



Biofuel Demonstration Project in Port of Seattle

A case study in regional maritime biofuel readiness

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A. Executive Summary

Holland America Line (HAL) and the Port of Seattle (the Port) jointly executed a real-world demonstration in 2025, to assess the feasibility, readiness, emissions implications, cost and operational risk of using non-fossil fuel alternatives (NFFAs)—specifically, marine biofuels—in cruise operations from Seattle. The “Biofuel Demonstration Project in Port of Seattle,” was conceived to generate practical, shareable insights that can accelerate decarbonization, while remaining technically and economically realistic at scale.

For context, global, state and port-level sustainability targets are coming into greater focus. While biofuels are often promoted as “drop-in” solutions for existing fleets, scaling them in U.S. marine applications faces a host of challenges, including fragmented certification standards, immature regional supply chains, infrastructure and permitting constraints, vessel-specific compatibility issues, and a wide cost gap versus conventional marine fuels.

In Europe, policy (*e.g.*, FuelEU Maritime) and incentives (*e.g.*, Dutch HBE credits) have catalyzed a robust bunkering market. However, U.S. maritime users generally cannot monetize federal or state road-fuel incentives. This causes a significant increase in delivered marine biofuel prices.

In planning the demonstration, HAL and the Port developed core requirements for a Seattle-based 2025 trial. These included barge delivery during the Alaska cruise season, fuels meeting marine specs (EN 14214/EN 15940/ISO 8217), lifecycle greenhouse gas (GHG) intensity ratings aligned with a recognized sustainability certification, and segregation from incompatible fuels. Following market surveys and technical due diligence, HAL selected the MS Eurodam as the test platform, due to its ability to fully isolate a dedicated tank, fuel skid and engine. Initially, another ship was selected, but the fuel systems could not accommodate the available biofuel.

The Project ultimately included 360 metric tons (MT) of renewable diesel (hydrotreated vegetable oil, or HVO), bunkered across three 120-MT barge deliveries (July 26, September 6, and September 20, 2025). HAL engaged original equipment manufacturers (OEMs), and flag and class organizations as participants in the Project. HAL also commissioned a contractor for onboard emissions verification.

Initial surveys of the regional marine biofuels market revealed a nascent market, in comparison to other global markets for marine biofuels. Suppliers frequently lacked integrated, marine-scale infrastructure (*e.g.*, waterfront tanks, barge capacity, dedicated lines, etc.), or were unwilling to incur cleaning and/or changeover costs for one-off deliveries.

For larger quantities of fuel, barge delivery is required, instead of truck delivery. In a cruise ship operations environment, where turn-times require high flow rates, truck fueling may not be feasible. In any case, it was prohibited at the HAL cruise berth by stormwater permit and may incur additional negative community impacts due to the larger number of truck deliveries.

On board the ship, plans included detailed compatibility analysis, fuel system mapping and an operational risk plan. These checks helped to ensure that a specific fuel was compatible with the specific ship and could be accommodated safely, within the cruise ship operational environment. Several iterations were required before identifying the right fuel for the right ship for this demonstration.

The final HVO cost was approximately \$2,200/MT, displacing the traditional maritime fuel marine gas oil (MGO, at a cost of \$900/MT). U.S. road-fuel incentives (RINs, 45Z, WA Clean Fuel Standard) either are not applicable to or practicable for international marine use, as WA Clean Fuels incentives are limited only to fuel consumed in Washington territorial waters—a very small portion of the voyage. As such, suppliers did not include in their prices the value of these credits (*e.g.*, D4 RINs). Estimated abatement cost for the selected HVO at ~55 gCO_{2e}/MJ resulted in ~\$1,000 per metric ton of CO_{2e} (MTCO_{2e}) avoided, versus ~\$120/MTCO_{2e} in areas within the European Union (EU), where advanced biodiesel incentives are available. Without policy parity, the cost gap is a major barrier to scalability.

The Project underscored the absence of a harmonized lifecycle carbon intensity reduction standard for marine biofuels. Carbon intensity values vary widely by scheme, feedstock and methodology (*e.g.*, indirect land-use change). Most fuels available for this demonstration project exceeded the IMO 33 gCO_{2e}/MJ threshold needed to claim “zero-carbon” credit under current guidance. This means there will be no recognized GHG credit for usage, despite higher costs. The lack of aligned certification conceals true climate benefit and muddles how emissions are accounted for.

Key learnings and recommendations

Vessel-specific feasibility: In the marine sector, biofuel is far from a “drop-in” fuel. Prerequisites include fuel system mapping and consultation with the engine manufacturer, class society and flag state organization. Significant fuel segregation on board the ship may be necessary.

Development of an industry-standard design for biofuel-compatible fuel systems could lead to more widespread adoption.

Recommendation: Expect different answers across ships—even within a single class. Early documentation of fuel system capabilities is helpful in understanding fleet capabilities to operate on biofuel. Class societies, fuel system designers and manufacturers, and other stakeholders should consider the benefits of a more biofuel-compatible design, in the context of other decarbonization strategies.

Distribution infrastructure is limited: Waterfront storage and dedicated barge capacity are scarce. This situation is made more complex by the short duration of the seasonal cruise schedule and its associated market. Cleaning or changeovers of equipment can add \$12,000–\$15,000 per event, and can discourage one-off deliveries.

Recommendation: Engage with suppliers and bunker barge operators to develop an understanding of infrastructure needs, including dedicated waterfront storage, barge tank configurations, and cleaning protocols sized to seasonal cruise demand. Evaluate both truck and barge delivery options where permits allow.

Biodiesel vs. renewable diesel tradeoffs: FAME (fatty acid methyl ester), a biodiesel, can meet marine needs at lower costs, but brings storage, cold-flow and oxidation risks, and requires stricter segregation. Renewable diesel aligns better with handling and performance, but demands additives, cannot contact certain types of traditional marine fuels and is significantly more expensive without incentives.

Recommendation: Stakeholders should fully understand and appreciate the technical considerations of biofuel use in the maritime sector, when developing policies to incentivize a sector-wide transition to biofuels.

Harmonize global certification standards: Without recognized certification for carbon intensity reduction levels, operators cannot reliably convert fuel choices into reportable decarbonization outcomes.

Recommendation: Advocate for an IMO-aligned global carbon intensity reduction certification framework to help incentivize biofuels usage. Such an effort is currently underway.

Close the cost gap with effective incentives: Biofuels in the U.S. exceed costs for traditional maritime fuels as well as biofuels in other sectors, such as road transport.

Recommendation: Work with stakeholders as well as state and federal partners, to extend or create incentives that narrow the biofuel cost gap for verified carbon intensity reductions. The Netherlands HBE scheme is an example.

Develop fuel-vessel compatibility assessments: Help vessel operators develop compatibility assessments. Most fleet operators can accomplish this task. However, resources, including technical assistance, could be made available to assist smaller operators and single-vessel operators.

Recommendation: Ensure that the assessments include identifying fuel pathways, segregation plans, OEM conditions for all relevant vessel components, additive management, special handling needs and pre-approval checklists developed with guidance from appropriate regulatory bodies.

Institutionalize safety & monitoring: First responder briefings and shipboard training are essential, given differing flammability and handling characteristics and emergency procedures.

Recommendation: Promote first responder engagement and shipboard training in locations where vessels bunker and operate.

Summary

The demonstration proved that marine biofuels can be bunkered and operated, safely and reliably, on a segregated cruise-ship pathway in Seattle—but, not yet at scale or cost levels that make them a primary decarbonization lever in this market. Progress will hinge on key factors, including global harmonization of carbon intensity certification practices, development of marine-focused incentives and adequacy of biofuel distribution infrastructure. With these enablers, biofuels can play a meaningful role, along with shore power, efficiency improvements, use of LNG/BioLNG and future zero-emission fuels, in the region’s pathway to net-zero. As noted in the Key Learnings and Recommendations section, specific recommendations are offered throughout this report to help advance progress toward these goals.

B. Introduction

Imagine, after seeing a billboard about the benefits of NFFAs, you decide to run an NFFA in your personal car. You drive to the gas station, only to discover there is no such option available. When you ask when it might arrive, the attendant explains that you are just one customer. Deliveries only come in large, minimum-quantity orders, and it would take a special request to make it happen.

Undeterred, you do your homework and call several suppliers. They confirm NFFA could be delivered, but it is complicated. The tanker truck would need to be completely cleaned out before loading NFFA. The gas station's storage tanks and pumps also would require cleaning, retrofitting, and certification to handle it. Some stations may not even be qualified to dispense NFFAs. On top of that, certain NFFAs cannot be shipped by certain modes of transport because of the product's viscosity or flammability characteristics. This might dictate more expensive delivery methods. All of these costs ultimately roll into the price you would pay.

Still, not impossible; just expensive and complicated. Next on the list is, whenever you change the type of fuel your vehicle needs to run, the Department of Motor Vehicles (DMV) must approve it. You start that approval process, and you call your car's manufacturer. Their answer? Every engine is different, even in vehicles of the same class. You need to conduct a full compatibility analysis of your fuel and engine systems. You may need additives for proper performance, and every part of your fuel pathway—filler neck, tank, and fuel lines—would need to be isolated to prevent contamination with other fuels.

You have made it this far, and despite the frustration of a lack of a single fuel standard for NFFAs, you have lined up technical approvals successfully. But, you want to know the carbon benefits of switching, as NFFAs are reputed to have inherently reduced life-cycle carbon levels. Here, the picture gets even cloudier. Carbon intensity reduction values for biofuels vary widely depending on the certifying body, the production feedstock and lifecycle assumptions. The difference can be 50% or more. That means, despite paying a higher price, you may or may not be able to receive official credit for this proactive decision to reduce emissions.

How much reduction you get credit for all depends on which standards body certifies your usage. Also, your DMV only recognizes carbon reduction benefits for your car if the NFFA is certified for carbon intensity reduction above a certain value. How do you determine whether using NFFA

is worth it, or is it more advantageous simply to invest in other decarbonization technologies, with better outcomes for your investment?

Finally, there is training and safety. You and anyone driving your vehicle need to understand how to manage the NFFA, if differences in operation are required. Will it still meet emissions standards? Will it affect other vehicle systems? Will you lose coverage of insurance or manufacturer warranties on your vehicle? And what happens if, in an emergency, first responders encounter your vehicle running NFFA instead of regular gas? Will they understand the risks or appreciate different behavior of the fuel, including flammability levels, in an emergency?

This analogy shows, in basic terms, the complexities involved in scaling a new fuel into a practical, technically acceptable and affordable option for regular use. For global vessel operators, with operations in many countries, the challenge becomes even more complex. This oversimplified analogy is but a snapshot of the lessons encapsulated in this report regarding a test of biofuels on a large cruise vessel in 2025. The observations included in this report are intended to help illuminate the real-world opportunities and challenges associated with integrating new fuels into broader transportation systems.

C. Background

1. Project genesis

In 2024, HAL (a subsidiary of Carnival Corporation & plc) and the Port agreed to conduct a demonstration project using a non-fossil fuel on one of HAL's or a sister line's cruise vessels. The agreement is included as a provision in the July 2, 2024 Preferential Berthing Agreement between the parties. The relevant text from this agreement is included in Appendix A.

The text reflects the parties' shared sustainability goals concerning a pathway toward decarbonization. For HAL's part, safeguarding the planet is a core sustainability focus area, and includes exploring future fuels, as indicated in the excerpt below:

We support the adaptation of alternative fuels and are testing new low-carbon or zero-carbon emission technologies as they become available. We are also partnering with organizations and stakeholders to support our decarbonization efforts and reduce overall consumption.¹

¹ **Source:** Carnival 2024 Sustainability Report, p.16, <https://www.carnivalcorp.com/wp-content/uploads/2025/08/FY2024-Sustainability-Report-FINAL.pdf>

Specifically, one of the company’s 2030 Sustainability Goals under its “Planet” focus stream includes “expanded battery and biofuel capabilities.”² HAL and its sister operating lines have experience in operating with biofuels in the EU and company participants were keenly interested in bringing this experience to bear in the U.S.

Similarly, the Port of Seattle has ambitious sustainability goals that require partnership. The Port’s 2021 “Charting the Course to Zero: Port of Seattle’s Maritime Climate and Air Action Plan”³ provides a detailed plan to reduce greenhouse gas emissions from the maritime sector, carrying out the *Northwest Ports Clean Air Strategy 2020 Vision*.⁴

The Port seeks to build on its proud history as the second port in the world to offer shore power to cruise ships. According to Port personnel participating in the project, the Port desires to signal demand for and foster acceleration toward a robust non-fossil fuel maritime market; identify market and policy obstacles for mitigation; and use the Port itself as a test bed. The Port’s website calls out its understanding of “the importance and urgency of finding greener solutions for our ports and waterways,” and specifically mentions biofuels derived from renewable sources as holding immense promise for reducing emissions and creating a more sustainable maritime future.⁵

This biofuels demonstration project serves as an important planning initiative designed to yield practical results for stakeholders, policymakers and others interested in understanding the opportunities and challenges involved in the use of biofuel as a maritime fuel in the U.S.

As detailed in Appendix B, the Project Team included representatives from HAL and Port of Seattle. The team began meeting regularly in the summer of 2024 to develop Project details. The HAL Team is comprised of employees from Carnival Corporation and HAL. These employees formed working groups. Specifically, the Technical Team, comprised of HAL employees with vessel technical management responsibilities, considered technical aspects of the Project. The Fuel Procurement Team, comprised of Carnival Corporation fuel procurement personnel, focused on fuel procurement for the Project.

² **Source:** Carnival 2024 Sustainability Report, p.17

³ **Source:** https://www.portseattle.org/sites/default/files/2021-11/MCAAP_November_2021_20210928_LowRes.pdf

⁴ **Source:** <https://www.nwseaportalliance.com/environment/clean-air/northwest-ports-clean-air-strategy>

⁵ **Source:** <https://www.portseattle.org/page/sustainable-marine-fuels>

2. Project goal

Per the terms of the Preferential Berthing Agreement, the NFFA Demonstration Project was designed as a real-world test of feasibility, readiness, emissions reduction potential, cost and risk of using NFFAs in the marine sector. The test was designed with sustainability and scalability in mind, and as a way of developing and sharing information useful to the maritime community. With this in mind, the results are expected to help reduce future risks and costs of using NFFAs as marine fuel sources.

HAL worked with the Port of Seattle to develop key test parameters, including those listed below.

- Selection of fuel, including:
 - Biofuels market study
 - Fuel certifications of lifecycle emissions assessment and reporting
 - Fuel technical specification analysis and review with applicable onboard equipment manufacturers (OEMs), engine OEM, and class and flag state authorities
 - Fuel cost
- Selection of test vessel, including
 - Review of ship fuel systems
 - Fuel compatibility analysis
 - Operational/risk assessment
- Identification of dates for the demonstration
- Logistics for fuel delivery
- Coordination with key stakeholders
- Documentation of results

While a limited number of biofuels are currently available for use at the Port of Seattle, their use is not widespread and few are geared toward use by marine vessels. The Port is interested in understanding the dynamics of deployment of biofuels in the region for oceangoing vessels. As a cruise line that is part of a larger fleet operator, HAL has the ability to conduct the test in a way that provides meaningful results that can inform questions of scalability and sustainability.

Given that the goal of the Project is to perform a real-world test, HAL and the Port conducted the Project in a manner that emphasized these scalability and sustainability impacts. For example, if certain results cannot be repeated at scale, those results have less relevance. At the same time, if the results cannot be achieved in a way that is environmentally and economically sustainable, those results also are less relevant. Test outcomes that are relevant only to the test scenario are treated as less relevant to the lessons learned from the Project.

HAL and the Port consider the potential use of marine biofuel at scale to be an exciting topic. HAL has spent considerable resources on this Project, compared to other fuel acquisition projects. Executives believe it comprises one of the most time-intensive deliveries of biofuel ever secured by the company, for what ultimately included three relatively small deliveries. This level of effort is indicative of the priority placed on the company's desire to complete the project as a means of developing and sharing useful information for all in the supply chain.

As stated by one Port of Seattle Project participant:

“The shift to decarbonization requires information sharing from everybody in the value chain, including fuel producers, refiners, sellers, resellers, transporters and others. All involved need to have a better understanding of what is possible short-term, mid-term and long-term. With these answers, we can better scale down emissions and costs.”

To this end, the Project is designed to share useful information, with the potential for replicable results.

3. Industry, nation, state and regional decarbonization goals

The International Maritime Organization (IMO, the United Nations' maritime arm), Carnival Corporation & plc, the state of Washington and the Port of Seattle are aligned with regard to the goal of reducing carbon emissions from the maritime sector, including through the use of alternative fuels.

Greenhouse Gas (GHG) Reduction Targets across Relevant Entities			
International Maritime Organization (IMO)	State of Washington	Port of Seattle	Carnival Corporation
<p>The 2023 IMO GHG Strategy envisages, in particular, a reduction in carbon intensity of international shipping (to reduce CO2 emissions per transport work), as an average across international shipping, by at least 40% by 2030. The 2023 IMO GHG Strategy also includes a new level of ambition relating to the uptake of zero or near-zero GHG emission technologies, fuels and/or energy sources which are to represent at least 5%, striving for 10%, of the energy used by international shipping by 2030.⁶</p>	<p>In summary, the state shall limit anthropogenic emissions of greenhouse gases to achieve the following emission reductions for Washington state:</p> <ul style="list-style-type: none"> (i) By 2020, reduce overall emissions of greenhouse gases in the state to 1990 levels, or 90,500,000 metric tons (ii) By 2030, reduce overall emissions of greenhouse gases in the state to 50,000,000 metric tons, or 45% below 1990 levels (iii) By 2040, reduce overall emissions of greenhouse gases in the state to 27,000,000 metric tons, or 70% below 1990 levels <p>By 2050, reduce overall emissions of greenhouse gases in the state to 5,000,000 metric tons, or 95% below 1990 levels.⁷</p>	<p>The Port has adopted GHG reduction targets that align with the Paris Climate Agreement, including GHG reduction targets of 50% absolute reduction by 2030 for scope 1 and 2, relative to 2005 baseline and net zero or better by 2040. Further, the Port aims to achieve 50% reduction in absolute Scope 3 GHG emissions by 2030 relative to 2007 baseline and carbon neutral or better by 2050.⁸</p>	<p>Carnival Corporation set a goal to achieve 20% GHG intensity reduction relative to the company’s 2019 baseline, measured in both grams of CO2e per ALB-km and kilograms of CO2e per ALBD by 2026. It also set a 2050 aspiration for net zero emissions from ship operations.⁹</p>

⁶ Source: <https://www.imo.org/en/ourwork/environment/pages/2023-imo-strategy-on-reduction-of-ghg-emissions-from-ships.aspx>

⁷ Source: <http://app.leg.wa.gov/RCW/default.aspx?cite=70A.45.020&pdf=true>

⁸ Source: Page ES-2: https://www.portseattle.org/sites/default/files/2021-11/MCAAP_November_2021_20210928_LowRes.pdf

⁹ Source: Pages 17-18: <https://www.carnivalcorp.com/wp-content/uploads/2025/08/FY2024-Sustainability-Report-FINAL.pdf>

4. Maritime biofuels market landscape

Biofuels are fuels derived from biomass feedstock, such as vegetable oils, animal fats, or woody and other biomass. In general, biofuels are comprised of two basic classes: (1) oxygenated biofuels, such as fatty acid methyl ester (FAME), or biodiesel, and (2) hydrocarbon biofuels, such as hydrotreated vegetable oil (HVO), or renewable diesel. While there are more types of fuels within these classes, biodiesel and renewable diesel are the most commercially available in the U.S.¹⁰

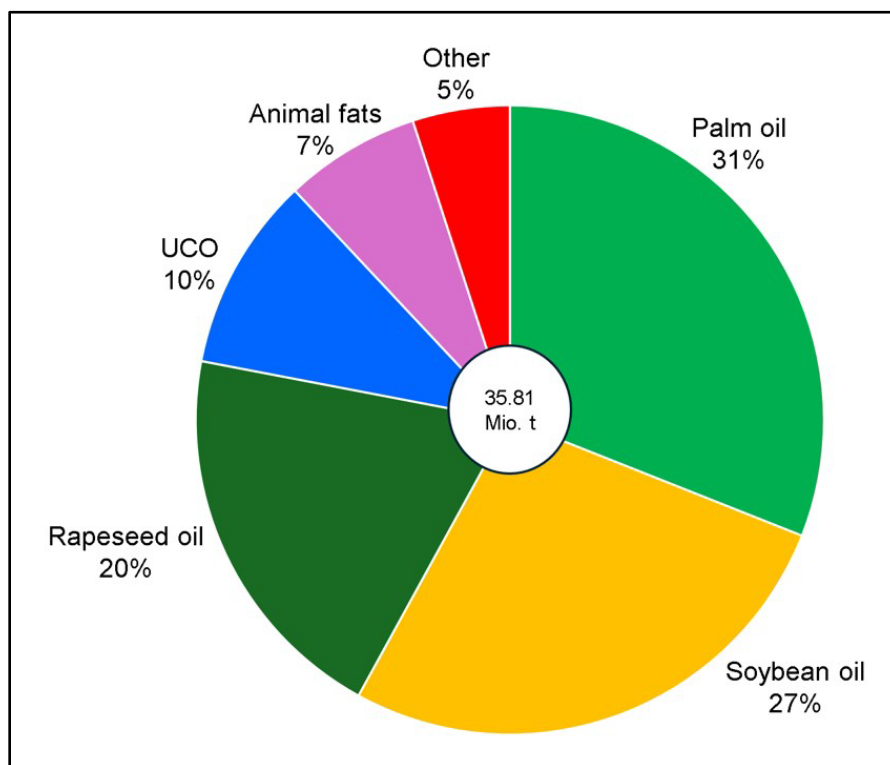


Figure 1. Current biofuels are sourced from a variety of biomass sources, both renewable and nonrenewable.

The first generation of biofuels, including FAME/biodiesel and HVO/renewable diesel, is a well-established market. These products are blended primarily with road transport fuel.

An emerging second generation of biofuels includes technologies that are currently at a smaller scale, with higher costs. These include products produced from non-food crops, industrial or agricultural waste, such as used cooking oil which can be processed into either FAME or HVO.

¹⁰ **Source:** pp.6-7, “Understanding the Opportunities of Biofuels for Marine Shipping,” Oak Ridge National Laboratory, Dec. 2018, <https://info.ornl.gov/sites/publications/Files/pub120597.pdf>

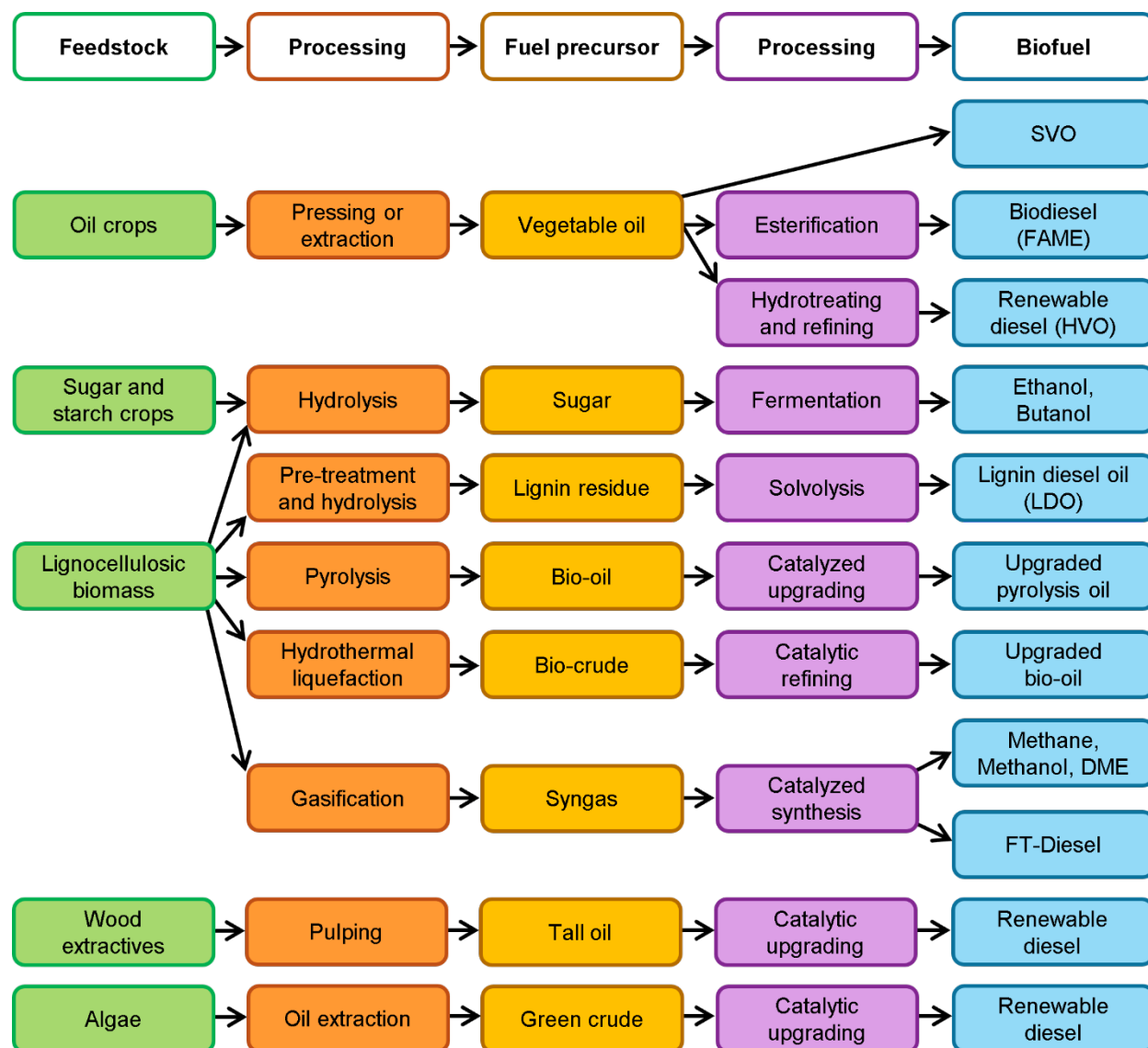


Figure 2. Diagram of biomass production processes across various feedstocks and product types.

Even among biofuel types, products can vary in key properties, such as density or specific gravity, energy content, viscosity, lubricity, and content of residual solids and water.

5. Potential for biofuels as a marine fuel

Biofuels are generally considered for their suitability as drop-in fuels to replace—or blend stocks to blend with—traditional marine fuels, such as Marine Gas Oil (MGO) and Heavy Fuel Oil (HFO), as biofuels have lower emissions levels and low carbon intensity. For example, use of biofuel oil derived from feedstocks, such as used cooking oil, which is classed as a waste or

residue, can reduce lifecycle (or “well to wake”) GHG emissions by up to 90% when compared to traditional marine fuels.

In the context of Carnival Corporation’s multipronged carbon reduction strategy, all new builds in the company’s entire fleet are now built on an LNG platform, launching a shift in fleet fuel mix towards Liquefied Natural Gas (LNG) and BioLNG. Consequently, biofuels may have the most promise as drop-in fuels for use in the existing fleet.

D. Biofuel maritime supply chain and compatibility considerations

In preparing for the demonstration, the Project Team researched many issues regarding the suitability of potential biofuels available in the Port, as well as operational requirements aboard the ship. These are described in the order of the table below.

Biofuel Maritime Supply Chain and Compatibility Considerations	
	<p>Biofuel market readiness</p> <p>The Fuel Procurement Team surveyed the market for potential biofuel suppliers.</p>
	<p>Regional distribution logistics</p> <p>The Fuel Procurement Team discussed with suppliers the distribution methods and how supply chain integrity can be maintained.</p>
	<p>Bunkering delivery logistics</p> <p>The Fuel Procurement Team considered supplier offerings for delivery of fuel to the ship.</p>
	<p>Shipboard fuel systems and operational requirements</p> <p>The Technical Team reviewed shipboard fuel systems to determine the ability to maintain segregation within fuel system equipment, and to identify operational safety risks.</p>

1. Biofuel market readiness

To ensure a meaningful evaluation of fuel options, the Project Team developed core requirements for the demonstration. This process included initial consultations with regulatory and manufacturer stakeholders. The resulting core requirements included the following:

Availability and delivery dates: Summer 2025. Alaska cruise seasons from Port of Seattle are limited to spring and summer. This determines timing requirements.

Stem sizes: Dependent on fuel cost. The quantity will be adjusted to match the Project budget and available dedicated fuel storage tanks on board the vessel.

Frequency: Bi-weekly delivery is dependent on delivery by barge; fuel will replace MGO.

Quality: Biodiesel or renewable diesel, with biodiesel being preferred due to lower cost; fuel must meet biofuel specification limits—EN15940 / EN 14214 / ISO 8217.

GHG Cap: “Well to wake” emissions of 33 gCO₂e/MJ, per IMO MEPC.1/Circ.905. This IMO standard requires a GHG cap for the fuel, in order for the vessel operator to receive credit for the GHG reduction at all.

Blend requirements: B100 (100% biofuel) is preferred, as it will simplify segregation and storage; blends can be considered.

Required supporting documentation: Sustainability is certified by an internationally recognized certification scheme.

Mode of delivery preference: Barge delivery is preferable for demonstrating scalability. In addition, the barge is required, as fuel trucks are not allowed on the HAL cruise dock. A single barge is required, because it is not possible to have multiple barge deliveries during a single 8-hour port call, when multiple deliveries take 8-10 hours.

The Fuel Procurement Team used these core Project requirements to survey the market and develop options for biofuel sources, as part of the demonstration. Using this survey criteria, the Fuel Procurement Team identified eight potential fuels for use. These fuels were analyzed further for suitability for the demonstration. The more detailed analysis criteria are specified in the Fuel Selection matrix, described in detail under the heading, “Demonstration.” The matrix included such requirements as whether the fuel met marine specifications, was compatible with ship systems and was capable of being delivered to a cruise ship.

The Fuel Procurement Team observed that the local marine biofuels market is largely nascent in its development, compared to international markets, particularly in the EU. Currently, HAL and its sister operating lines have several cruise vessels using advanced biofuels on routes between

major EU ports, such as Rotterdam and Hamburg. This demonstrates the company’s experience with large-scale biofuel adoption in the region. However, the markets for such fuels and accompanying regulatory schemes in the EU are much different in the U.S. The EU market for biofuels is seen as far more developed, with more available incentives and regulatory schemes, as well as mature supply chains.

Global Examples of Biofuel Incentives
<p>1. <i>Netherlands HBE System reduces cost of biofuels to end consumer:</i> https://www.emissionsauthority.nl/topics/renewable-energy-for-transport/general---renewable-energy-for-transport/market-mechanism-and-hbes</p>
<p>2. <i>Singapore Port Dues Concessions:</i> Ships using B100 biofuel can be eligible for 100% fee reduction. https://www.mpa.gov.sg/finance-e-services/tariff-fees-and-charges/ocean-going-vessels/port-dues-concessions</p>

In the U.S., the cost difference is much more acute, as the result of the market study illustrated below. In the Netherlands, the maritime industry has had access to biofuel subsidies through a government-implemented scheme of renewable fuel units, known as *Hernieuwbare Brandstofeenheden*, or (HBEs)—equivalent to one gigajoule of renewable energy. This scheme uses a trading system where participants can cooperatively deliver their mandatory share of renewable energy in the most cost-effective way. Participants can choose whether to deliver and claim delivery of renewable energy themselves, thereby creating HBEs, or buy HBEs to comply with their obligations. This means that a fuel supplier delivering biofuels to maritime users can generate these HBEs that have a market value that offsets some of the additional cost. Over time, this has developed the infrastructure for a robust maritime biofuels market in Rotterdam—already a global bunkering hub.

On January 1, 2025, the EU implemented a regulation to contribute to the decarbonization of the global maritime industry. “FuelEU Maritime” requires an annual reduction in GHG energy intensity (including fuel and shore power, etc.) used aboard all ships above 5,000 gross tonnages, calling at EU ports, regardless of flag registry. Government action is now continuing to drive demand for maritime biofuels.

As observed by the HAL Team, the availability of subsidies is an important incentivizing cost factor for vessel operators to accelerate testing and adoption of biofuels. Importantly, none of the U.S. biofuels incentives are effectively applicable to maritime fuels bunkered for international consumption. Therefore, to take delivery of biofuel in the U.S., international shippers must pay

the full cost of these fuels, without any incentives. This results in fuel cost increases that are substantially above market rates.

2. Regional distribution logistics

As described previously, the market survey using the fuel selection criteria revealed a local Seattle marine biofuels market that is in an early stage of development, in comparison to international markets, particularly in the EU. This level of market immaturity was evident by the lack of biofuel-dedicated supply chain infrastructure in the region. Many suppliers contacted for this Project had not fully considered the logistics of delivery of biofuels in marine-relevant quantities. These deliveries require a dedicated supply chain, using equipment and infrastructure handling only the specified fuel. Required supply chain components can include pipelines, rail cars, storage tanks, barges, transfer systems and other equipment.

For example, one seller provided a more carbon-friendly fuel, but the fuel could not be effectively segregated from HFO within the supply chain. Such biofuels would need to be transferred by rail from a Midwest location. Further, the provider also would have had to utilize an HFO storage tank to avoid cross contamination of the fuels with MGO. As such, this would have contaminated the biofuel. This lack of last mile delivery infrastructure was not sufficient to support the fuel's supply chain.

The primary logistical challenge relates to the difference between the characteristics of varying available biofuel types. Biodiesel generally is a more cost-effective product than Renewable Diesel, and it is suitable for marine engines. However, biodiesel can have poor cold flow properties and oxidation stability. These factors limit its use in over-the-road transport fuels, and its use onboard ships must be managed correctly. For this reason, the fuel suppliers do not carry biodiesel and conventional fuel, such as MGO, in the same storage tank without cleaning between deliveries, due to the risk of cross contamination. This activity presented an impractical logistical hurdle for some suppliers.

This is not the case for renewable diesel, which has been developed to be chemically similar to conventional diesel and there is no risk of cross contamination. Therefore, the fuel suppliers were able to deliver renewable diesel, along with conventional fuels, via an existing bunker barge.

The Project's quest to identify fuel suppliers with integrated biofuel supply chains provided insight into the region's current state of readiness to serve the marine sector. The complexity of shoreside delivery required customized logistical solutions, as consistent demand has not driven solutions specific to marine customers. In addition, the short cruising season (five months)

presents challenges for return on investment in dedicated infrastructure. Further, the short season increases logistical complexity for the supply chain.

For example, one fuel supplier offered locally available renewable diesel. However, the fuel had a lower flash point, as it was formulated for over-the-road use. The product with a higher flash point, suitable for marine use, had to be sourced from a more distant refinery. Unfortunately, the supplier could not accommodate the delivery of the volume of biofuel (450 tons) needed for the demonstration. This was because the supplier lacked shoreside tank storage capacity to accommodate the delivery. Local storage capacity was not available due to the supplier's need to maintain inventory levels of distillate marine fuel (DMA) during a high demand season.

Another factor considered in bunkering logistics is the availability of waterside storage capacity, which is needed to fuel a barge. Given the limited amount of real estate available at a port to transfer fuel to bunker barges, fuel suppliers need to carefully plan use of their capacity. As such, they are unlikely to have additional capacity on short notice, as they generally plan to maximize existing capacity to serve their customers over the course of a season. Even if physical capacity exists, the storage tank and associated infrastructure may require cleaning to accommodate a biofuel. This would add costs to the price of the biofuel, if the supplier has the capacity to spare.

To maintain a competitive and available biofuel supply in the region, fuel suppliers must overcome these challenges by taking actions to ensure sufficient biofuel delivery infrastructure capacity. Based on HAL procurement discussions with fuel suppliers, it is likely that a minimum quantity of biofuel must be in demand to justify new infrastructure expenditures. The Port may consider how it can help bridge risk gaps to build a sustainable market for these alternative fuels, through identifying and addressing marine biofuel delivery infrastructure needs.

3. Bunkering delivery logistics

Typically, cruise ships fuel by bunker barge. Barges contain the fuel systems, flow rate capabilities and volumes needed to supply a cruise ship during the limited time they are in port. Vessels often utilize barges and pipelines for fueling. Smaller vessels, or those using specialty products or smaller deliveries, may take delivery by truck.

To get a sense of the requirements underlying these logistical considerations, fueling a cruise ship with biofuel via truck would require approximately 20-25 trucks to supply the necessary volume for a single fuel “drop,” or stem—500 tons @ ~25 tons per truck. Delivery times per truck take approximately one hour. For some cruise ports, trucks could be accommodated physically over the 20-25 hours it takes to fuel by truck.

However, in Seattle and most turn ports, short vessel turnaround times require barge flow velocities to enable completion in under six hours for fueling. In addition, fueling trucks would need to compete for limited apron space among passenger movements, luggage loading operations and onboard provisioning operations. Finally, the addition of 20-25 over-the-road fuel trucks adds considerable diesel trucking emissions and other undesirable community impacts. To receive by truck, smaller, more frequent fuel drops would be required due to infrastructure limitations.

In any case, the Project Team determined early on that truck deliveries of biofuels could not be accommodated at the Port of Seattle cruise dock used by HAL. This is due to a limitation of the facility's existing Stormwater Management Permit that prohibits transfer of fuel from trucks. The Project Team determined that, while truck delivery possibly included more potential suppliers, the pursuit of an amendment to the stormwater permit likely would not result in action within a predictable timeframe needed to accommodate the Project schedule.

After sourcing renewable diesel from a supplier that typically serves the domestic over-the-road biofuel market, the Fuel Procurement Team learned that additives would need to be blended in, to enhance the lubricity of the fuel to meet marine specifications. This is a common difference in renewable diesel formulations across various markets.

Finally, the bunker barge would need to be dedicated to the specific biofuel. If not, there would be a risk of contamination of other fuel types and additives. The bunker barge would require cleaning after each delivery to ensure that fuel types and additives are not comingled. This activity would present a substantial logistical hurdle and would add \$12,000-\$15,000 to each delivery.

4. Shipboard fuel systems and operational requirements

a. Review of shipboard fuel systems and vessel selection

As mentioned previously, HAL is no stranger to the operation of ships using biofuels. However, "drop in" fuels simply cannot be dropped in without significant planning and technical compatibility analysis. Large cruise ships are complex machines, typically with 4-8 generator sets that consume multiple types of fuel. Ships, even in the same fleet or same class, are configured differently. This means that the ships have differences in the quantity and specifications of engines, fuel system configurations, flag state, etc., that can impact their use of alternative fuels.

Similar to logistics systems delivering biofuel to the ship, internal shipboard systems must be capable of preventing comingling of biofuel with traditional maritime fuels. The Technical Team prepared a shipboard handling plan to ensure dedicated handling and storage of the fuel, starting with the ship's flange system for receiving fuel. Each ship has only two flanges for receiving fuel—one for residual fuels and one for diesel products. For alternative products, such as biofuels, the MGO system is used and a dedicated pathway to the storage tank is created.

To further reduce risk of fuel contamination, the Technical Team decided that all storage tanks should be empty and free from water before loading biofuel. The Technical Team decided not to use the HFO fuel system as this would require cleaning of tanks and lines to ensure there is no cross contamination of the biofuel.

Since the HAL Team decided to use biofuel as a direct replacement for MGO (an ultra-low sulfur fuel), the team isolated specific systems that should not use biofuels. For example, emergency diesel generators and lifeboats are fed from the MGO system and should not use the biofuel as they are safety critical systems. This is particularly relevant for FAME, as storage limits of 7-9 months are recommended to prevent growth of bacteria and attraction of water condensation from bio feedstocks.

The Technical Team also identified that biofuel should not be used in boilers and incinerators without prior approval from the OEM. Upon further discussion with the boiler OEM, there was no objection to running the biofuel; however, the incinerator OEM raised concerns with running on biofuel unless an upgrade of the burner was carried out.

As to processing and storage, the Technical Team observed that all biofuel loaded should be purified using onboard systems, if available; however, not all ships have purifiers on their MGO system. Further, biofuels kept in storage tanks equipped with tank heating are required to be kept at a temperature 10 degrees Celsius higher than cold filter plugging point (CFPP), to reduce the risk of filter clogs.

To meet these requirements, the Technical Team initially focused on the cruise vessel "Discovery Princess." The team analyzed the various shipboard systems involved and developed a plan for shipboard handling of the biofuel. The Discovery Princess is equipped with four engines, all of which are capable of switching between HFO and MGO. If renewable diesel is used to replace MGO, it would come into contact with the HFO during the fuel changeover procedure, potentially causing sediment formation and increasing risk of blocked injector or other issues.

Alternatively, the HAL "MS Eurodam" is equipped with six engines, two of which are dedicated to MGO operation (*i.e.*, no fuel changeover involved). On further review of the fuel and tank

arrangement, the HAL Technical Team confirmed that it would be possible to fully isolate one MGO storage tank, fuel skid and engine, solely for biofuel operation. Also, Eurodam's fuel system arrangement allowed isolation of the biofuel from the boiler and incinerator. Given these fuel system flexibility advantages, the HAL Team selected Eurodam as the most appropriate vessel for the demonstration.

b. Operational assessment and complete risk assessment for operations

As part of the HAL goal to conduct the Project with safety and efficiency as priorities, the Technical Team developed an Operational Responsibility Matrix, to ensure accountability for analyzing potential Project risks. This matrix included the topics listed below.

Operational Responsibility Matrix Requirements
Designate a point of contact for technical topics.
Establish procurement processes, logistics and interface with suppliers.
Notify authorities of intention to consume biofuels and discuss any specific requirements.
Notify authorities of intention to consume biofuels; obtain any necessary permits.
Arrange lab tests of the fuel and confirmation with engine manufacturer.
Analyze fuel systems and prepare definition of biofuel handling and segregation onboard.
Select tanks, service and settling; clean, if necessary, prior to the operation.
Check compatibility of gasket material for manholes on settling and service tanks; order new, if necessary.
Install new injectors, if necessary, on selected diesel generator, and plan for inspection during or after trial.
Replace fuel filters prior to biofuel operation and keep spares onboard.
Check fuel specifications with manufacturers of incinerator, boiler maker and purifier.
Discuss with the engine maker the operational procedures for selected biofuel, including any necessary inspections and performance tests.
Plan for the amount of engine run time with 100% biofuel.
Prepare procedures, using insights and recommendations (e.g., tanks, pipes, flushing, bunkering, storage, instrumentation, fuel feed system, materials, etc.).
Complete Class Risk Assessment form and address any risks, if necessary.
Arrange training for proper fuel handling to ensure optimal fuel conditions to run the trials.
Arrange for the measurement of NO _x , CO ₂ and other pollutants.

Operational Responsibility Matrix Requirements
Determine whether lube oil is suitable; provide previous results of monthly tests, as necessary.
Evaluate suitability of the sustainability certification and process for compliance with IMO requirements, including requirements for recording consumption and reporting to the IMO Data Collection System.
Document key lessons learned and develop recommendations for the use of biofuels in maritime in the Port of Seattle.
Develop a process for considering questions or concerns raised.

c. Engine emissions regulatory requirements

Ensuring regulatory compliance

Under MARPOL Annex VI regulation 18.3.2.2, when a vessel operates on B100 (100% biofuel) or any biofuel blend exceeding 30%, it must be demonstrated that the engine's NOx emissions remain within the limits set by regulation 13. There are two accepted routes to establish compliance. The first is to conduct onboard NOx emission testing. Such trials must be formally requested through the Flag Administration in accordance with regulation 3.2 of Annex VI, with results submitted to verify compliance. The second route is to obtain a statement from the engine manufacturer (OEM) confirming that operation on B100 does not require any changes to NOx-critical components or to the engine's approved Technical File settings.

In cases where the OEM provides this confirmation, the unified interpretation set out in MEPC.1/Circ.795/Rev.8—and reaffirmed in MEPC.1/Circ.795/Rev.9—applies. This interpretation requires that, where an engine's NOx-critical settings remain unchanged, the use of biofuels greater than 30%, including B100, does not trigger a requirement for additional onboard NOx testing to demonstrate compliance with regulation 13. Accordingly, vessels may operate on B100 without further emissions trials, provided that either the OEM statement is in place or, in its absence, testing is conducted under Flag supervision in line with regulation 3.2.

In order to participate in the Project and operate a non-fossil marine fuel, the vessel's flag registry was notified to ensure that the HAL Team's interpretation of the regulations was aligned.

Guidance from the class society included the following requirements for use of biofuel:

- Biofuel is expected to meet EN 14214 for FAME and EN15940 for HVO.
- Biofuel is expected to be within engine makers specification limits and the OEM will advise on the operational requirements.

- Flag registry will be notified of biofuel operation.
- HAL Team will need to seek flag registry interpretation of MARPOL VI reg 18.3.2, to ensure alignment with NO_x emissions limits.
- The HAL Team confirmed that NO_x critical setting will remain unchanged; therefore, no emissions measurement should be required by Flag.

These requirements reinforce the notion that altering common operations and practices for a vessel designed and built to certain class specifications requires regulatory approval.

Monitoring of criteria pollutants

While fuel lifecycle CO₂ emissions are subject to calculation levels set by the fuel's certifying body, the introduction of a new fuel may result in varying levels of stack air emissions that may exceed regulatory requirements, such as the IMO NO_x "tier limits." For example, one biodiesel fuel considered would have been supplied via an HFO storage tank. Without prior cleaning of this storage tank, the fuel cannot be guaranteed to be low sulfur. This would have required the biodiesel to be used in combination with the vessel's Advanced Air Quality System (AAQS). This system, commonly referred to as the exhaust gas cleaning system or "scrubber," is used to ensure compliance with stack air emissions requirements.

For purposes of this demonstration, the HAL Team commissioned an emissions monitoring expert to attend the vessel and carry out verification measurements for NO_x, CO, CO₂, O₂, and SO₂, when operating on renewable diesel. This monitoring would confirm that the stack emissions resulting from biofuel consumption continue to remain within the applicable limits.

E. Demonstration

1. Fuel selection matrix

After developing core project requirements to survey the market, the Fuel Procurement Team analyzed each fuel individually for compatibility with the specific fuel quality standard, carbon intensity values and cost. The lack of a harmonized standard for these values means that purchasers cannot price the carbon reduction benefits of each fuel without making some assumptions on the methodology.

Development of matrix

The Fuel Procurement Team developed a matrix to compare the various parameters of each biofuel option with respect to suitability for the Project, as shown in the sample below.

Supplier	Fuel Type	Feedstock	Carbon Intensity	Certification Scheme	Delivery	Comments
#1	FAME	Canola Oil	50.1	Washington State	Truck	Delivery only possible via truck and licensing for truck deliveries would be time consuming for the port, potentially delaying the Project.
#2	HVO	Comingled Veg Oils	>50	Washington State	Barge	Delivery via the same barge as conventional MGO and HFO. Co-mingled product for road transport fuels with higher CI score.
#3	FAME	Animal Fats	16.8	ISCC EU	Barge	Would be supplied through the shoreside HFO tanks, and therefore, cannot guarantee sulfur content and fuel quality.
#4	HVO	Comingled Veg Oils	>50	Washington State	Barge	Can be delivered on the same barge as conventional MGO and HFO. Co-mingled product for road transport fuels with higher CI score.
#5	FAME	Soybean Oils	>50	Washington State	Barge	Delivery would be via second barge to the HFO delivery with potential delays to the vessel departure.

Figure 4. Sample portion of fuel matrix

This matrix compared key fuel characteristics, including delivery and availability across several fuel types, including:

Supplier: In total, four potential suppliers were initially identified.

Fuel Type: Biodiesel and renewable diesel

Feedstock: The range of feedstocks included canola oil, animal fats, crop oil and soybean oil. The difference in feedstocks ultimately weighed strongly in the differences in carbon intensity score.

Carbon Intensity (CI) and Certification Scheme: The biofuel options could be supplied under different schemes with mostly Washington Clean Fuels Program assessment. There was one fuel option with a low CI score certified under the International Sustainability and Carbon Certification (ISCC) scheme used in the EU and most familiar to HAL and Carnival.

Delivery availability in Port of Seattle: One supplier did not have a barge option, meaning delivery would be via truck. Other suppliers could offer biodiesel on a dedicated barge, or renewable diesel on the same barge as conventional fuels.

Cost differential: The premium compared to MGO fuel was determined, to ensure efficient use of demonstration budget resources and correlation to scalability. Only initial price indications were received from most suppliers as the final delivered cost depended on the pricing of taxes and incentives determined prior to delivery.

Status as current HAL supplier: The Fuel Procurement Team evaluated whether the supplier currently serves HAL or its sister operating lines, which would simplify contractual obligations and logistics.

Other information garnered: The Fuel Procurement Team collected information about the interaction, including the willingness of the supplier to provide biofuel on terms consistent with the Project requirements and, critically, the ability to deliver the biofuel on the same barge as conventional fuels.

Data collected on available biofuel options was analyzed through this lens of suitability for the Project, in order to support a demonstration with relevant, meaningful and scalable results.

Comparison of biodiesel and renewable diesel

Key differences between biodiesel and renewable diesel are indicated in the table below. On average, biodiesel (FAME) has around 10-15% less energy content than regular MGO, whilst renewable diesel has comparable energy content to MGO. On the other hand, renewable diesel has a lower density than MGO. Fuels must be compared on a megajoule basis and the energy density must also be considered when calculating the bunkering plan in combination with the tank volumes. Therefore, a reduction in energy content or density ultimately affects the vessel's energy storage capacity and range.

Metric	Biodiesel (FAME)	Renewable Diesel (HVO)
Energy Content (MJ/kg)	37	44
Density (kg/m ³)	910	780
Estimated Delivered Cost (\$/MT)	1,200*	2,200**

Metric	Biodiesel (FAME)	Renewable Diesel (HVO)
GHG Reduction Options (gCO ₂ e/MJ)	<33	>33
Compatibility with MGO	Yes	Yes
Compatibility with HFO	Yes	No
Lubricity Additive	No	Yes
Storage Challenges	Oxidation/Solvent/Cold flow	None
Barge Delivery Option	None	Yes

*Initial indication from potential suppliers

**Final fuel price paid

As mentioned previously, the HAL Team was informed that additives would need to be blended with the renewable diesel to enhance the lubricity of the fuel, to meet marine specifications. A testing campaign was completed with lubricity additives at differing dosage rates, to ensure compliance with the standard.

During fuel testing, the HAL Team considered the fact that renewable diesel is not compatible with HFO and may cause formation of sediment, if blended. As such, in general, renewable diesel should be fully segregated from HFO, requiring a vessel fuel system capable of such segregation.

2. Cost and impact of incentives

The Fuel Procurement Team compared costs of the various biofuels, as cost will play a major role in ensuring scalability and sustainability of the use of biofuels in the region. If use of biofuels comes at too high a cost, these fuels may come at the expense of other, less costly and/or more effective decarbonization activities, on a dollar per ton of carbon reduction basis.

The renewable diesel utilized for the demonstration was priced at \$2,200 per ton (approximately \$6.50 per gallon), representing a considerable premium compared to the standard cost of MGO (approximately \$900 per ton or \$3.00 per gallon). While alternative biodiesel options were available at roughly \$1,500 per ton, those options were logistically unattainable.

The CO₂ abatement cost for the selected renewable diesel—with a cost of \$2,200 per ton and a Carbon Intensity of 55 gCO₂e/MJ—is roughly 1,000 \$/MTCO₂e being avoided. For comparison, in the EU, where advanced biodiesel is available with subsidies, this abatement cost typically is less than 120 \$/MTCO₂e being avoided. This significant difference is due to two primary

factors: (1) the high cost of renewable diesel, and (2) the higher carbon intensity value attributed to the fuel.

The major cost implications are related to the incentives that are available for road transport fuel in the U.S., but are not available for maritime transport. This disparity results in higher pricing of biofuels for maritime use, as explained below.

Federal tax credit applicable usage: Federal Tax Credits are applicable to biofuels, but are not available for the maritime industry. Consequently, the incentives offered, such as the Washington Low Carbon Fuel Standard, 45Z or Renewable Fuel Standard (RINs), are not applicable to the maritime industry, or are so narrowly limited (as described below, the Washington Clean Fuel Program incentives are limited to fuel consumed within Washington territorial waters) that they are effectively of no value.

Clean fuels standard limitation: Only biofuel consumed in Washington State waters qualifies for the Clean Fuel Standard credits. This is a very small amount for cruise itineraries that transit Alaska. The majority of the CI score of the fuel cannot be monetized through the CFS program, and the supplier loses the opportunity to generate credits, similar to the way RINs are lost in marine applications.

No carbon intensity credits transferred

Factor	Status for the Seattle Biofuel Project
RINs	Lost—should be priced into biofuel cost
CFS (Washington)	Majority lost—only applicable to fuel consumed in Washington
CI Score Monetization	Not applicable

RINs would have to be purchased by Seaport and retired for the entire volume: RINs are credits used to track renewable fuel production and usage under the U.S. Renewable Fuel Standard (RFS) program, managed by the EPA. The credits are used to track renewable fuel production and usage. These “D4” RINs are assigned to biodiesel and renewable diesel.

Marine fuel use aboard ocean-going vessels (such as used on cruise ships) currently is not covered under the RFS as a qualifying end-use for RIN generation or retirement. Even if the vessel burns renewable diesel, unless it is used in a qualifying application (such as road transport or heating oil), no RINs can be generated or retired for that fuel, and the supplier would receive no credits.

Pricing example of incentives: The renewable diesel was quoted at \$6.40 per gallon, depending on the price of RINs which can fluctuate. If the “D4” RINs are trading at \$1.20 per RIN, and Renewable Diesel generates 1.7 RINs per gallon, that is:

$$\$1.20 \times 1.7 = \$2.04 \text{ per gallon in potential RIN value.}$$

This “lost” RIN value roughly accounts for the differential between renewable diesel priced for road transport (\$4.50 per gallon) and renewable diesel for marine use (\$6.54 per gallon).

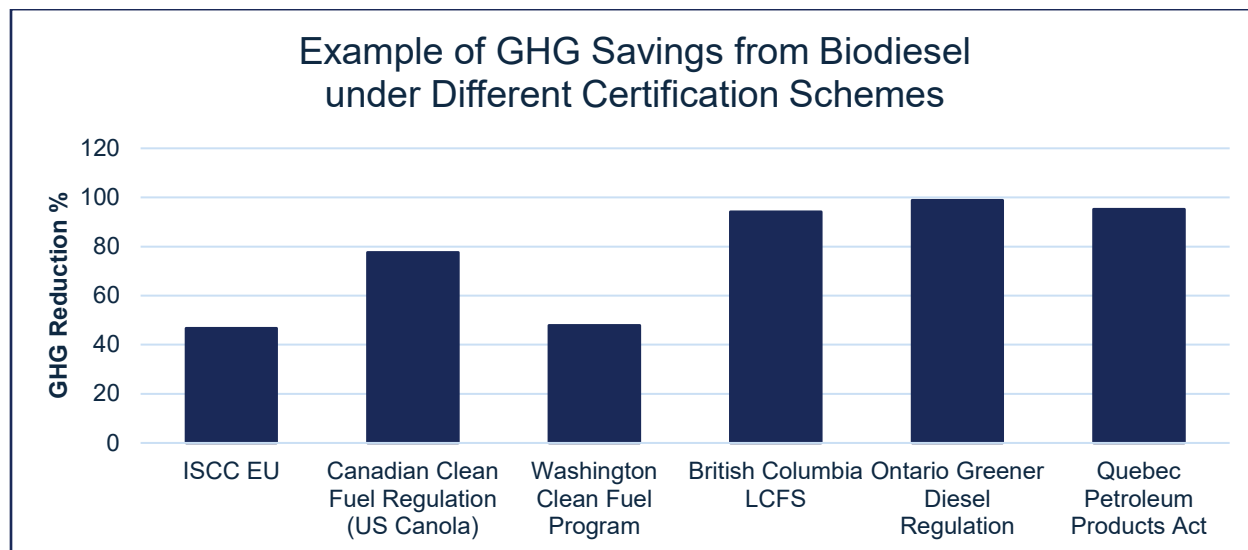
3. Carbon reduction certification schemes

While IMO currently is developing guidelines on Life Cycle GHG Intensity of Marine Fuels (MEPC.391(81)), there is no current global standard for the evaluation of carbon reductions for biofuel. The lack of a common certification scheme prevents assignment of a consistent quantitative decarbonization value to the use of biofuels on a per cost-unit basis.

Today, multiple certification schemes assign different carbon intensity ratings for similar fuel types. ISCC-certified biofuels are common in the EU, but in the U.S., certification schemes can vary significantly by state. Most certifiers consider the well-to-wake lifecycle emission of the fuel, focusing on the production side, rather than simply using tailpipe or stack emissions measurements.

The lack of a singular global biofuel lifecycle emissions assessment standard has a key outcome—specifically, a patchwork of nations and states with varying standards that have little correlation, even for the same fuel. For example, the Fuel Procurement Team evaluated how canola oil-based biodiesel is rated among seven different certification schemes. Emission intensities ranged from 1.00 to 50 gCO₂e/MJ *for the same fuel*. One certification agency provided different intensity values, depending on the country from which the canola oil was sourced. Rates differed by the methodology applied, with one of the primary drivers being the quantification of ‘indirect land use change’ for crop-based feedstocks.

At the outset, Project participants identified this as a major challenge with the absence of a singular standard for measuring how much the life cycle use of biofuels reduces CO₂ emissions. For example, the data in the chart below illustrates the variation in lifecycle emissions for one biofuel under different U.S. state level schemes, when compared to the ISCC EU standard.



In addition, the current IMO regulatory regime has strict requirements for fuel carbon intensity in order to qualify for recognition as a carbon reduction. These requirements are listed below.

- The carbon intensity must be below 33 gCO₂e/MJ [MEPC.1-Circ.905], and
- Proof of Sustainability or similar documentation from a recognized scheme should be provided along with the Bunker Delivery Note.

Regarding the 33 gCO₂e/MJ requirement, three of the seven certification agencies would have rated the canola oil biofuel emission intensity above this level, making it ineligible for recognition as decarbonization credit. Further, IMO requirements include a “Sustainability Statement,” provided by the fuel supplier if the Proof of Sustainability is not available. The Certificate must contain the same required values as included in the Proof of Sustainability. Finally, the supplier’s Certificate must be submitted, in case it is not publicly available.

When the Fuel Procurement Team requested ISCC certifications for biofuels offered by suppliers, most said biofuels were certified at levels exceeding the IMO 33 gCO₂e/MJ cutoff rate. This means *use of the fuel would not qualify to be reported as zero carbon*. No ISCC certifications were available for soy-based or canola-based feedstocks in the U.S.

The producer of the renewable diesel fuel ultimately selected for Project could not guarantee the exact CI score, as the product is co-mingled with different batches of fuel. However, the producer stated it will all be in the range of 50-55 gCO₂e/MJ, according to the Washington LCFS pathway (i.e. above the desired 33 gCO₂e/MJ threshold). Depending on the feedstock, the score could be lower, but this is a range that the producer felt comfortable stating.

Finally, it was unclear to Project participants whether the Port can include the benefits of marine biofuel in its emissions inventory, if it is loaded in the port, but consumed in areas outside of the Port's jurisdiction. The current emissions inventory appears to consider only stack emissions, and not life cycle emissions. This methodology obscures true life cycle emission impacts of biofuel.

4. Stakeholder engagement and concerns

The Project Team developed a comprehensive list of Project stakeholders, beyond the Port and HAL, and invited them to attend one of two webinars. Invitees included representatives from:

- Puget Sound Harbor Safety Committee
- City of Seattle Fire Department
- U.S. Coast Guard (Puget Sound)
- Washington State Department of Ecology, including representatives across programs covering clean fuels, spills prevention and renewable fuels
- Magnolia Community Council

During the webinars, the Project Team presented the Project background, focusing on the operational plans for the loading of fuel. Next, the team made key personnel available for participant questions. First responder stakeholders were interested in the technical properties of the fuel as well as fuel bunkering logistics plans. Most were pleased to be offered the briefing and viewed the Project favorably.

As described above, in addition to the stakeholders who participated in the webinars, representatives from the engine and component OEMs, the class society and the flag registry played key roles in the Project, as well.

5. Demonstration results

As described in previous sections of this report, the Project Team conducted a considerable amount of preparation and coordination to identify the delivery of the appropriate fuel on the appropriate vessel, and the appropriate test at the appropriate time. But, despite the Team's best laid plans, unexpected complexities uncovered during fuel compatibility analyses led to several revisions in expected Project approach.

Initial approach: In accordance with the initial Project vessel requirements and expected budget, the Fuel Procurement Team set out to identify a supplier for roughly 800 metric tons of engine-compatible biofuel for May-July 2025 delivery aboard the Discovery Princess.

Initial evaluation: The Fuel Procurement Team evaluated a renewable diesel supplier that could deliver 620 metric tons, in two deliveries, on May 18, 2025 and June 1, 2025. The trial would be scheduled over a period of four weeks. The ship's engine OEM was enlisted to conduct engine performance and emissions measurements.

Plan revision #1: Bunkering dates were extended to July 27, 2025, and August 10, 2025, due to logistics issues, as the locally sourced fuel originally identified for use was not available in sufficient quantities for marine use. The fuel had to be shipped from California by barge, extending the delivery date. The engine manufacturer's technician changed plans to be on board on August 3, 2025, to collect data resulting from the test. The demonstration now would include running the engine on biofuel, starting July 27, 2025, for four weeks. The fuel provider identified a barge to make the delivery. During the fuel analysis, the Fuel Procurement Team found that the fuel had low lubricity. This required a lubricity additive. One additive was sourced and sent for analysis.

Plan revision #2: Further compatibility analysis flagged a challenge with the renewable diesel. Upon confirmation that renewable diesel generally is not compatible with HFO, Discovery Princess was ruled out. The ship was not designed to maintain total separation of two fuels that it currently uses (MGO and HFO). Use of renewable diesel aboard Discovery Princess presents risks of contamination of fuel lines with harmful deposits if renewable diesel came into contact with HFO. As such, the Technical Team sought a different vessel for the demonstration—one with a fuel system and engine types that could maintain separation of two incompatible fuels.

Plan revision #3: The HAL Team identified the HAL Eurodam, a vessel that can completely segregate an entire fuel tank, fuel handling system and engine, to maintain separation of incompatible fuels. However, Eurodam fuel system design limited the amount of biofuel capacity to one tank for the test with a capacity of 120 MT. The engine OEM (different from the one whose engines are installed in Discovery Princess) was contacted, and the Fuel Procurement Team identified a new fuel supplier that could make delivery On July 26, 2025. The Technical Team worked to complete a new fuel compatibility analysis with the new product and new ship, based on a fuel amount of 400-500 metric tons, revised due to the updated pricing for barge delivery.

The renewable diesel/HVO has low lubricity. As such, the Technical Team learned that an additive would be required to correct the lubricity level, per engine OEM recommendations. Based on updated pricing of \$2,200/MT, the fueling plan was changed to 360 metric tons of fuel over three loadings on July 26, 2025, August 9, 2025, and August 23, 2025.

Bunkering activities and emissions compliance testing results: All bunkering activities were completed successfully, with 360 metric tons delivered aboard HAL Eurodam, in three separate deliveries of 120MT. The final Project budget is provided in Appendix C. HAL’s contractor took stack emission level measurements from the same engine, for both MGO and the tested Renewable Diesel. These results are presented in Appendix D. Overall, the stack emission levels showed little variation. The renewable diesel had slightly less specific NOx emissions than MGO. In both cases it remained below the NOx tier limit. The sulfur emissions were low for both fuels and close to the equipment’s detection limit. The specific fuel consumption rate for the renewable diesel was marginally improved when compared to the MGO due to the high calorific content.

F. Key learnings and recommendations

The Project brought to light several opportunities and challenges for scaling the use of marine biofuels in the Port of Seattle. Key learnings from the Project are presented below, in the order in which the topics are presented above.

1. Biofuel market readiness

Fuel producers must be incentivized to provide sufficient volumes, necessary certifications and competitive pricing of biofuels to increase the use of marine biofuels in the Port of Seattle: As described in detail below, the cost gap between biofuels and traditional maritime fuels must be reduced for scalability to be realized in this market. Producer incentives are commonly offered in other regions and industries.

Recommendation: Based on discussions with fuel suppliers throughout the course of the Project, the HAL Team recommends that the Port engage with stakeholders, including biofuel producers and relevant government agencies, to better understand barriers to offering market incentives to maritime biofuels and work to identify potential incentives that could be made available.

2. Regional distribution logistics

Combinations of high infrastructure barriers and low market demand: The Fuel Procurement Team observed that the biofuel sourcing took longer than expected, compared to biofuel procurements conducted in other markets. In the end, only one viable option was identified, as many suppliers dropped out, often losing interest due to logistics challenges, lack of volume, etc. Some suppliers tried hard to make it work, but other suppliers deemed the effort too high, citing needs to clean tanks, etc., to accommodate a one-off biofuel delivery.

Recommendation: Sufficient fuel delivery infrastructure must be developed to ensure cost-effective delivery. At the same time, sufficient demand must be identified to justify such investments. These conditions suggest a classic chicken-or-egg dilemma.

Seasonality of cruise operations in Seattle: The bunker suppliers in Seattle that supply the cruise industry operate on a highly seasonal market. During the summer months, barge availability and scheduling are tight, and there is limited opportunity to perform extraordinary deliveries of specialized biofuels. If demand for biofuel was consistent throughout the season, it could be more worthwhile for a supplier to offer cruise ship customers a dedicated barge service for specialized biofuels.

Recommendation: Work to identify scale levels needed to justify investments in biofuel delivery infrastructure to accommodate the seasonal cruise industry. Also, identify other potential consumers of biofuel outside of the cruise industry, to determine whether sufficient demand exists to justify investments in infrastructure that will ensure a year-round supply.

Lack of sufficient infrastructure for marine biofuels: The Project highlighted the lack of dedicated, scaled infrastructure for marine biofuels, compared to other high-volume refined products, including jet fuel, gasoline and over-the-road diesel fuel. For these products, significant investment in dedicated infrastructure has been made, including terminals, storage facilities and pipelines, all the way to last-mile delivery connections to round out at-scale integrated supply chains.

The infrastructure needs for marine biofuel supply chains may vary. Vessel operators present myriad sets of requirements, including quantities, timing and other logistical considerations, such as user needs ranging from barge delivery to truck delivery.

Existing storage and delivery capacity appear largely spoken for in meeting current marine fuel market demand. In discussions with suppliers, it did not appear to the Technical Team that infrastructure capacity might become available to supply biofuel on a short-term basis, particularly if switching fuels and cleaning is required for large volume tanks. While this challenge could be attributed to the short-term, limited-quantity nature of the demonstration, it could impact scalability, unless it is made clear that biofuels are replacement volumes offsetting traditional marine fuel consumption for Seattle customers.

Recommendation: The Port should work to identify and document biofuels infrastructure needs from a supplier perspective, and then identify potential solutions to address these needs.

3. Bunkering delivery logistics

Barge and truck delivery options may enhance the availability of biofuels: Ruling out truck delivery further reduced biofuel options, as not all suppliers offered barge delivery. This is due to the fact that barges require dedicated storage tanks accessible near the waterfront. The Fuel Procurement Team found that fuel suppliers are unlikely to have a fully integrated supply chain to accommodate delivery of a specialty fuel, particularly without more expensive, port-adjacent fuel storage tanks allocated to known maritime customer needs. Fuel suppliers delivering truckable quantities of fuel have more flexibility in siting storage tanks away from limited shoreside locations. However, the Project revealed that certain Port dock facilities may not accommodate fuel deliveries by truck, due to stormwater permit requirements.

Recommendation: To ensure the widest possible selection of marine biofuels, the Port should provide to vessel operators seeking to receive deliveries of biofuels any information about regulatory or logistical restrictions at its terminal facility, related to fuel deliveries.

Flexibility to accommodate vessels with multiple fuel “diets”: Barges serving larger vessels often must be able to serve vessels with multiple fuel types—normally MGO, HFO or VLSFO. This means the bunker barge itself must have multiple tanks to accommodate multiple fuel types. In the case of cruise vessels, Seattle port times are limited. Often, only one barge must be used for fueling. A multiple barge bunkering operation cannot be accommodated within the strict schedules of these vessels. Every hour of ship delay requires higher speeds to make the next port of call on schedule, thereby increasing GHG emissions and reducing the GHG benefits provided by use of biofuel. Dedicating a bunker barge tank solely for biodiesel (FAME) could impact the economics of the barge bunkering operation, particularly if offered only for seasonal or occasional customers. This option may not be economically viable for the barge operator.

Recommendation: The Port should engage with bunkering companies to determine the capabilities to supply multiple fuels on a single barge, and work to understand what additional investments are needed to accommodate such operations.

Scalability to different vessel types: Test results do not necessarily inform how vessel types other than cruise ships may approach a transition to biofuels. However, lessons concerning the complexity of shipboard systems, the need to secure regulatory approvals and the complexity of fueling logistics—particularly with limited bunkering windows of 8-10 hours—illustrate the level of planning required and potential best practices for such a transition. It is highly unlikely that a single biofuel type will work for multiple vessel types in a port, given the complexity and variety found in fuels and in shipboard systems, even among vessels of a similar class.

Recommendation: The Port should work with stakeholders to identify bunker barge and other port equipment that may be needed to accommodate greater use of biofuels by Port of Seattle vessel operators.

4. Shipboard fuel systems and operational requirements

Biofuel compatibility with vessel systems: The HAL Team found significant diversity associated with fuel system compatibility for each biofuel type. This was consistent, not only among biofuel offerings, but also among HAL's own fleet and sister line fleets. This variability is likely even higher when considering other cruise lines and other vessel types that call on the Port.

As demonstrated by the Project Team's need to change selection of both vessel and biofuel during the course of the Project, due to challenges uncovered during the fuel compatibility analyses, biofuels compatibility alone can be a major challenge for scalability. It is likely that more than one type of biofuel will be required by ships, even in the same fleet, due to specific fuel diets required by each ship. This complexity further compounds the infrastructure and logistics challenges described above. Finally, in addition to fuel compatibility with engines and propulsion systems, the HAL Team found fuel compatibility issues for several vessel components, including generators, lifeboats, boilers, incinerators, etc.

Recommendation: To help prepare for more widespread adoption of the use of marine biofuels, the HAL Team recommends that vessel operators evaluating biofuels first secure a complete understanding of how their fleets of existing and new vessels can accommodate biofuels, both for propulsion systems as well as other vessel components that consume the fuel being displaced. This can include an evaluation of the vessel fuel system layout, involving engines, fuel skids and storage tanks for use of biofuels; the ability to maintain onboard separation from other fuels where required; consultation with vessel component OEMs; and training and awareness of key personnel, including Chief Engineers.

Shipboard fuel systems cannot accommodate all biofuels: While conducting compatibility analyses, the HAL Team found that some vessel fuel system designs could not maintain segregation of incompatible fuels, such as renewable diesel and HFO. This led to changing the ship selected for the demonstration to one with a fuel system design that could accommodate the necessary separation, using separate engines, fuel storage tanks and pump skids. This is not expected to be the case for biodiesel (FAME). At this time, fuel systems are designed such that renewable diesel is compatible only with MGO, and biodiesel is compatible only with HFO.

Recommendation: Vessel operators seeking to expand the use of renewable diesel should carry out a complete review of fuel systems and understand whether existing layouts, without modification, will permit full segregation from HFO.

Managing fuel contamination risks: As HAL evaluated potential vessels and routes for participation in the demonstration, the company considered that Alaska operations leave little margin for error, due to the sensitive marine environment and distance from fuel and shipyard facilities. For example, compared to other markets, vessels conducting Alaska operations generally require more planning, have more spares on board and have more environmental response systems on standby.

Recommendation: For long-term operations, the HAL Team believes selection of a fuel presenting a low risk of mishaps such as fuel contamination is important.

Compatibility analysis to consider air pollution impacts: When considering utilization of alternative fuels, vessel operators should consider potential changes to resultant stack emissions.

Recommendation: The HAL Team recommends, as part of the due diligence process described above, taking steps to ensure that utilization of biofuels does not negatively impact vessel air emissions for pollutants, such as NO_x, to the point of noncompliance with vessel emission requirements.

5. Costs and the impact of incentives

Cost gap is a significant barrier to scalability: The Project demonstrated a significant cost gap—nearly 3x—for use of biofuel, instead of traditional maritime fuels. This gap was enhanced due to the limited choices available that would meet vessel equipment and operating requirements. The lower-priced biodiesel products would have cost approximately twice as much as traditional maritime fuels, if these products had been compatible with the vessel, equipment and operations. **Biofuels incentives available to other sectors, such as vehicle transportation, are not available to maritime users.** As such, maritime users must pay the unsubsidized fuel cost. If the lower cost biodiesel with incentives was available, via the same barge as traditional maritime fuels, this would make it a significantly more attractive proposition for decarbonization. From the perspective of the HAL Team, these significant increases in cost associated with biofuels are neither scalable nor sustainable over the long term.

Recommendation: The Port should work to identify potential incentives that will close the cost gap to make biofuels competitive from a cost standpoint.

Market limitations without incentives: The HAL team observed that participants in the biofuel supply chain do not appear to be taking a speculative position on marine applications, due to considerable investment requirements and competing industries that often include incentives. Without incentives, it may be difficult to help address this cost gap to conventional fuels.

Recommendation: Policymakers at all levels should focus on potential policies impacting fuel producers, suppliers and users, to incentivize production, delivery and consumption. All involved in the supply chain must be sufficiently incentivized to act.

The Port should work to identify any incentive types, forms and amounts at the local, state and federal levels, including incentives for vessel operators and fuel producers, as well as effective incentive types in other markets. Maritime biofuels incentives offered in the Netherlands are seen generally as a successful model for creating a robust marketplace for biofuels. Policymakers in the region should also be aware of how the impacts of incentives offered in other regions and other industries—such as vehicle transportation—will impact the market for marine biofuels in Seattle. This could include an evaluation of biofuel incentives planned or in place in other U.S. west coast or Canadian regions.

6. Carbon reduction certification schemes

The criticality of biofuel certification: As the demonstration revealed, renewable diesel used in the demonstration did not meet the carbon intensity reduction level of 33 gCO₂e/MJ required by the IMO, in order to receive credit for the emissions reduction. Therefore, neither HAL nor any other cruise operator could receive any applicable GHG reduction credits for using this fuel. Further, most of the fuels evaluated during the demonstration did not meet this threshold and were not ISCC-certified. If vessel operators cannot qualify or receive the decarbonization credit incentive based upon the certification associated with a specific biofuel, the goal of GHG reduction by switching to the use of biofuel will not be achieved.

Recommendation: The Port should work to identify biofuels with a carbon intensity reduction level that meets IMO requirements (33 gCO₂e/MJ). Further, stakeholders should seek to harmonize certification regimes, or recognize common decarbonization qualities for marine biofuels. Ideally, an international standard from an accepted standards body, such as IMO, would be most effective.

Certifications for fuels available in Seattle: The majority of available biofuels identified in the Port of Seattle were crop-based biofuels. These fuels are questionable as to sustainability certifications.

Recommendation: The Port should conduct an evaluation to determine whether locally available crop-based biofuels can be considered “sustainable” and how a vessel operator could receive credit for the emissions reduction, even if the 33 gCO₂e/MJ threshold cannot be met.

7. Stakeholder engagement

Stakeholders included interested port users and first responders, who reminded vessel operators that biofuels may exhibit different characteristics as well as different chemical and physical behaviors, including flammability.

Recommendation: The Port should ensure that first responders have awareness and technical information about all fuels being handled at the port. Differences from traditional fuels in fuel flammability and other characteristics are determined by physical and chemical properties of each fuel.

Appendices

Appendix A: Relevant Language from July 2, 2024, Preferential Berthing Agreement between Carnival Lines and Port of Seattle

Appendix B: Project Team Participants

Appendix C: Project Budget

Appendix D: Results of Engine Monitoring during Demonstration

Appendix A

Relevant Language from July 2, 2024, Preferential Berthing Agreement between Carnival Lines and Port of Seattle

Excerpt from page 8 of the July 2, 2024 Preferential Berthing Agreement
between Carnival Lines and Port of Seattle

6.5.1 The Carnival Lines agree to bunker non-fossil fuel as a demonstration project in Seattle during the 2024 cruise season, subject to availability. The Carnival Lines will collaborate with the Port on the scope of the demonstration project, the total cost of which will be at least \$500,000, but not to exceed \$600,000. As part of the project, a detailed report summarizing the demonstration project will be compiled and shared with the Port of Seattle. The report will include a description of key learnings and recommendations for employing use of similar fuels at scale. Upon receipt, review and approval of the detailed report of the demonstration project by the Port, Carnival Lines will be entitled to a \$300,000 credit against the bundled fees for the 2024 season, if the report is received prior to September 15, 2024, or otherwise for the 2025 cruise season if received prior to September 15, 2025.

If the parties agree that a minimum amount of suitable fuel is not available in 2024, the parties will attempt this demonstration project again during the 2025 season subject to the same availability constraints as above, and the \$300,000 credit associated with the receipt, review and approval of the detailed report of the demonstration project would be applied against the bundled fees for the 2025 cruise season if the report is received by September 15, 2025, or 2026 cruise season if received by December 31, 2025.

The Port and Carnival Lines will jointly work on a campaign to ensure the non-fossil fuel pilot test is leveraged to draw broad awareness among Government stakeholders, fuel supply chain and regulators to support economic transition of maritime alternative fuels.

Appendix B

Project Team Participants

Project Team Participants

Project Team		
	Name	Title
Holland America Lines	Bob Alton	Senior Director, Technical Programs and Decarbonization
	Dominic Tasker	Senior Manager Decarbonization
	Paul Rutherford	Director, HAL Fleet Technical Operations
	Graeme Pollock	Superintendent, HAL Eurodam
	Peter Grooteman / Fitzwarren Kirkland	Chief Engineer, HAL Eurodam
Carnival Corporation	Kosta Somoza	Director, Global Sourcing Fuels
	Teresa Jaramillo	Agent, Global Sourcing Fuels
	Sandy Olsen	Vice President, Corporate Affairs
	Robert Morgenstern	Senior Vice President, Alaska Operations
	Ashli Austen	Director, Business Development Project Lead
Port of Seattle	Linda Springmann	Director, Cruise Business & Elliott Bay Operations
	Stephania Jones Stebbins	Managing Director, Maritime
	Lucian Go	Environmental Program Manager
	Alex Adams	Senior Manager, Environmental Programs
	David Fujimoto	Senior Environmental Program Manager
	Sarah Ogier	Director of Maritime Environment and Sustainability

Appendix C

Project Budget

Budget for Biofuel Demonstration Project in Port of Seattle

Project Budget	
Additional Fuel Items	Amount (\$)
Baseline MGO (360mt @ 931 \$/mt)	\$ 334,994
Biofuel cost (360mt @ 2,198 \$/mt)	\$ 791,432
Additional RD taxes	\$ 868
TOTAL Additional Fuel Cost	\$ 457,306
Project Items	Amount (\$)
Emissions measurement	\$ 33,819
Logistics	\$ 5,000
Fuel analysis VPS	\$ 6,000
<i>Subtotal Project Items</i>	<i>\$ 44,819</i>
TOTAL Project Costs	\$ 502,126

Appendix D

Results of Engine Monitoring during Demonstration

Results of engine monitoring during demonstration

Through the use of a specialized contractor, HAL compiled the following test results of stack air emissions using renewable diesel fuel with additives, as well as traditional MGO.

Postal and visiting address:
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Org.-number: 985 351 724 MVA



Title:

Emission measurement report for Eurodam

Ship/installation, IMO no.:

Eurodam, IMO no.: 9378448

Customer:

Carnival Corporation

Customers ref:

Dominic Tasker
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Ingvar Garåsen
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Project number:
P0621

Document number:
1559-R-01

Date of test:
14.09.2025

Date of report:
23.09.2025

Number of pages (incl. appendices):
11

Summary:

Ecoxy AS has performed a measurement of the emissions from one main engine with two different fuels at the vessel Eurodam according to ISO 8178 / IMO NO_x Technical Code. The calculated emission factors are shown in the table below.

Engine type (Serial no.)	Engine manufacturer and model	Fuel Type	NO _x emission factor [g/kg fuel]	Specific NO _x ² [g/kWh]	CO emission factor [g/kg fuel]	SO ₂ emission factor ³ [g/kg fuel]	Test type
Main engine (69011)	MAK 12M43C	MGO	53.44	10.26	2.04	<0.11	E2 ¹
		Biofuel	52.34	9.83	2.11	<0.12	

1: Weighted according to ISO8178-4 test cycle E2, based on measurements at approximately 25, 50, 75 and 100% engine load.

2: Specific NO_x calculations are based on the accredited results from the NO_x emission measurements, fuel consumption and engine power according to description in 2.4.

3: Not accredited measurement

Ecoxy AS is accredited according to NS-EN ISO/IEC 17025:2017 with reference standards ISO 8178-2:2021, ISO 11042-1:1996, NS-EN 12619:2013, ISO 12039:2019, NS-EN 13284-1:2017, NS-EN 14789:2017, NS-EN 14792:2017 and NS-EN 15058:2017. This test report shall not be reproduced except in full, without written approval from Ecoxy. The test results in this report apply exclusively to the tested objects under the described conditions.

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1 INTRODUCTION

Ecoxy has performed a measurement of the main emission species from one main engine on board the vessel Eurodam, to investigate the possible differences between emissions when using MGO and Biofuel.

The measurements were performed during sailing the 14th of September 2025.

2 TEST SETUP

The measurement equipment was set up as shown in Figure 1.

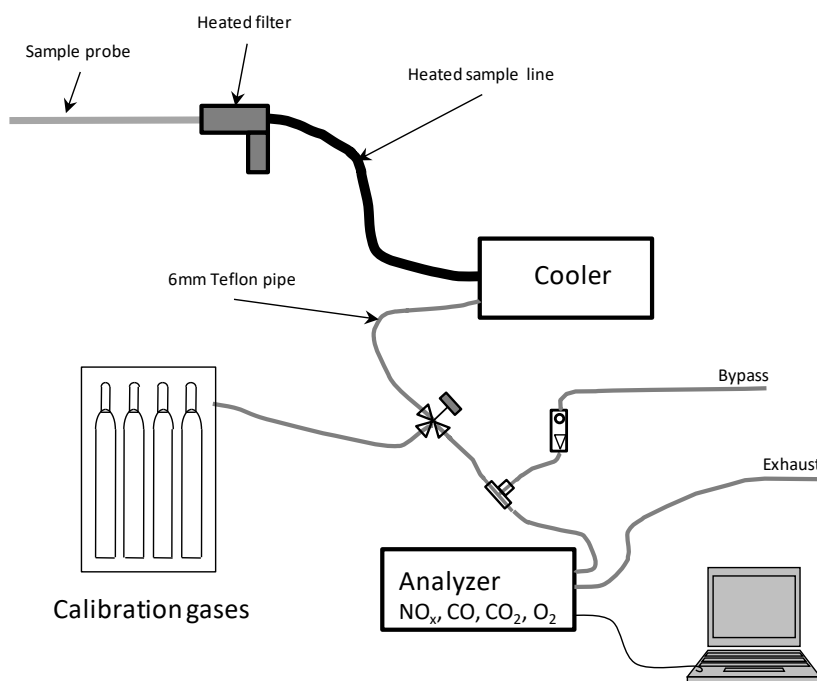


Figure 1: Sketch of the measurement equipment setup

2.1 Test cycles and measured engines

Eurodam has a diesel electric system with four MAK 12M43C main engines (serial no. of measured engine: 69011) as generator drivers.

The engine was measured according to ISO 8178-4 test cycle E2 (at constant engine speed and at approximately 25, 50, 75 and 100 % engine load). The engine loads were achieved by setting the corresponding generator powers, displayed from the PMS.

Barometric pressure, ambient temperature and relative humidity of the inlet air to the engine was measured close to the turbo charger inlet.

2.2 Sample logging and analyzer calibration.

The emissions were logged every second for approximately ten minutes. To ensure thermal stability of the engine during the measurements, the engine was run on stable conditions on the given loads before every measurement started (no significant gradient of NO_x concentration). The averages of the emission values during the measuring periods were used for the emission factor calculations.

The instrument was calibrated before and after the measurements. The calibration gases used are listed in Table 1.

Table 1: Calibration gases

Gas	Gas tube Ecoxy ID	Concentration
NO	366	970 ppm
CO	433	156 ppm
CO ₂		7.99%
O ₂	Amb. air	20.95 %
N ₂	438	99.999 %
SO ₂	419	49 ppm

2.3 Sample point(s) and sample probe

A sample probe of SS316 steel with one hole in the tube wall close to the end of the probe was used for the emission measurements. The outer diameter of the probe was 10 mm. The sample probe was installed perpendicular to the exhaust flow. Figure 2 shows the installation of the sample probe in the exhaust pipe for the engine.

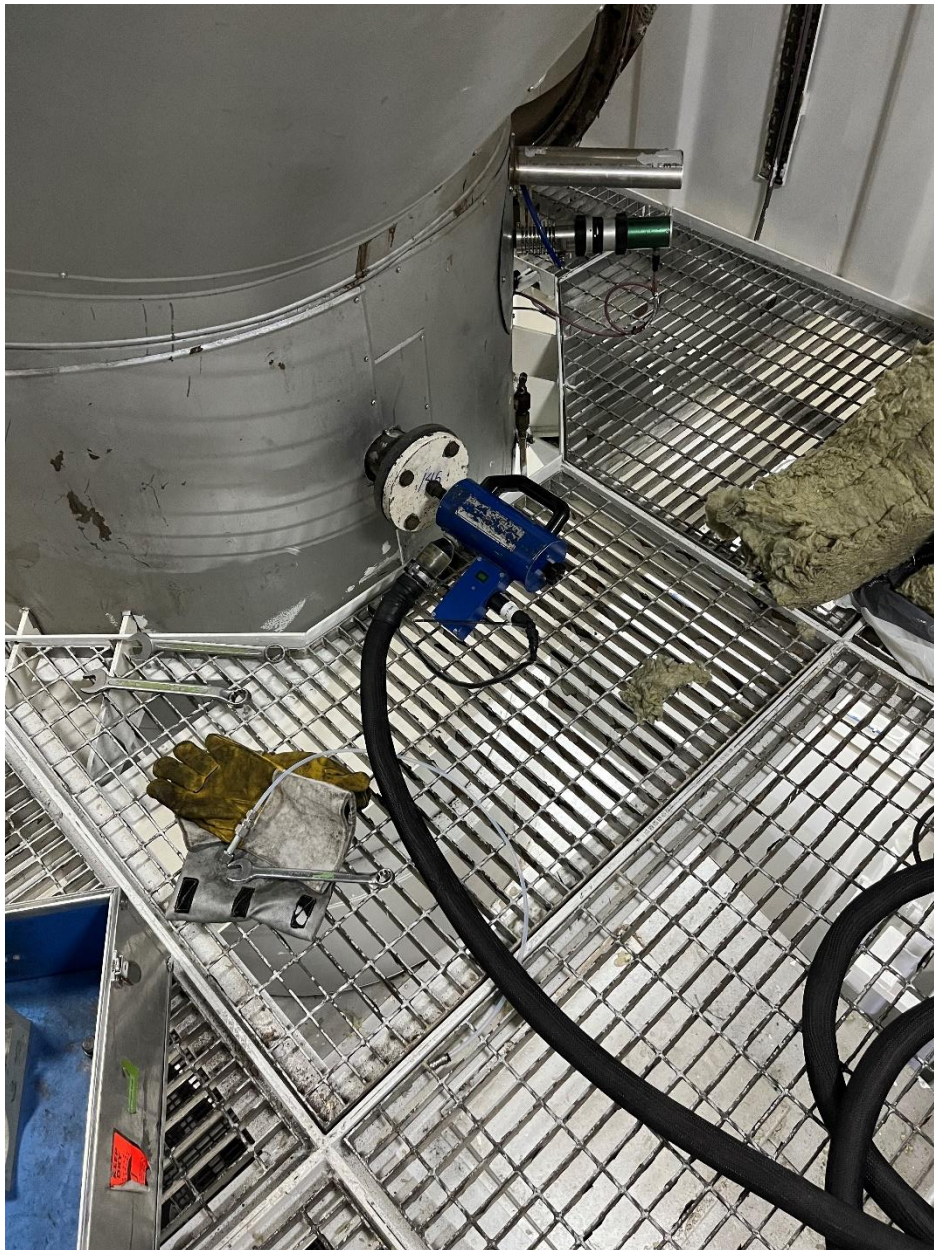


Figure 2: The location of the sample probe on the main engine.

2.4 Methods and calculation

The measurements were performed according to ISO 8178-2:2021 / IMO NO_x Technical Code (2008), Annex VI. Calculation of the emission factors are performed according to the “Carbon Balance Method, 1-step calculation procedure” in ISO8178-1:2020 and Annex A / IMO NO_x Technical Code (2008), Annex VI.

Calculation of specific NO_x factor (g/kWh) are based on the following 3 factors:

- Engine loads are calculated from generator power, registered from the PMS, and the corresponding generator efficiencies estimated to 97%.
- Fuel consumptions were measured from the on-board installed flowmeter.
- The accredited emission measurements performed by Ecoxy on board the vessel.

2.5 Deviation from methods

The Lack of Fit-test and the NO₂ converter check of the gas analyzer were done 112 days prior to the measurements. According to the standard, this shall be done maximum 90 days prior to the measurements.

This is our newest instrument which has proved excellent stability in between these tests. The deviation is not expected to influence the reported emission factors in any way.

3 RESULTS

Comprehensive test results are presented in Appendix 3.

Two different fuels were used during the emission tests; MGO with 0.0012 w-% S and biofuel with <0.03 w-% S. Due to the fuels low sulphur content, the measured SO₂ concentrations are close to the detection limit for the instrument. The uncertainty for the SO₂ measurements can therefore not be calculated, but is considered to be high.

Note that the mass burn rate and engine load was in general a bit higher at all load steps on MGO than with biofuel. The fuel rack positions were quite similar at both test runs, so the volume of fuel delivered from the pumps should be fairly equal, but the density of the fuels are different (0.8521 kg/liter for MGO and 0.784 kg/liter for biofuel). When calculating the specific NO_x emission factors [g/kWh], the electric powers generated from the generator and the fuel consumption on mass basis are taken into account, compensating for the small variations in load.

Based on the composition of the fuel (13.6 w-% H and 86.2 w-% C for MGO and 15.0 w-% H and 86.2 w-% C for BIO) the mole fraction of hydrogen to carbon (H/C ratio) used in the calculations for MGO and BIO are 1.8800 and 2.0736, respectively [1]. To check if the fuel values used in the calculations are correct, Ecoxy always compares the calculated excess air ratio based on the O₂ and CO₂ measurements. In Figure 3 and 4 the red and blue lines are the theoretical values for the O₂ and CO₂ concentrations, respectively. The points plotted in the figure are measured values. The figure shows that the measured values are in good accordance with the theoretical values.

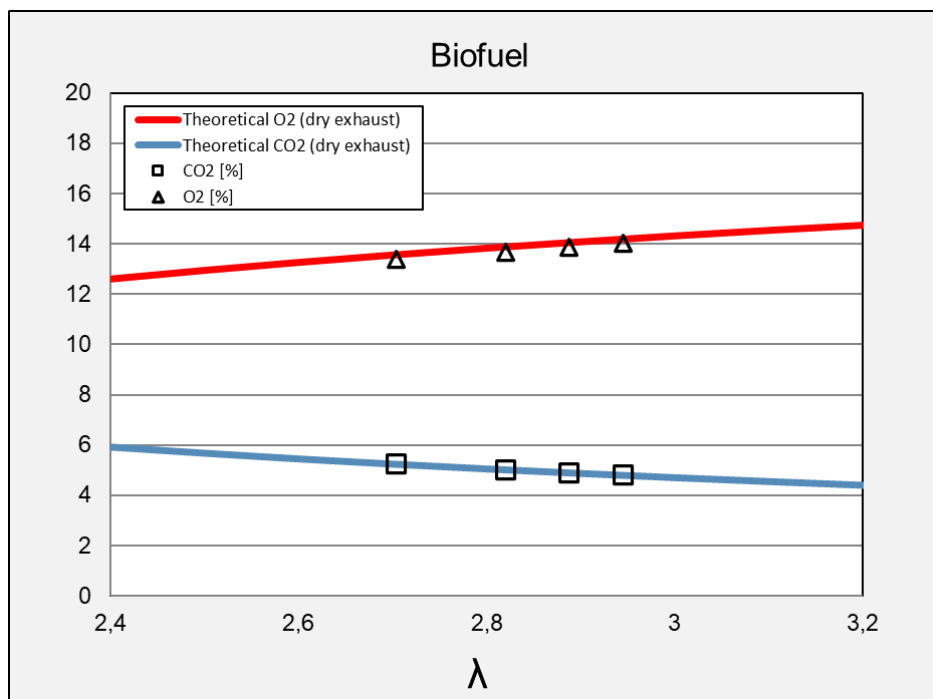


Figure 3: Theoretical and measured O₂ and CO₂ concentrations at varying excess air ratios (λ), measured with biofuel.

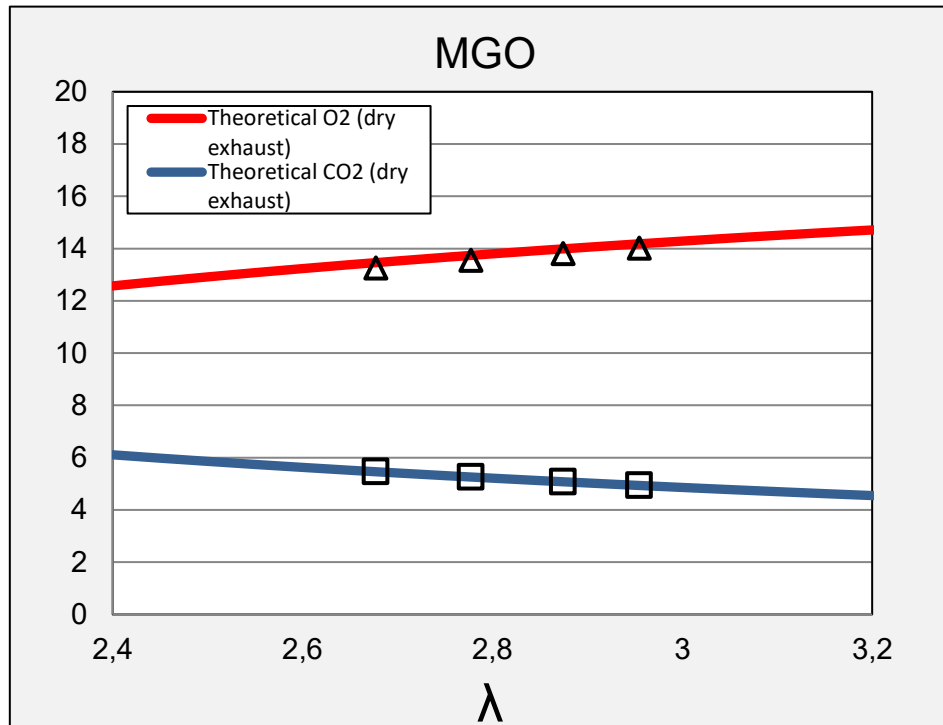


Figure 4: Theoretical and measured O_2 and CO_2 concentrations at varying excess air ratios (λ), measured with MGO.

4 REFERENCES

- [1] IMO MEPC 58/23/Add.1 - Annex 14 - Resolution MEPC.177 (58): "Amendments to the technical code on control of emission of nitrogen oxides from marine diesel engines" - NOx Technical Code 2008. – Chapter 6 – Simplified Measurement Method. ([https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/177\(58\).pdf](https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/177(58).pdf))

APPENDIX 1: INSTRUMENT LIST

Type of equipment	Manufacturer/Model	Ecoxy ID no
Analyser	Horiba PG-350	I-089
Cooler	M&C PSS-5	I-078
Heated sample line	M&C PSP 4M 4/6	T-006
Filter housing	M&C PSP 4000-H	T-005
Thermometer	Vaisala HMI 41	I-032
Moisture meter	Vaisala HMI 41	I-032
Barometer	Testo 511	I-094

APPENDIX 2: INSTRUMENT MEASURING RANGES AND DRIFT

The analyzer readings with span and zero gases were recorded before after the measurements. After each calibration, the instrument was reset to correct values. The following measuring ranges were used:

Gas Component	NO	CO	CO ₂	O ₂	SO ₂
Measuring range	0 – 2500 ppm	0 – 500 ppm	0 – 10 %	0 – 25 %	0-50 ppm

According to ISO8178-2 deviation of more than $\pm 2\%$ of the nominal span gas value is not allowed for both the span and the zero point.

Calibration #	Time [hh:mm]	Zero					Span				
		NO [ppm]	CO [ppm]	CO ₂ [%]	O ₂ [%]	SO ₂ [ppm]	NO [ppm]	CO [ppm]	CO ₂ [%]	O ₂ [%]	SO ₂ [ppm]
Analysis values w/max deviation		0 ±19	0 ±3.1	0 ±0.16	0 ±0.42	0 ±1.0	970 ±19	156±3.1	7.99±0.16	20.95±0.42	49 ±1.0
1 ¹⁾	18:45	0	0.0	0.00	0.00	0.00	970	158.8	7.92	20.95	49.0
2	20:55	0	0.1	0.01	0.01	0.00	967	154.9	8.00	20.98	48.3
Relative deviation	-	0%	0%	1%	0.5%	0%	-0.3%	-0.7%	0.1%	0.1%	-1.4%
3 ¹⁾	00:03	0	0.0	0.00	0.00	0.00	970	158.8	7.92	20.95	49.0
4	02:06	0	0.1	0.01	-0.01	0.00	967	156.1	7.99	20.99	48.8
Relative deviation	-	0%	0%	1%	0.5%	0%	-0.3%	0.1%	0%	0.2%	-0.4%

¹⁾ Before the first measurement series the instrument is adjusted.

APPENDIX 2: RESULTS – MGO

NO_x-beregninger/-calculations

ecoxy as

Skip / Vessel: Eurodam

Date of measurements:

IMO nr. / IMO no.: 9378448

14.09.2025

Motor/Engine:	MAK 12M43C
Serienr. / Serial no.:	69011
Nominell effekt / nominal power:	12000 kW
Nominelt turtall / nominal engine speed:	514 rpm

Måleingeniør / Surveyor:

Rune Moen

Fuel element	H (%-w)	C (%-w)	S (%-w)	H/C (m)
MGO	13,6	86,2	0,0012	1,8800

Test cycle: E2

Load		90 %	78 %	56 %	25 %	Weighted values
Weight factors	[%]	20	50	15	15	
Time for measuring average result	[hh:mm- hh:mm]	00:38 - 00:48	01:02 - 01:12	01:30 - 01:40	01:54 - 02:04	
Power	[kW]	10744	9402	6685	3021	
Engine speed	[rpm]	514	514	515	515	
Concentration of NOx	[ppm]	879	904	947	874	
Concentration of CO	[ppm]	75	57	36	35	
Concentration of CO2	[%]	5,46	5,26	5,08	4,94	
Concentration of O2	[%]	13,26	13,54	13,81	14,01	
Concentration of SO2	[ppm]	1,38	1,15	1,13	1,31	
Ambient pressure (pB)	[kPa]	101,64	101,71	101,66	101,65	
Relative humidity, air intake (Ra)	[%]	43,5	41,0	38,2	37,0	
Temperature, air intake (ta)	[°C]	21,3	21,6	22,3	22,8	
Charge air pressure	[kPa abs]	400	360	270	150	
Charge air temperature	[°C]	55,0	55,0	56,0	56,0	
Engine Fuel Consumption	[kg/hr]	2063	1795	1302	683	1608
Calculated saturated steam pressure	[kPa]	2,53	2,58	2,69	2,77	
Intake air humidity (Ha)	[g/kg]	6,81	6,53	6,36	6,35	
NOx humidity correction factor (KHdies2)	[-]	0,95	0,94	0,94	0,94	
Excess air ratio (Lambda CO2)	[-]	2,68	2,78	2,87	2,95	
Dry/wet correction factor, intake air (kw2)	[-]	0,0108	0,0104	0,0101	0,0101	
Dry/wet correction factor, raw exhaust (KWr2)	[-]	0,9481	0,9502	0,9520	0,9533	
Carbon factor [Fc]	[-]	2,9584	2,8475	2,7476	2,6709	
Fuel specific factor for exhaust flow, dry [Ffd]	[-]	-0,7561	-0,7561	-0,7561	-0,7561	
Wet exhaust to fuel ratio (QmeW/Qmf)	[-]	39,87	41,34	42,76	43,93	
Corrected wet NOx concentration (NOxWET)	[ppm]	833	859	902	834	
Corrected wet CO concentration (COWET)	[ppm]	71	54	34	33	
Source specific NOx emission factor F(NOx)	[g/kg fuel]	49,86	53,16	57,72	54,87	53,44
Specific NOx emission factor - IMO Tier factor	[g/kWh]	9,57	10,15	11,24	12,40	10,26
Source specific SO2 emission factor	[g/kg fuel]	<0,12	<0,10	<0,11	<0,13	<0,11
Source specific CO emission factor	[g/kg fuel]	2,75	2,15	1,40	1,41	2,04

Measurement uncertainty (confidence interval: 95 %, coverage factor: 2):

Nox [ppm] ± 45	CO2 [%] ± 0,15	Amb. pressure [mbar] ±: 3,5	THC emission factor [g/kg]: ±	NOx emission factor [g/kg]: ± 6,2
CO [ppm] ± 9,1	O2 [%] ± 0,38	Rel. humidity [RH%] ±: 2,6	±	NOx [g/kWh]: 1,19
	THC [ppm] ±	Temp. °C ±: 0,38		

Uncertainty for the NOx emission factor [g/kWh] is calculated for the emission measurements only, NOT included SFOC and engine power.

The measurements of SO2 are NOT accredited.

Calculations based on the "Carbon-balance method, 1-step calculation procedure" in ISO 8178-2:2021 / IMO NOx Technical Code 2008, Appendix VI

APPENDIX 3: RESULTS – BIOFUEL

NO_x-beregninger/-calculations

ecoxy as

Skip / Vessel: Eurodam

Date of measurements:

IMO nr. / IMO no.: 9378448

14.09.2025

Motor/Engine:	MAK 12M43C
Serienr. / Serial no.:	69011
Nominell effekt / nominal power:	12000 kW
Nominelt turtall / nominal engine speed:	514 rpm

Måleingeniør / Surveyor:

Rune Moen

Fuel elements	H (%-w)	C (%-w)	S (%-w)	H/C (m)
Bio	15	86,2	<0,03	2,0736

Load		Test cycle: E2				Weighted values
		88 %	76 %	50 %	25 %	
Weight factors	[%]	20	50	15	15	
Time for measuring average result	[hh:mm- hh:mm]	19:31 - 19:41	19:53 - 20:03	20:15 - 20:25	20:42 - 20:52	
Power (from generator switch board)	[kW]	10589	9111	6040	2988	
Engine speed	[rpm]	513	512	514	514	
Concentration of NO _x	[ppm]	824	854	892	837	
Concentration of CO	[ppm]	77	54	35	39	
Concentration of CO ₂	[%]	5,24	5,02	4,90	4,80	
Concentration of O ₂	[%]	13,37	13,68	13,87	14,01	
Concentration of SO ₂	[ppm]	1,31	1,18	1,23	1,49	
Ambient pressure (pB)	[kPa]	101,70	101,61	101,62	101,61	
Relative humidity, air intake (Ra)	[%]	43,0	45,3	43,5	41,4	
Temperature, air intake (ta)	[°C]	20,6	20,4	20,7	21,0	
Charge air pressure	[kPa abs]	400	350	250	150	
Charge air temperature	[°C]	55,0	55,0	54,0	53,0	
Engine Fuel Consumption	[kg/hr]	2008	1697	1158	660	1523
Calculated saturated steam pressure	[kPa]	2,43	2,40	2,44	2,49	
Intake air humidity (Ha)	[g/kg]	6,45	6,72	6,57	6,36	
NO _x humidity correction factor (KHdies2)	[-]	0,94	0,94	0,94	0,94	
Excess air ratio (Lambda CO ₂)	[-]	2,70	2,82	2,89	2,95	
Dry/wet correction factor, intake air (kw2)	[-]	0,0103	0,0107	0,0104	0,0101	
Dry/wet correction factor, raw exhaust (KW _{r2})	[-]	0,9459	0,9476	0,9489	0,9502	
Carbon factor [Fc]	[-]	2,8393	2,7181	2,6519	2,5980	
Fuel specific factor for exhaust flow, dry [Ffd]	[-]	-0,8339	-0,8339	-0,8339	-0,8339	
Wet exhaust to fuel ratio (Q _{meW} /Q _{mf})	[-]	41,55	43,32	44,35	45,21	
Corrected wet NO _x concentration (NO _x WET)	[ppm]	779	810	846	795	
Corrected wet CO concentration (COWET)	[ppm]	73	51	33	37	
Source specific NO_x emission factor F(NO_x)	[g/kg fuel]	48,28	52,45	56,08	53,65	52,34
Specific NO _x emission factor - IMO Tier factor	[g/kWh]	9,15	9,77	10,75	11,86	9,83
Source specific SO ₂ emission factor	[g/kg fuel]	<0,12	<0,11	<0,12	<0,15	<0,12
Source specific CO emission factor	[g/kg fuel]	2,92	2,15	1,40	1,60	2,11

Measurement uncertainty (confidence interval: 95 %, coverage factor: 2):

Nox [ppm] ± 45	CO ₂ [%] ± 0,15	Amb. pressure [mbar] ±: 3,5	THC emission factor	NO _x emission factor [g/kg]
CO [ppm] ± 9,1	O ₂ [%] ± 0,38	Rel. humidity [RH%] ±: 2,6	[g/kg]:	± 6,4
	THC [ppm] ±	Temp. °C ±: 0,38	±	NO _x [g/kWh] 1,20

Uncertainty for the NO_x emission factor [g/kWh] is calculated for the emission measurements only, NOT included SFOC and engine power.

The measurements of SO₂ are NOT accredited.

Calculations based on the "Carbon-balance method, 1-step calculation procedure" in ISO 8178-2:2021 / IMO NO_x Technical Code 2008, Appendix VI