62, pp. 94-95, pp. 121-130]. Recently, the ISO 8217:2024 update has gone even further by specifically incorporating parameters for biofuel blends up to B100.

Regardless of the blend, all marine fuels must strictly meet these specifications to remain compatible with a ship's existing fuel system [Stamatopoulos, 2026].

4.1.3 TRACEABILITY AND HUB CONCENTRATION

The logistical integrity of the traditional fuel system is secured by **Bunker Delivery Notes (BDNs)** and MARPOL sampling procedures. These link suppliers and operators through traceable documentation [Stamatopoulos & Stamatopoulos, 2021, pp. 262-263]. However, maintaining this certification across a global network remains a significant hurdle, as verification and traceability processes are highly complex [Global Fuels Director Interview, 2026]. The existing fossil fuel infrastructure is now increasingly being used to distribute **bio-blends**.

This infrastructure is heavily concentrated in major global bunkering hubs. Singapore and the ARA region (Rotterdam, Amsterdam, Antwerp) accounted for approximately 50% of the global biogenic and low-sulphur fuel supply in 2023 [DNV, 2025; Bunker Broker Interview, 2026]. Despite the increase in volumes, the market remains highly centralized around these specific locations [DNV, 2025].

Consequently, any crisis escalation in these key locations leads to higher absolute prices for both fossil and biofuel markets [Bunker Broker Price Data, 2026].

4.2 BIOFUEL SUPPLY CHAIN CHALLENGES

4.2.1 FEEDSTOCK DIVERSITY AND ORIGIN

Biodiesel marine fuels are produced through transesterification. This process converts feedstocks like vegetable oils, animal fats, and UCO into FAME [Zhang et al., 2025]. Advanced biofuels originate from non-food sources such as agricultural residues, waste materials, and recycled cooking oils [DNV, 2025]. Production also relies on forest waste and similar residues processed through gasification, pyrolysis, or fermentation [Harahap et al., 2023]. Even waste streams like manure and wastewater are used to produce biogas fuels [DNV, 2025]. Using lignocellulosic and waste feedstocks reduces iLUC risks and competition with food production [Cherwoo et al., 2023]. These circular bioeconomy principles focus on waste valorisation and resource efficiency within the supply chain [Mahapatra et al., 2021].

4.2.2 SUPPLY SCARCITY AND COMPETITION

Large-scale biofuel deployment is limited by the amount of available feedstock [Robalo-Cabrera et al., 2025]. The scarcity of UCO is a particular problem. It restricts how much biofuel can be produced and how quickly the market can grow. This shortage is driven by cross-sector competition, as the shipping industry must fight for the same limited supplies as the aviation and road transport sectors [DNV, 2025]. Shipping and aviation together account for nearly 10% of global GHG emissions. This creates a high sense of urgency in these “hard-to-abate” sectors [Urban et al., 2024]. Competition for sustainable feedstock is also increasing under the EU RED III directive, which is associated with all renewable energy sectors, not just transport [Global Fuels Director Interview, 2026]. To manage these risks, policy frameworks should prioritize waste-based and non-competitive feedstocks. This approach aims to protect food security and optimize environmental, economic, and social Sustainable Development Goals (SDGs) [Cabrera-Jiménez et al., 2022].

4.2.3 MARKET HUBS AND LOGISTICS

In the past, refineries prioritized high-value fuels like aviation fuel, diesel, gasoline, LPG, and naphtha production. They redirected the lower-value residual fractions to the shipping industry [Stamatopoulos & Stamatopoulos, 2021, pp. 36-39]. Today, biofuel bunkering is concentrated in major hubs like the Port of Singapore and the Port of Rotterdam. Supply volumes in these locations have shown rapid growth, increasing from 300,000 mt in 2021 to over 1.3 million mt by late 2024 [DNV, 2025]. This highlights that while biofuel adoption is rising, it is currently limited to the infrastructure of established global hubs.

Multiple biofuel grades are available in the ARA region and the Mediterranean. However, standard grades often vary across ports, which limits uniform access to identical bunker specifications for the global fleet [Bunker Broker Interview, 2026]. To support high-blend adoption, the ISO 8217:2024 standard now formally incorporates FAME and HVO blends up to B100 [Global Fuels Director Interview, 2026]. Despite this standard, maintaining certification integrity through schemes like ISCC and RSB presents practical challenges in verification and traceability [DNV, 2025; Global Fuels Director Interview, 2026]. Quality verification also requires Certificates of Quality (CoQ). Specifically, fuels must comply with the EN 14214 standard for FAME and EN 15940 for HVO [Stamatopoulos, 2026; Global Fuels Director Interview, 2026**].** This complexity often leads to different fuel grades being available in different ports [Bunker Broker Interview, 2026].

As shown in **Box 4.1** and **Figure 4.1**, while B100 is now commercially available in mature hubs like Rotterdam and Singapore, supply remains uneven across the global bunkering network. For the Greek tramp shipping sector, where port calls are less predictable, this geographical concentration turns fuel procurement into a complex supply chain planning challenge [Stamatopoulos, 2026]. See Appendix F for a detailed Global Port Directory.

Box 4.1: Global Commercial Availability of B100 Biodiesel (2025-2026)

Mature Markets (Commercial): Rotterdam, Amsterdam, Antwerp, Singapore.
Available/Growing: Hamburg, Marseille, Gibraltar, Algeciras, Barcelona.
Emerging/Project-Based: USA (Houston, Galveston, Long Beach), Canada, Australia.

Source: Stamatopoulos, B. (2026). *B100: Impacts and Aspects*. Presentation at CIMAC Hellas.

Map of locations where biofuel bunkering operations have taken place since 2015 (green) or where biofuel suppliers have indicated that biofuels are available (blue). Each dot represents one port. Bunkering of FAME, HVO, bio-LNG, and bio-methanol is included

● Biofuel bunkering operations confirmed

● Biofuel bunkering operations not confirmed but supply of biofuels available according to fuel suppliers

©DNV 2025

Source: DNV; as of December 2024

Figure 4.1: Global Biofuel Bunkering Hub Concentration

Source: Adapted from DNV (2025).

4.3 FUEL COSTS AND MARKET PRICING

4.3.1 HISTORICAL PRICE VOLATILITY

Historically, the shipping industry shifted from high-quality distillates to cheaper residual fuels. This was driven by constant price pressure and supply limits. Past oil crises, such as those in 1973-1974 and 1978-1980 under OPEC control (Organization of the Petroleum Exporting Countries), caused sharp global price increases and fuel shortages [Stamatopoulos & Stamatopoulos, 2021, pp. 36-39]. Today, the large-scale adoption of B100 remains exposed to similar market volatility [Stamatopoulos, 2026]. In addition, high demand for biofuel feedstock can lead to **crop switching.** This happens when farmers move from food to energy production, which can cause food prices to become unstable and rise [Morone et al., 2020].

4.3.2 THE GREEN PREMIUM REALITY

Current market data confirms a persistent price gap between fossil fuels and biofuels. In Rotterdam (February/March 2026), unsubsidized B30 costs significantly more than conventional VLSFO (USD 488/mt). This results in a USD 172/mt Green Premium, even after subsidies are applied. In contrast, the Singapore market shows a narrower gap of USD 57/mt during crisis periods. At that time, VLSFO reached USD 1,133/mt while B24 was priced at USD 1,190/mt (see Appendix E for the complete price comparison table). However, availability in Singapore is often restricted. The market primarily supplies B24 and B30 under term contracts to liner operators. While surplus volumes are occasionally released into spot markets, availability there remains limited by operational constraints. Furthermore, spot procurement typically requires extended lead times and minimum order quantities of approximately 500 metric mt to be feasible for suppliers. This high minimum volume creates a significant entry barrier for smaller operators who require smaller, occasional blends [Bunker Broker Interview, 2026].

The price data reveals a significant discrepancy in how these two main hubs react to fossil fuel volatility. In Rotterdam, even with subsidies, the Green Premium is high and even expanded during the 2026 oil crisis from USD 172/mt to USD 230/mt (see **Table 4.1**). This indicates that in European markets, fixed subsidies are often insufficient to offset the rapid spike in biofuel feedstock during a conflict.

Conversely, the Singapore market experienced a different story. Due to its geographic proximity to the crisis and heavy reliance on Middle Eastern crude, fossil VLSFO prices skyrocketed more intensely than biofuel blends. This caused the price gap to narrow significantly from USD 204/mt to only USD 57/mt. In simple terms, this proves that biofuels reach their highest economic competitiveness during extreme fossil fuel supply shocks, due to the rapid inflation of the fossil baseline [Appendix E].

4.3.3 REGULATORY PRICE INCENTIVES

To reduce investment uncertainty and encourage adoption, policy mechanisms like subsidies and harmonized standards are required [Oloruntobi et al., 2025; Arias et al., 2024]. Frameworks using blending mandates and financial incentives have already driven biofuel growth in other transport sectors [Ebadian et al., 2020]. Current shipping policies rely on instruments such as carbon taxation (EU ETS) and production incentives to promote the substitution of fossil fuels [Suali & Suali, 2023].

In **voluntary** biofuel markets, **Scope 3** decarbonization contracts allow some cargo owners to pay green freight premiums to cover these higher costs [DNV, 2025]. Carbon intensity targets and renewable fuel incentives also help reduce investment risks. These mechanisms, along with climate-aligned shipping finance, directly improve the market viability of maritime biofuels [Arias et al., 2024]. In the long term, a transition toward fossil fuel elimination could provide the incentive needed to scale up the biofuel supply chain [van Leeuwen & Monios, 2022] [Halpe et al., 2025].

Table 4.1: Biofuel Price Premiums (Rotterdam vs. Singapore)

Market Hub	**Period (2026)**	**Fossil (VLSFO)**	**Bio-Blend (B24/B30)**	**The Green Premium**
Rotterdam	**Pre-Crisis (Feb 24)**	$488	$660 (Subsidized)	**+$172**
Rotterdam	**Post-Crisis (Mar 13)**	$800	$1,030 (Subsidized)	**+$230**
Singapore	**Pre-Crisis (Feb 24)**	$506	$710	**+$204**
Singapore	**Post-Crisis (Mar 13)**	$1,133	$1,190	**+$57**

Source: Adapted from Appendix E (2026).

Note: Rotterdam data reflects B30 blends; Singapore data reflects B24 blends.

CHAPTER 5: RESULTS AND ANALYSIS

5.1 TECHNICAL COMPARISON OF FUELS

5.1.1 ENERGY DENSITY AND CONSUMPTION

The primary operational difference between fossil and biofuels is the energy density deficit. Fossil MGO or VLSFO maintain a high energy baseline between 40-43 MJ/kg [Stamatopoulos & Stamatopoulos, 2021, pp. 78-79]. In contrast, biofuels typically exhibit a lower density of 37-40 MJ/kg [Manikandan et al., 2025]. This 10-12% energy gap directly reduces energy efficiency and raises fuel consumption during long-distance operations [Bilgili, 2023; Manikandan et al., 2025].

The specific energy (MJ/kg) determines the combustion heat release, which influences vessel operational efficiency [Stamatopoulos & Stamatopoulos, 2021, pp. 78-79]. Industry insights confirm that lower energy density results in higher volumetric consumption. This forces shipowners to recalibrate voyage range calculations and fuel planning strategies [Global Fuels Director Interview, 2026]. While third-generation microalgae fuels promise higher density, they remain technologically immature and commercially unviable at a large scale [Gollakota & Shu, 2023; Manikandan et al., 2025; Cabrera-Jiménez et al., 2022; Perin & Jones, 2019].

5.1.2 THERMAL STABILITY AND GELLING

Biofuel integration introduces geographic limits due to cold-flow properties. Standard fossil fuels are not affected to the same degree. FAME-based blends are susceptible to wax formation and “gelling” in low-temperature marine environments [Szeto & Leung, 2022]. This specifically affects the **Cloud Point (CP)** and **Pour Point (PP)** [Selvam et al., 2025]. This risk also extends to ULSFO blending (Ultra Low Sulphur Fuel Oil), where uncertain cold-flow behaviour is a key operational hazard for the crew.

These properties necessitate post-bunkering laboratory testing because wax deposits can block filters and shorten maintenance cycles [Stamatopoulos & Stamatopoulos, 2021, pp. 105-107, pp. 114-120]. High CPs restrict operational reliability in colder maritime regions. This means the drop-in flexibility of biofuels is restricted by the vessel's trading route [Selvam et al., 2025].

5.1.3 OXIDATION AND STORAGE RISKS

There is a major difference in long-term stability between fossil and bio-feedstocks. FAME demonstrates lower storage stability because it is prone to oxidation [DNV, 2025]. This leads to increased acidity and sludge formation over time. This chemical breakdown is often accompanied by high water affinity, which increases the risk of microbial contamination during storage periods exceeding four to six months [Stamatopoulos & Stamatopoulos, 2021, pp. 105-107].

In contrast, HVO exhibits high oxidation stability and water resistance [Oloruntobi et al., 2025]. This makes it a superior “drop-in” fuel for extended storage [DNV, 2025]. To mitigate the risks of degradation, operators must implement rigorous housekeeping, such as tank drainage and filter cleaning [Stamatopoulos & Stamatopoulos, 2021, pp. 102-105]. These technical vulnerabilities validate the 83% intensified monitoring requirement identified in this survey. Biofuel processing and quality monitoring differ significantly from fossil fuels. They require additional operational steps to ensure compliance with fuel standards and engine requirements [Energy Manager Interview, 2026]. According to industry insights, the susceptibility of FAME-based biofuels to these storage risks necessitates a shift toward continuous onboard testing and active monitoring protocols [Global Fuels Director Interview, 2026].

5.2 ENVIRONMENTAL AND REGULATORY PERFORMANCE

5.2.1 LIFECYCLE (WTW) EMISSION FACTORS

The environmental value of marine biofuels is determined by **Life Cycle Assessment (LCA)** and WtW methodologies. These evaluate emissions across the entire production, transport, and combustion cycle [Li et al., 2025]. While **Tank-to-Wake (TtW)** emissions show only modest reductions, full LCA reveals significantly lower net GHG emissions [Robalo-Cabrera et al., 2025]. This improvement is driven by the biogenic carbon cycle, where carbon absorbed during biomass growth partially offsets the CO_2 released during combustion [DNV, 2025].

Currently, the maritime sector contributes approximately 2-3% of global anthropogenic GHG emissions [Halpe et al., 2025; van Leeuwen & Monios, 2022]. To address this, tools like the CII and DCS now recognize emission reductions from certified biofuels by applying specific lifecycle emission factors [DNV, 2025].

5.2.2 FEEDSTOCK-BASED GHG SAVINGS

The capacity for GHG reduction depends heavily on the feedstock and production pathway. Advanced second- and third-generation biofuels use non-edible biomass and waste to reduce lifecycle impacts [Cherwoo et al., 2023]. Empirical data indicates that biofuels can reduce GHG emissions by 70-90% per tonne-km (tonne-kilometre) [Ahmed et al., 2025]. Under favorable conditions, reductions of up to 78% are possible compared to conventional marine fuels [Kanchiralla et al., 2024].

To meet the IMO CII requirement, biofuels must provide a WtW GHG reduction of at least 65% compared to the fossil **MGO baseline of 94 gCO_2eq/MJ** [DNV, 2025]. These high-performance fuels serve as an essential interim compliance pathway for meeting global decarbonization regulations [Stamatopoulos, 2026].

5.2.3 REGULATORY COMPLIANCE AND FINANCIAL IMPACT

Regulatory frameworks like the EU ETS create financial incentives by allowing certified biofuels to reduce reported emissions and the number of required allowances [DNV, 2025]. Under FuelEU Maritime, shipowners can use a “compliance surplus” mechanism to manage fleet emissions. For example, a B25 scenario allows one biofuel vessel to offset the deficits of five additional ships. Theoretically, a B100 scenario enables a single vessel to offset an entire fleet's **compliance deficit** [Stamatopoulos, 2026].

However, high-blend adoption increases operational and administrative requirements. Biofuel components must comply with EN 14214 (for FAME) or EN 15940 (for HVO), and final blends must meet ISO 8217:2024 specifications. Furthermore, FuelEU mandates third-party certification through schemes like ISCC or RSB. Blends exceeding B30 require operators to maintain NO_X Technical File validity and coordinate with classification societies for verification [Global Fuels Director Interview, 2026].

When compliant fuel is unavailable, the Fuel Oil Non-Availability Report (FONAR) allows for temporary non-compliance reporting [Stamatopoulos & Stamatopoulos, 2021, pp. 270-271]. Ultimately, these fuels are a transitional solution that supports the gradual shift toward lower-emission maritime energy systems [Qualitative Survey Insights, 2026]. The financial impact for shipowners is that they can save money on regulatory fines and carbon taxes, but they invest in higher fuel premiums and administrative compliance [Energy Manager Interview, 2026].

5.3 SURVEY RESULTS AND STAKEHOLDER FEEDBACK

Table 5.0: Summary of Survey Figures

Figure	Title	Description
5.1	**Respondent Roles**	Professional distribution of the survey sample (n=30)
5.2	**Fuels Used**	Current fuel mix in Greek fleet operations
5.3	**Reliability Comparison**	Mean scores for Fossil vs. Biofuel (Likert Scale)
5.4	**Operational Issues**	Specific technical risks reported by stakeholders
5.5	**Monitoring Requirement**	Consensus on the need for intensified surveillance
5.6	**Local Availability**	Supply status in respondents' operating ports
5.7	**Adoption Barriers**	Main hurdles preventing biofuel adoption

Source: Author’s Survey (2026).

5.3.1 PARTICIPANTS AND RELIABILITY

The survey included 30 Greek maritime professionals. Most participants were Technical Managers (47%, n=14) and Ship Operators (30%, n=9) (see **Figure 5.1**). A complete summary of the survey responses is documented in Appendix B.

While everyone currently utilizes MGO and VLSFO, only 33% (n=10) reported active experience with biofuel blends (see **Figure 5.2**).

This professional group identifies a clear reliability gap. On the 5-point scale, fossil fuels achieved a mean score of 4.23, while biofuels scored significantly lower at 3.37 (see **Figure 5.3**) [Author's Survey Results, 2026].

Key stakeholder perceptions are summarized in the below **Table 5.1.**

Table 5.1: Key Stakeholder Perceptions on Marine Biofuels (n=30)

Metric	**Fossil Fuels**	**Biofuels**	**Gap / Result**
Reliability Score (1-5)	4.23	3.37	**0.86 (Confidence Gap)**
Monitoring Needed	-	**83%**	**Intensified Surveillance**
Local Availability	-	**77%**	**Limited Supply**
Primary Adoption Barriers	-	-	**Cost (57%) / Availability (57%)**

Source: Author's Survey (2026).

Note: For the full detailed dataset of survey responses, see Appendix B.

Although 10% to 20% bio-blends are technically reliable [Sagin et al., 2024], this lower score reflects industry concerns about gelling in cold weather and limited reliability in certain regions [Selvam et al., 2025].

5.3.2 RISKS AND MONITORING

Stakeholders identified specific technical risks that differentiate biofuels from the fossil baseline. While 60% (n=18) reported no immediate issues, participants with bio-experience highlighted storage instability (30%, n=9) as a main concern (see **Figure 5.4**) [Author's Survey Results, 2026].

Biofuels like FAME are prone to oxidative degradation and increased acidity over time [DNV, 2025; Global Fuels Director Interview, 2026]. Their **hygroscopic nature** also increases water absorption, promoting microbial growth during storage exceeding two months [DNV, 2025; Selvam et al., 2025]. Furthermore, the solvent properties of FAME can mobilize existing tank sediments, increasing the risk of filter blockage during the initial transition [Global Fuels Director Interview, 2026]. Because of these risks, 83% (n=25) of respondents confirmed that biofuels need intensified monitoring protocols (see **Figure 5.5**) [Qualitative Survey Insights, 2026].

This includes continuous engine surveillance and additional chemical analysis to detect performance deviations and protect engine integrity [Damian et al., 2025; Qualitative Survey Insights, 2026; Global Fuels Director Interview, 2026].

5.3.3 BARRIERS AND MARKET REALITY

The survey reveals two different barriers that equally limit biofuel adoption. Specifically, 77% (n=23) of stakeholders described current biofuel supply in their operating ports as "Limited" (see **Figure 5.6**) [Author's Survey Results, 2026].

Because of this scarcity, 57% (n=17) of respondents cited Availability and 57% (n=17) cited Cost as their primary barriers (see **Figure 5.7**) [Author's Survey Results, 2026].

This economic pressure is validated by market data. For example, in Rotterdam, subsidized B30 prices of USD 660/mt remain significantly higher than conventional VLSFO at USD 488/mt [Bunker Broker Price Data, 2026]. Without policy incentives, these high market prices create a massive economic barrier [Robalo-Cabrera et al., 2025; Amdi et al., 2024]. Other hurdles include Technical Risk (30%, n=9) and Regulatory Uncertainty (23%, n=7).

The limited availability, reported in the survey, creates a logistical bottleneck. This problem is further intensified because bunker fuel costs are a ship's largest operational expense [Energy Manager Interview, 2026; Balci et al., 2024]. In the tanker and bulk sectors, there are no green freights to help owners recover these costs. While some cargo owners pay for Scope 3 reductions on a voluntary basis, this currently only happens in the container and cruise sectors [Energy Manager Interview, 2026]. In the end, limited supply and the need for more monitoring define the current transitional role of biofuels [Author's Survey Results, 2026]. Ports must play a larger role by providing better bunkering infrastructure and increasing fuel availability [Halpe et al., 2025].

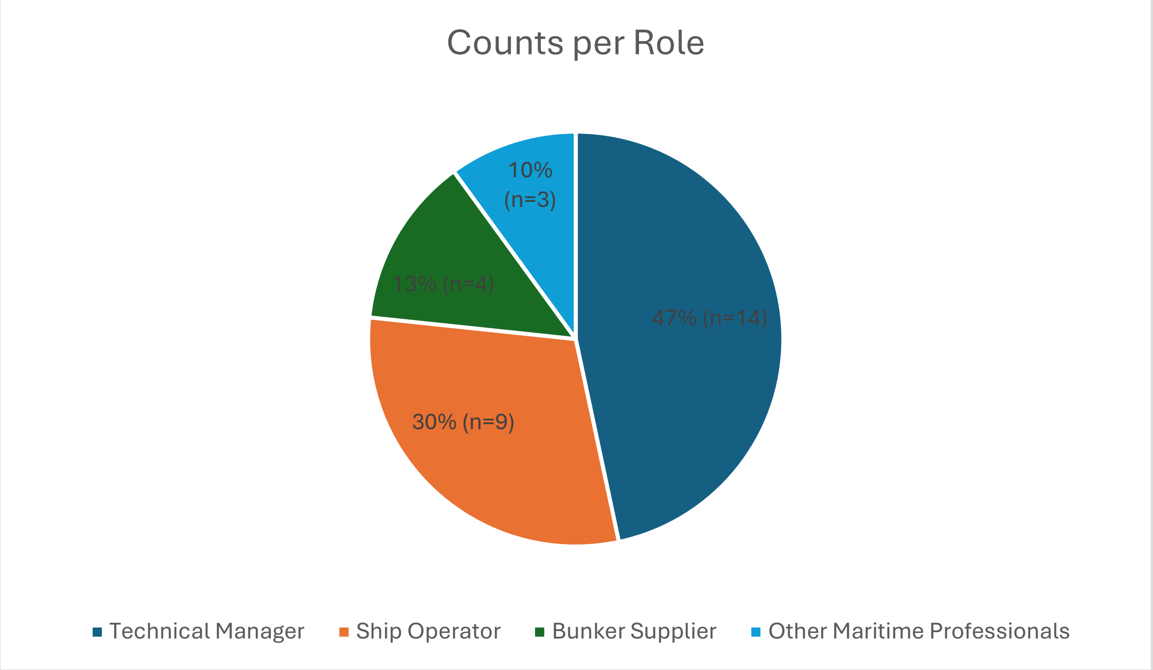


Figure 5.1: Respondent Roles

Source: Author's Survey (2026).

Note: Survey responses based on 30 Greek shipping stakeholders (n=30).

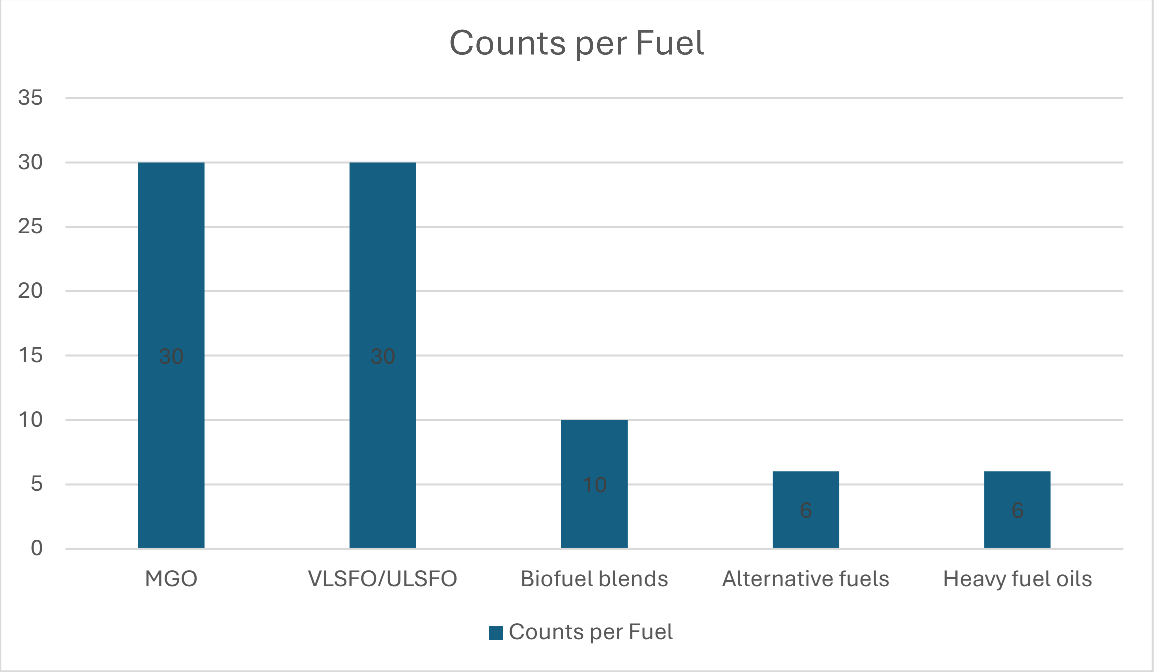


Figure 5.2: Marine Fuels Currently Used

Source: Author’s Survey (2026).

Note: Participants were permitted to select multiple responses.

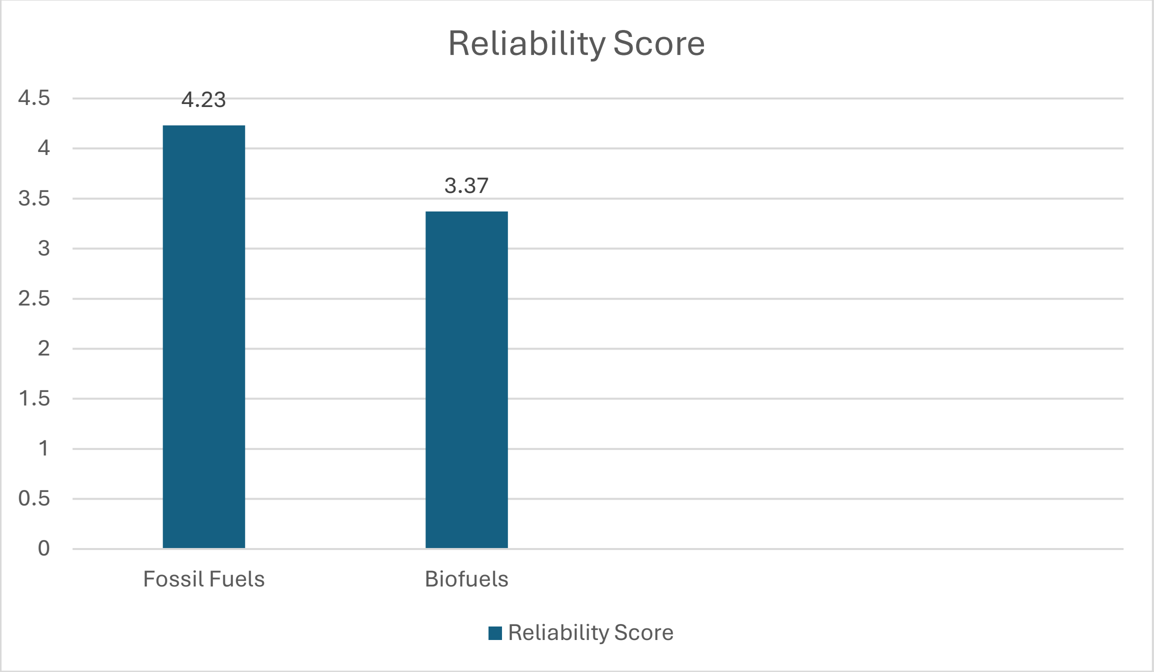


Figure 5.3: Reliability Comparison (Fossil vs Biofuel)

Source: Author’s Survey (2026).

Note: Scores based on a 1-5 Likert Scale (1=Very Low, 5=Very High).

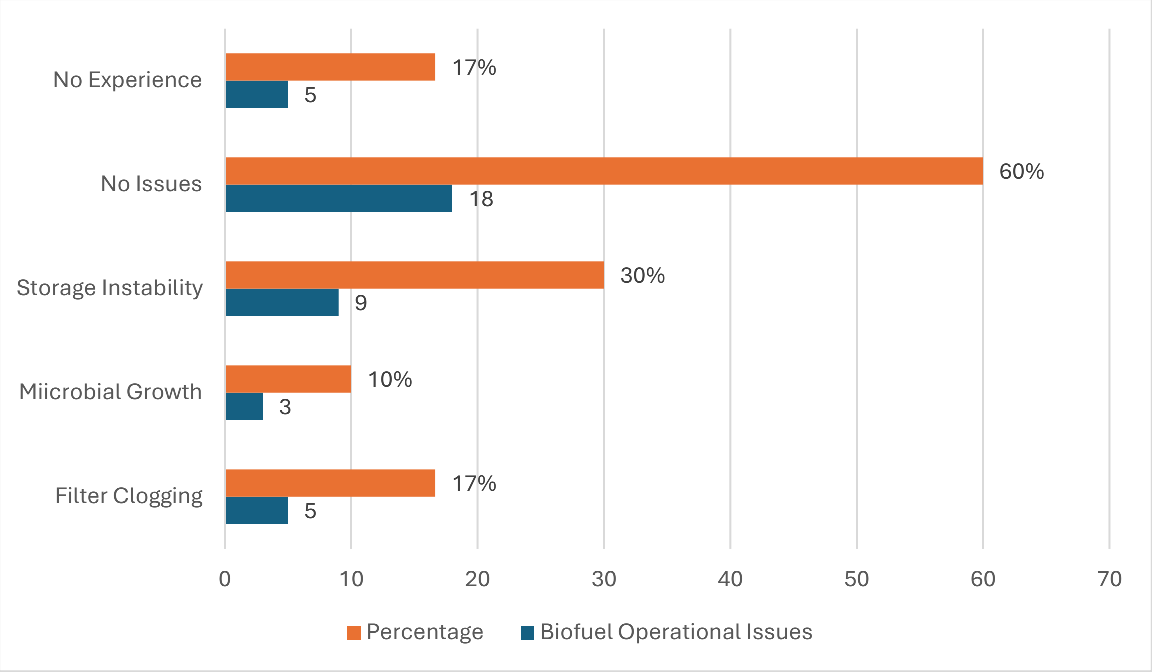


Figure 5.4: Biofuel Technical and Operational Issues

Source: Author's Survey (2026).

Note: Participants were permitted to select multiple responses.

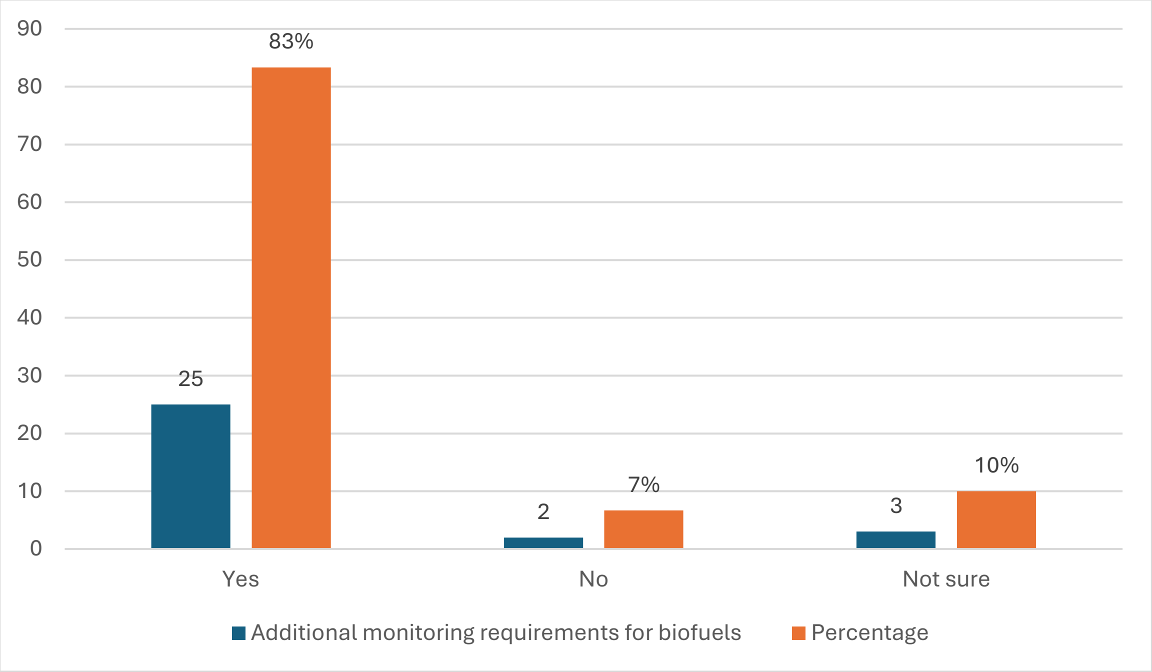


Figure 5.5: Biofuel Monitoring Requirement

Source: Author's Survey (2026).

Note: Percentages based on 30 Greek shipping stakeholders (n=30).

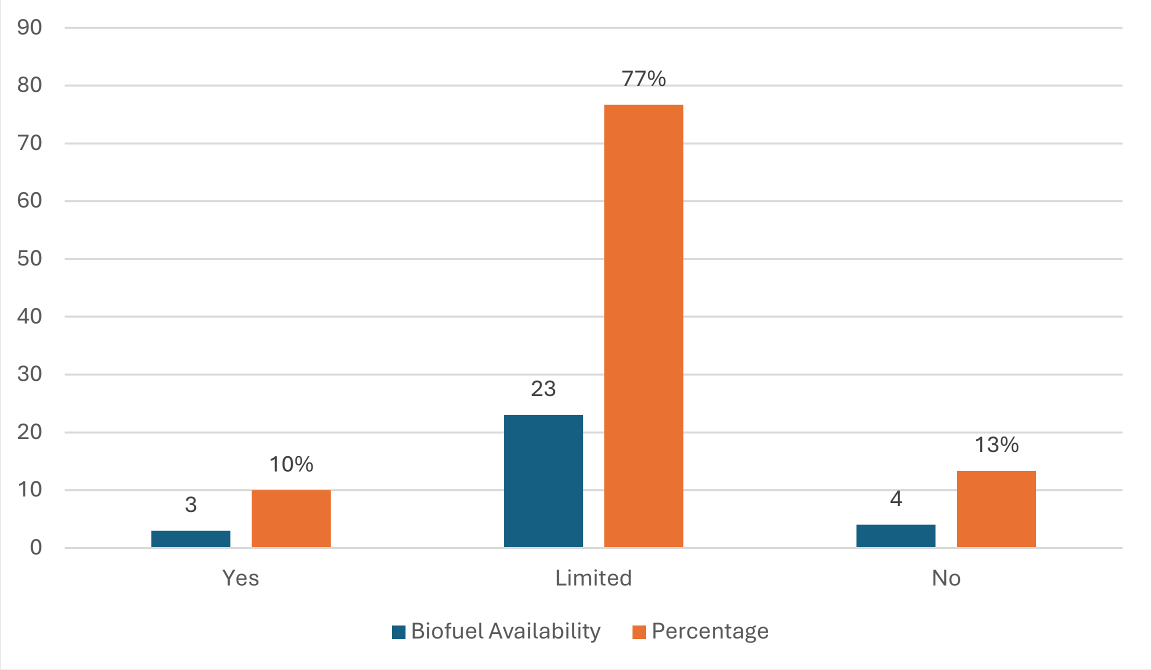


Figure 5.6: Biofuel Availability in Operating Ports

Source: Author’s Survey (2026).

Note: Assessment of fuel availability across respondents’ current global trading routes (n=30).

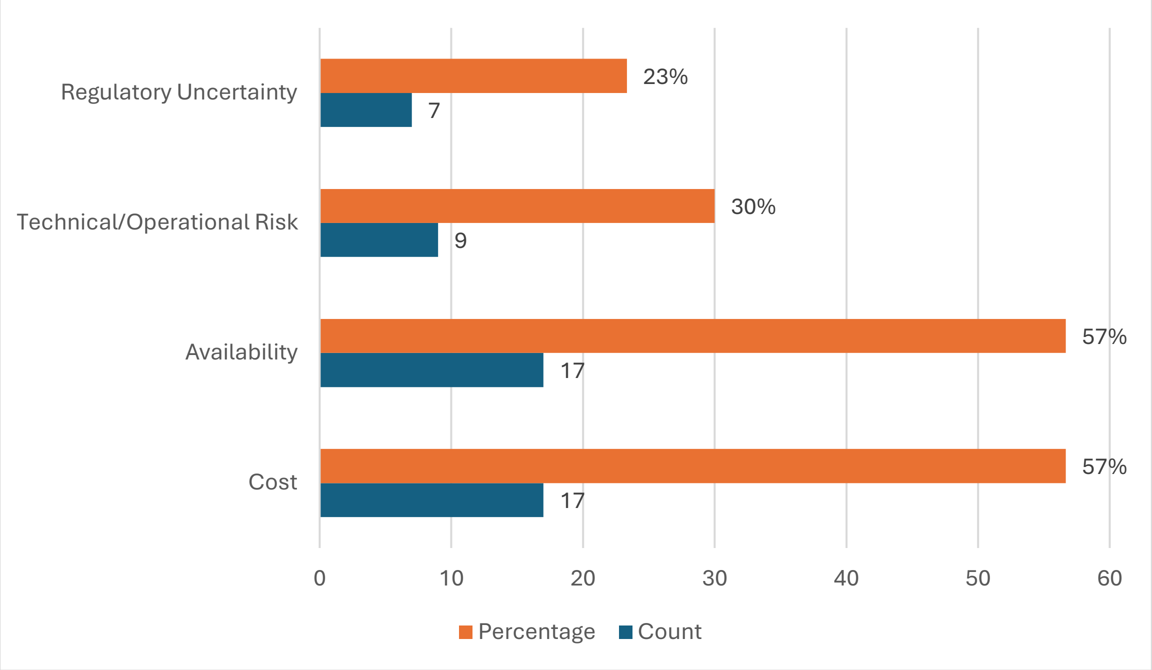


Figure 5.7: Main Barriers to Biofuel Adoption

Source: Author’s Survey (2026).

Note: Participants were permitted to select multiple primary barriers (n=30).

CHAPTER 6: BARRIERS AND OPPORTUNITIES

6.1 TECHNICAL AND OPERATIONAL HURDLES

The transition to biofuels introduces specific risks linked to fuel handling and storage. Reported issues include storage instability, filter clogging, and microbial growth [Author's Survey Results, 2026]. FAME-based biofuels are susceptible to oxidative degradation and contamination during long storage periods. This requires continuous onboard testing and monitoring protocols to manage quality risks [Global Fuels Director Interview, 2026; Qualitative Survey Insights, 2026].

A primary risk during the initial transition is the solvent effect of FAME. This effect can loosen existing tank sediments and increase the risk of filter blockage. Furthermore, FAME has higher chemical reactivity than fossil diesel. Depending on the concentration, it can degrade plastics, elastomers, and metals within the fuel system [Global Fuels Director Interview, 2026].

Temperature management is also a critical factor. Cold flow properties, such as the CP and PP, define the risk of wax formation. Storage temperatures must remain above the **Cold Filter Plugging Point (CFPP)** to prevent system blockages [Stamatopoulos & Stamatopoulos, 2021, p. 98, pp. 116-120]. Over the long term, use may also cause injector deposits and lubrication contamination within the engine [Mohammadpour & Salehi, 2025].

Moving to biofuels therefore requires a systematic review of fuel systems and maintenance procedures. Using higher blends also necessitates detailed engine documentation. Shipowners must coordinate with classification societies to satisfy these regulatory verification requirements [Global Fuels Director Interview, 2026].

6.2 COMMERCIAL AND MARKET BARRIERS

A persistent price premium drives the economic barrier to biofuel adoption. In the ARA market, pure (B100) advanced FAME biofuels cost between USD 520 and USD 1,000 per mt more than conventional VLSFO. In contrast, the premium for blended products (B24-B30) is lower, yet still represents a significant operational increase. While subsidies in hubs like Rotterdam help reduce this cost, the premium remains a major hurdle [Bunker Broker Price Data, 2026; DNV, 2025]. Because of these high costs, shipowners require commercial mechanisms like charter adjustments or regulatory incentives to share the financial burden [Global Fuels Director Interview, 2026].

A primary challenge is the absence of green freights in the tanker and bulk carrier segments. While biofuels avoid the huge upfront costs of ammonia or hydrogen engines [Energy Manager Interview, 2026], the ongoing price premium of USD 520-1,000 per mt for pure bio-products remains a prohibitive operational expense [DNV, 2025]. Unlike other sectors, the tramp shipping market currently lacks mechanisms to pass these costs onto the customer [Energy Manager Interview, 2026]. However, voluntary markets now allow some cargo owners to pay premiums for lower Scope 3 emissions. These specific decarbonization contracts support early-stage adoption by covering the green freight premium [DNV, 2025].

Beyond the Green Premium, shipowners face severe operational and legal risks under Port State Control (PSC). If a vessel is found with non-compliant fuel, the consequences go far beyond a simple fine. In major hubs like Fos, France, a fuel-related detention can cost an owner over €100,000 in immediate fees, while in stricter jurisdictions like Australia, the costs can be even higher. For a Greek bulk carrier, a detention often means missing the next cargo or being placed off-hire if the vessel is on a time charter. Such financial risks, along with the potential damage to an owner’s commercial reputation, are the reason why the 83% intensified monitoring requirement identified in the present survey is seen as a vital necessity for risk mitigation. While charterers focus on regulatory compliance and fuel value, shipowners must prioritize the technical properties that affect engine health [Stamatopoulos & Stamatopoulos, 2021, p. 41, pp. 274-275].

Despite these costs, biofuels offer higher compatibility with existing engines than other alternative fuels. This reduces the complexity of the transition for current operations [Energy Manager Interview, 2026]. However, **carbon lock-in** and path dependency from existing infrastructure still delay the shift away from fossil fuels [Urban et al., 2024]. To overcome this, carbon pricing and early-adopter companies are acting as essential drivers for new investment [Balci et al., 2024].

6.3 FUTURE PATHWAYS TO 2030

Biofuels, especially second-generation types like Used Cooking Oil (UCO), allow for decarbonization without the need for new engines or major infrastructure [Global Fuels Director Interview, 2026]. Blending up to 50% with traditional marine diesel is technically possible. This supports a gradual transition using existing fuel systems [Bullermann et al., 2024]. As **drop-in fuels**, they enable emission reductions without immediate engine retrofitting [Schulz et al., 2025]. This compatibility reduces transition risks compared to fuels like hydrogen or ammonia, which require entirely new storage and propulsion technologies [Tadros et al., 2023].

However, the commercial scale of these fuels remains limited. Projections suggest biofuels will supply only 5-10% of global marine fuel demand by 2030 [Selvam et al., 2025]. While current biofuels like FAME (first-generation) and HVO (second generation) are available now, they present sustainability and feedstock concerns [Mohammadpour & Salehi, 2025]. Cross-sector competition for these feedstocks further restricts their growth in the maritime sector [Selvam et al., 2025]. Additionally, advanced systems like algae-based fuels face high energy intensity during production. This makes them currently unviable for large-scale use [Amdi et al., 2024; Gollakota & Shu, 2023; Manikandan et al., 2025].

The path forward is largely governance-driven. Regulatory frameworks and market signals must precede the spread of these technologies [Balci et al., 2024]. While the CII and EEXI rules may recognize biofuel use, changing carbon accounting methods still create commercial uncertainty [Global Fuels Director Interview, 2026]. Current evidence regarding life-cycle emissions also lacks the consistency needed to guide long-term transition strategies [Roux et al., 2024].

Overall, biofuels are seen as a transitional solution through the 2030s while other infrastructures mature [Global Fuels Director Interview, 2026]. This shift includes a mix of advanced biofuels, electro-fuels, and hydrogen to maintain operational continuity [Urban et al., 2024]. Stakeholders emphasize that this role is shaped by limited supply and the need for increased monitoring [Author’s Survey Results, 2026]. Therefore, transitioning requires a systematic review of fuel systems and maintenance procedures [Global Fuels Director Interview, 2026].

CHAPTER 7: CONCLUSIONS AND RECOMMENDATIONS

7.1 SUMMARY OF MAIN FINDINGS

The research confirms that biofuels, specifically second-generation HVO and existing FAME blends, are the primary bridge for the maritime sector's decarbonization. Their biggest advantage is drop-in compatibility. This allows for immediate emission cuts without the massive expense of engine retrofitting or new port infrastructure [Kim & Choi, 2023; Foretich et al., 2021]. While fossil fuels still dominate because they are cheaper and more reliable, the "ticking clock" of IMO and EU mandates is forcing a shift. The speed of this transition depends on technological maturity. Until biofuel production reaches a truly industrial scale, the industry must accept a temporary drop in economic efficiency [Barreto, 2018].

7.2 THE SCALABILITY AND SUPPLY WARNING

Even if every ship is technically ready to use biofuels, the long-term problem is the scalability of feedstock [Global Fuels Director Interview, 2026]. Scientific literature identifies severe bottlenecks in feedstock logistics, transport, and storage. These issues prevent biofuels from becoming a global commodity like fossil oil [Zhang et al., 2025]. Specifically, the scarcity of Used Cooking Oil (UCO) and the competition for land with food crops are major hurdles [Solakivi et al., 2022; DNV, 2025]. This scarcity bottleneck is made worse by the uneven global supply, which might force ships to change their routes just to find fuel [Sagin et al., 2024]. While advanced options like microalgae offer hope, they are currently too expensive to meet the massive demand of global shipping [Azadi et al., 2017; Bach et al., 2021; Oloruntobi et al., 2025].

7.3 STRATEGIC ADVICE FOR THE INDUSTRY

The findings conclude that biofuels are not yet naturally competitive. Their current value is created by regulatory pressure rather than market demand. Without the financial protection of carbon taxes and subsidies, the high cost of bio-blends remains a major barrier [Bach et al., 2021]. Based on these findings, the following strategy is proposed:

- Use Regional Rules to Lower Costs: For the Greek fleet, the priority should be the refinement of the FuelEU Maritime and the EU ETS. Owners should view B100 scenarios as a way to create a compliance surplus. Instead of a fuel expense, biofuel should be seen as a regulatory asset that can be pooled to protect an entire fleet from fines [Stamatopoulos, 2026].
- Focus on Waste-Based (Second-Generation) Fuels: To stay legally safe and avoid the conflict between food and fuel, owners must prioritize waste-based feedstocks [DNV, 2025]. Shifting European laws will likely restrict food-based fuels soon. This makes advanced second-generation alternatives the only safe long-term investment [Mizik, 2025; Bunker Broker Interview, 2026].
- Fix the Supply Bottleneck: Policymakers must move beyond minor operational changes and start building global bunkering infrastructure. We need harmonized standards to give investors the confidence to scale up production [Oloruntobi et al., 2025; van Leeuwen & Monios, 2022; Balci et al., 2024].
- Accept the Multi-Fuel Future: Biofuels are a partial solution, not the final answer. Indeed, results from Question 9 of the current survey confirm this view, with 57% (n=17) of respondents recognizing biofuels as a temporary or partial entity [Author’s Survey Results, 2026]. As we move toward 2040, the focus will shift to synthetic e-fuels and hydrogen [Padder et al., 2024]. Biofuels should therefore be utilized as the immediate but temporary bridge to maintain existing fleet operations while the future energy field matures.

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APPENDIX A: Stakeholder Survey Questionnaire

Title: Biofuels compared to fossil fuels in the shipping supply chain

The following questionnaire was used to collect primary data from stakeholders in the Greek shipping industry regarding the use of marine fuels and the potential adoption of biofuels.

Q1. What is your role?
- Ship operator
- Technical manager
- Bunker supplier
- Other

Q2. What fuels are currently used in your operations? (Multiple selection allowed)
- MGO
- VLSFO
- FAME blends
- HVO
- Other

Q3. Rate the operational reliability of fossil fuels (1-5).
(1 = Very low, 5 = Very high)

Q4. Rate the operational reliability of biofuels (1-5).
(1 = Very low, 5 = Very high)

Q5. Have you experienced any of the following with biofuels? (Multiple selection allowed)
- Filter clogging
- Microbial growth
- Storage instability
- No issues
- No experience

Q6. Does biofuel use require additional monitoring compared to fossil fuels?
- Yes
- No
- Not sure

Q7. Are biofuels readily available in your operating ports?
- Yes
- No
- Limited availability

Q8. What is the main barrier to biofuel adoption? (Multiple selection allowed)
- Cost
- Availability
- Technical risk
- Regulatory uncertainty

Q9. Do you consider biofuels a viable long-term decarbonization solution?
- Yes
- No
- Partially

Q10. Additional comments (optional)

APPENDIX B: Summary of Stakeholder Survey Responses (n=30)

Question	**Category**	**Count**	**Percentage (%)**
Q1 Role	Ship operator	9	30%
	Technical manager	14	47%
	Bunker supplier	4	13%
	Other	3	10%
Q2 Fuels used*	MGO	30	100%
	VLSFO / ULSFO	30	100%
	Biofuel blends	10	33%
	Alternative fuels	6	20%
	Heavy fuel oils	6	20%
Q3 Fossil reliability	Mean score	4.23	-
Q4 Biofuel reliability	Mean score	3.37	-
Q5 Biofuel issues*	Filter clogging	5	17%
	Microbial growth	3	10%
	Storage instability	9	30%
	No issues	18	60%
	No experience	5	17%
Q6 Monitoring	Yes (Requirement)	25	83%
	No	2	7%
	Not sure	3	10%
Q7 Availability	Yes	3	10%
	Limited	23	77%
	No	4	13%
Q8 Barriers*	Cost	17	57%
	Availability	17	57%
	Technical risk	9	30%
	Regulatory uncertainty	7	23%
Q9 Long-term viability	Yes	5	17%
	Partially	17	57%
	No	8	26%

Source: Author's Survey (2026).

Notes: *Multiple responses allowed. Percentages based on total respondents (n = 30).

APPENDIX C: Qualitative Stakeholder Feedback (Open Comments Q10)

This appendix presents selected qualitative insights provided by survey respondents regarding the use of biofuels in the shipping sector.

Insight 1

“Biofuel supply is limited, and current consumption represents only a small fraction of total fuel use. Additional chemical analyses and periodic tests are required to monitor quality during storage, while cost and regulatory uncertainty remain significant barriers”.

Insight 2

“The use of biofuels is still in its infancy, making it difficult to have a comprehensive operational perspective”.

Insight 3

“Biofuels should be considered as a transitional fuel towards greener options, as they currently represent the best alternative to comply with existing regulations”.

APPENDIX D: Expert Interview Transcripts (Q&A)

Bunker Broker Stan Anagnostoloulos - Industry Insights (market perspective, fuel availability & pricing)

1. How available are biofuels in major bunkering hubs today?

Biofuels of various grades are available in major bunkering hubs such as Singapore, the ARA region, and the Mediterranean. However, the standard grades offered in each port may differ, which in turn affects availability.

For example, in the Singapore market the most commonly available fuel oil blends are B24 and B30 (24% and 30% biofuel blends). At present, these grades are largely supplied under term contracts to liner operators, with any surplus volumes occasionally offered to the spot market. As a result, spot inquiries for biofuels generally require sufficient lead time and are typically considered for quantities of around 500 MT or more.

Suppliers are technically able to blend biofuels to the required percentage, ranging from B10 up to B100. However, such custom blending normally requires larger order sizes, as allocating dedicated storage capacity for a specific blend can significantly increase costs.

In summary, major bunkering hubs are capable of supporting a wide range of biofuel blends on a contractual basis, while certain standard blends may also be available on a spot basis subject to availability and operational constraints.

2. What are the main supply chain challenges for biofuels in shipping?

One of the main supply chain challenges for biofuels relates to the type of feedstock used. Certain vessels and engine manufacturers require specific feedstocks to ensure compatibility with their equipment, while some suppliers prefer to work with alternative feedstocks that are more suitable or commercially viable for their blending operations.

Another constraint concerns the availability of storage tanks where the blending takes place. Tank capacity is often limited, as suppliers need to accommodate the blending and storage of various fuel oil and gasoil grades. As a result, using specific feedstocks requested by vessel operators may not always align with the feedstocks readily available within the supplier's existing blending infrastructure.

3. How large is the price difference between biofuels and conventional marine fuels?

In normal market conditions (prior to the recent Middle East crisis), the price spread between conventional fuel and B30 biofuel blends was typically around USD 300-350 per metric ton. However, in Dutch ports such as Rotterdam and Amsterdam, the government has introduced initiatives to subsidize certain biofuel feedstocks used for blending. As a result, the price differential has narrowed to approximately USD 120-150 per metric ton compared with conventional fuel.

In addition, an increasing number of European countries are now considering or implementing incentive schemes to support the use of specific biofuel feedstocks, with the aim of encouraging greater adoption of bio-blended marine fuels.

Energy Performance Manager Evaggelos Boutsianis - Industry Insights (technical & strategic perspective)

1. What operational or technical challenges may arise when using biofuels on existing vessels?

There are several operational challenges, such as securing sufficient quantities and possessing the space in the tanks onboard to avoid mixing with fossil or other biofuel batches. Additionally, it is critical to estimate the necessary quantities accurately so that they can be burned in the time that one can get the regulatory benefits. For example, a change in the itinerary away from Europe with remaining biofuels onboard will cancel a significant part of the expected benefits. Long term storage is to be avoided as well, which in combination with the need to avoid fuel mixing may handicap the operational range of that vessel. Moreover, change over procedures from fossil to biofuel and vice versa has to be conducted very carefully by the crew onboard to avoid technical defects in the engine fuel supply systems. Finally, the need for proper certification (sustainability) entails regulatory risks. Typically, the **sustainability certifications** become available at a much later date than the procurement and consumption of the said batch. A failure in this aspect will invalidate completely the anticipated cost reduction of the emissions aspects.

2. How compatible are biofuels with the current marine fuel infrastructure and engines? Biofuels are more compatible with current marine fuel infrastructure and engines than any other propose alternative fuel. Fuel producers and suppliers have to overcome manageable production, blending, storage and distribution difficulties. Processing and quality monitoring is of course different and requires additional steps. Vessels main engines are largely compatible even with B100. Although long term use may lead to technical challenges in the fuel supply system. Smaller engines, such as Diesel Generators, are more susceptible to damage.

3. How important is fuel cost when shipping companies consider switching to biofuels? The fuel cost is of outmost importance. Bunker costs are the highest element of the vessel’s operational expenses. Unless regulatory incentives, such as under FuelEU and EU-ETS, are given the uptake will be very limited. Green freight premiums do not exist in the Tankers and Bulk Carriers segments. It is only in the Containerships, Car Carriers and Leisure Cruise trades that green fares exist and the customer can be willing to pay for them.

Global Marine Fuels Business Development Director Bill Stamatopoulos - Industry Insights (technical & regulatory perspective)

1. What technical considerations should be addressed when vessels use biofuels?

The main technical considerations fall into several interconnected areas.
Fuel quality: the biocomponents should meet their respective standards namely EN 14214 for FAME and EN 15940 for HVO. The final (finished) blend should also meet the respective Table of ISO 8217:2024
Stability: biofuels - particularly FAME-based blends - are susceptible to oxidative degradation and microbial contamination, especially during prolonged storage. This makes robust onboard testing and monitoring protocols essential, not optional.
Material compatibility: FAME tends to react with materials more readily than diesel fuel and this may lead to material compatibility problems. FAME can damage or degrade certain plastics, elastomers, and metals. FAME may not be compatible with materials present in the fuel system, the severity of which depends on the concentration of FAME in the fuel. Additionally, the solvent effect of FAME can mobilise pre-existing tank sediments, leading to filter blockage, particularly at the early stages of transitioning to biofuel blends.
From a machinery perspective, although biofuels offer improved lubricity, their lower energy density means higher volumetric fuel consumption, which affects range calculations and fuel planning.
In short, the transition to biofuels is not plug-and-play - it requires a systematic review of the vessel's fuel system, storage arrangements, and maintenance procedures - challenges that, while requiring due diligence, are manageable within existing technical and operational frameworks.

2. Are there regulatory or certification challenges associated with biofuel use in shipping?

ISO 8217:2024 - the current edition of the primary marine fuel quality standard - represents a major evolution: it now formally accommodates FAME and HVO blends all the way up to B100, providing a comprehensive quality framework that aligns with where the market is heading. This is a landmark change and gives operators, suppliers, and testing laboratories a credible technical basis for working with high-blend biofuels.

On NO_X emissions, the regulatory picture is nuanced. Under MARPOL Annex VI Regulation 13, biofuel blends up to B30 are treated as petroleum hydrocarbons, meaning vessels can operate within their existing NO_X Technical File without further demonstration. However, for blends above B30, the operator must actively demonstrate that no critical engine settings have been altered, in order to maintain the validity of the vessel's NO_X Technical File. This is a meaningful compliance burden that requires careful engine management documentation and coordination with the relevant Class Society.

At the IMO level, the CII and EEXI frameworks offer potential credit for biofuel use, but the methodology for accounting lifecycle GHG emissions - the well-to-wake approach - is still evolving and does not yet provide full commercial certainty. Within the EU, FuelEU Maritime requires biofuels to carry valid third-party certification under recognised schemes such as ISCC or RSB to count toward compliance. Ensuring the integrity of these certification chains across a global bunker supply network remains a practical challenge.

3. Do you consider biofuels a realistic transitional fuel for the maritime sector?

Yes, but with important caveats. Biofuels - particularly second-generation feedstocks such as used cooking oil, represent one of the very few decarbonisation pathways available today that do not require new propulsion technology or significant infrastructure investment.

For existing vessels, especially those with long remaining service lives, biofuel blends offer a tangible and relatively accessible means of reducing carbon intensity in the near term. This is particularly relevant in the context of Greek shipping, which operates a large and diverse fleet across multiple vessel types and trade routes. However, scalability remains the critical constraint. Competition for sustainable feedstocks from aviation and road transport under the EU's RED III directive will intensify, and marine biofuel supply chains are still fragmented in terms of availability, quality consistency, and pricing.

The cost premium over conventional bunkers is also non-trivial and will require commercial mechanisms - whether through charter party adjustments, green premium sharing, or regulatory incentives - to be absorbed equitably across the supply chain. My overall assessment is that biofuels will form a meaningful component of the marine fuel mix through the 2030s, primarily as a bridge technology while green methanol, ammonia, and hydrogen infrastructure reach commercial maturity - but their long-term role will ultimately be determined by feedstock sustainability at scale, not by technical or regulatory readiness alone.

APPENDIX E: Indicative Bunker Price Dataset (February-March 2026)

Market Hub	Date / Period	Fuel Type	Price (USD/mt)
Rotterdam	Feb 24 (Pre-Crisis)	Conventional VLSFO	$488
		VLSFO B30 (Subsidized)	$660
		VLSFO B30 (Unsubsidized)	$775
Rotterdam	Mar 13 (Post-Crisis)	Conventional VLSFO	$800
		VLSFO B30 (Subsidized)	$1,030
		VLSFO B30 (Unsubsidized)	$1,100
Singapore	Feb 24 (Pre-Crisis)	Conventional VLSFO	$506
		VLSFO B24	$710
Singapore	Mar 13 (Post-Crisis)	Conventional VLSFO	$1,133
		VLSFO B24	$1,190

Source: Industry Market Data (2026).
Note: Prices represent indicative benchmarks for Greek shipping operations during market volatility.

APPENDIX F: Global Biofuel Bunkering Port Directory

This directory provides a non-exhaustive list of global maritime hubs where biofuel bunkering (B24, B30, or B100) has been reported as commercially available or project-ready as of 2025-2026.

Region	**Port**	**Availability Status**
Europe (ARA)	Rotterdam / Amsterdam	Commercial / Mature Market
	Antwerp	Commercial / Mature Market
Europe (Med)	Algeciras / Gibraltar / Barcelona	Commercially Available
	Marseille	Available
	Piraeus	Emerging / Project-based
Europe (North)	Hamburg	Available
	Gothenburg	Available
Asia	Singapore	Commercial / Mature Market
	Hong Kong	Available
	Guangzhou / Shanghai	Emerging / Project-based
Americas	Houston / Galveston	Emerging / Project-based
	Long Beach / Los Angeles	Available
	Great Lakes (various)	Commercial (CSL Fleet operations)
Oceania	Sydney / Melbourne	Spot / Project-based

Source: Compiled from DNV (2025) and Stamatopoulos (2026).
Note: Availability is subject to seasonal feedstock supply and local regulatory incentives (e.g., Rotterdam subsidies).