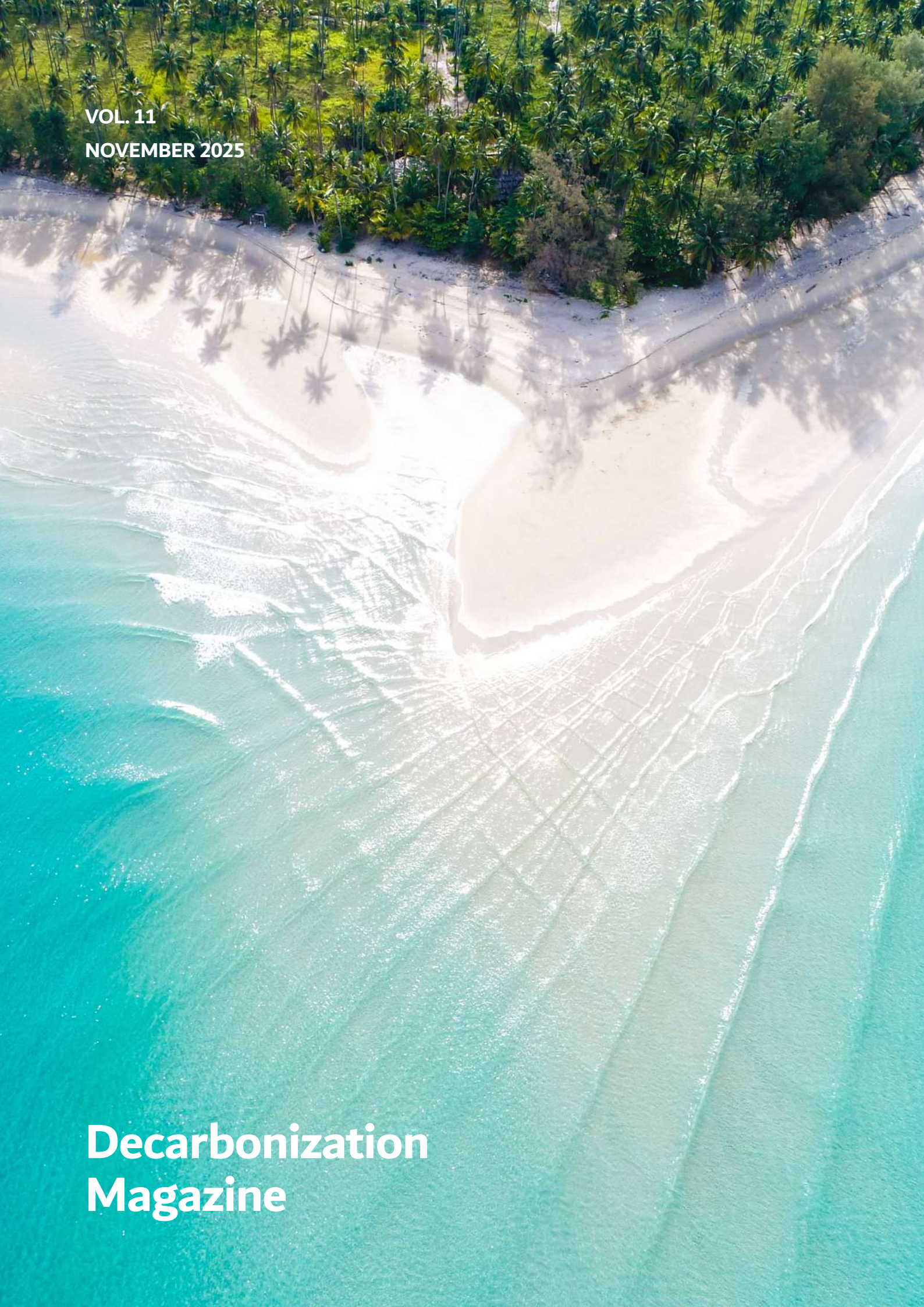

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An aerial photograph of a tropical coastline. The top half of the image shows a dense forest of palm trees and other greenery. Below the forest is a wide, white sandy beach. The bottom half of the image shows the turquoise ocean with gentle waves washing onto the shore. Long, dark shadows of the palm trees are cast onto the sand and the shallow water, indicating a low sun position. The overall scene is peaceful and idyllic.

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CONTENTS

Editor's Note		04
Insights	Data-Driven Ship Operational Performance Analysis and Energy-Saving Device Performance Estimation (ESD: WAPS)	08
	Biofuel Series – Part I Biofuels in the Pathway to Net-Zero: Technical Challenges and Operational Perspectives	16
Interview	Navigating Decarbonization: Danaos Shipping's Strategic Response Ms. Evi Politi, R&D Director of Danaos Shipping	26
Regulatory Updates	IIACS Trends I	34
Inside KR	KR Approves Ammonia-Fueled Ship Safety Solution 'Hi-CLEARs' Developed by HD Hyundai	38
	KR Grants AIP to HD Hyundai's LNG Boil-off Gas Treatment System	39
	KR Approves 'IMO Type-C Tank Design Based on Engineering Critical Assessment' Jointly Developed by HD Hyundai Mipo and HD KSOE	40
	KR and HD Hyundai Samho Launch Joint Development of Ammonia Fuel Piping Safety System	41
	KR Grants Approval in Principle (AIP) for SHI's "SnapWindFloat", a 15MW Floating Offshore Wind Substructure	42
	KR Grants Approval in Principle for Hanwha Engine's Ammonia Fuel Supply System	43

Editor's Note

In the fall of 2025, the maritime industry's decarbonization journey moved from setting direction to executing action. Following the formal adoption of the Net-Zero GHG Framework at the 83rd IMO MEPC in April, international shipping now has a clear and measurable pathway for greenhouse gas reduction. Decarbonization is no longer a matter of voluntary commitment — it is evolving into an integrated management system that connects operations, fuel, certification, and data within a unified framework.

Meanwhile, the formal adoption of the Net-Zero GHG Framework has been postponed for one year, temporarily adding uncertainty to the regulatory timeline. However, this delay represents only a shift in timing — not in direction. Humanity's efforts to combat global warming continue, and the decarbonization of international shipping has already become an irreversible course toward a sustainable future. Ultimately, the question is no longer when to begin, but rather what actions we take now to make that future real.

In the European Union, EU ETS and FuelEU Maritime have already come into force, translating greenhouse gas emissions directly into monetary costs. Shipowners must now demonstrate their decarbonization strategies through tangible performance, while shipyards and equipment manufacturers are entering an era in which alternative fuel technologies, energy-saving devices (ESDs), and operational efficiency solutions must all undergo systematic verification.

In this issue, we focus on performance analysis based on operational data and the estimation of ESD performance, exploring how real-world operational insights can drive energy efficiency improvements and enable quantitative performance validation. Operational data is no longer merely a reporting metric — it has become a key asset for demonstrating fuel savings and quantifying emission reductions. Based on this data, KR is developing analytical and modeling methodologies to evaluate propulsion efficiency and estimate the performance of various ESDs. This research is expected to evolve into an international verification standard that aligns not only with EEXI and CII assessments but also with the FuelEU Maritime MRV framework.

This issue also features KR's recent work on biofuel commercialization and the development of the 'KR SusBio' notation. Biofuels have already emerged as a practical alternative fuel, recognized by both the IMO and the EU as one of the most viable pathways for low-carbon transition. In response, KR has developed the 'KR SusBio' notation, which comprehensively evaluates the fuel's type, blending ratio, combustion characteristics, storage and handling safety, and engine certification requirements.

This notation provides assurance for both the sustainability and operational safety of biofuels, supporting compliance with international regulations while strengthening the commercial reliability of ships operating with alternative fuels.

We are also pleased to include an exclusive interview with Dr. Evi Politi, R&D Director at Danaos Shipping. Dr. Politi shared broad insights across a spectrum of technical and policy issues — including the transition to alternative fuels, ESD implementation, digital optimization of operations, the allocation of carbon tax burdens, the potential application of SMR (Small Modular Reactors) to shipping, and the geopolitical implications of U.S. shipbuilding and maritime policies on the global decarbonization landscape.

She emphasized that “decarbonization is not merely a technological challenge, but a complex issue interwoven with policy, market, and energy security.”

To address this, Danaos has developed a data-driven operational decision-making platform that integrates real-time energy management with comparative analysis of emission reductions and cost efficiency across multiple fuel options.

Dr. Politi also highlighted the growing importance of classification societies and accredited institutions in establishing common frameworks for technical verification and data standardization, underscoring the need for a shared, reliable data ecosystem across the maritime sector. Her perspective extends beyond the technological dimension of decarbonization, offering a balanced view of its political and economic context.

This reminds us that maritime decarbonization is no longer a matter of isolated technologies but a comprehensive transformation requiring both international cooperation and policy alignment.

The Inside KR section of this issue showcases KR’s collaborative achievements at Gastech 2025, featuring joint developments and Approvals in Principle (AiPs) with leading shipyards, engine makers, and equipment manufacturers on next-generation clean technologies such as ammonia, LNG, and offshore wind. These outcomes reflect the strengthened spirit of industry collaboration fostered through Gastech 2025 and underscore KR’s expanding role as a trusted partner in the verification of green and alternative fuel technologies on the global stage.

We extend our sincere gratitude to all domestic and international experts who contributed to this issue, and especially to Dr. Evi Politi of Danaos Shipping for sharing her valuable insights.

As we move forward, the focus is no longer on setting goals but on delivering results. KR will continue to serve as a “Bridge for Decarbonization”, connecting technological integrity with industrial sustainability — and helping to shape the future of international shipping. 



SONG Kanghyun

Head of KR Decarbonization · Ship R&D Center

KR Decarbonization Magazine

Insights

Insights 1

Data-Driven Ship Operational Performance Analysis and
Energy-Saving Device Performance Estimation (ESD: WAPS)

Insights 2

Biofuel Series – Part I
Biofuels in the Pathway to Net-Zero:
Technical Challenges and Operational Perspectives



Data-Driven Ship Operational Performance Analysis and Energy-Saving Device Performance Estimation (ESD: WAPS)



KIM Minsu Senior Surveyor of KR Ship & Offshore Technology Team



Impact of Global Environmental Regulations

In April this year, the International Maritime Organization (IMO) approved the Net-Zero Framework, further accelerating the shipping industry's transition toward decarbonization. While earlier short-term measures (such as EEDI and CII) were entirely regulation-focused, the new framework expands its scope to promote fuel transition and introduces direct carbon costs on greenhouse gas emissions.

When a vessel uses HFO while calling at European ports, it becomes subject to both IMO and EU regulations. In such cases, assuming the vessel's CAPEX is set at 1, OPEX is estimated at 2, while carbon costs are

expected to reach 4–6. As a result, shipping companies are making every effort to minimize these unexpected carbon costs.

Carbon costs are classified into Tier 1 or Tier 2 depending on whether IMO's Direct and Base criteria are met. Failure to meet the Base criterion results in Tier 2 classification, which carries punitive costs. Conversely, if the Direct criterion is exceeded by using zero-emission fuels, the shipowner (or shipping company) can receive incentives.

To minimize carbon costs, shipping companies must focus on reducing their annual Greenhouse Gas Fuel Intensity (GFI) while simultaneously improving overall energy efficiency.

- ▶ GFI can be lowered by switching to alternative fuels to reduce GHG emissions or by utilizing zero-emission energy sources such as shore power, wind, and solar.
- ▶ Energy efficiency can be improved by managing hull and propeller fouling, maintaining engine efficiency, installing Energy Saving Devices (ESDs), and optimizing operations.

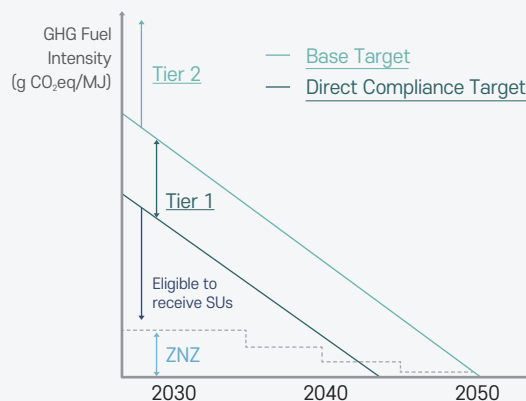
Since fuel transition has been continuously featured in Decarbonization Magazine, this article will instead introduce two key topics:

measures to improve energy efficiency and the adoption of wind-assisted propulsion systems (WAPS) as a zero-emission energy source.

$$\text{GFI}_{\text{attained}} = \frac{\sum_{j=1}^J EI_j \times \text{Energy}_j}{\text{Energy}_{\text{total}}}$$

EI_j : GHG Intensity of Fuel j

$\text{Energy}_{\text{total}}$: Total energy used from all sources (Fuel, AMP, Wind, etc.)



- Fuel Transition from HFO to ZNZ or zero emission energy
- Improvement of Energy Efficiency by Operational or Technical measures

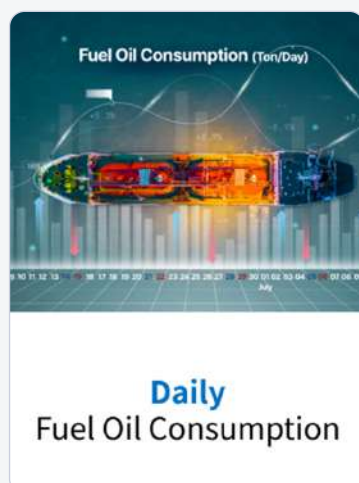
$$\text{Tier 1 RU} = \text{Annual GFI}(\text{Direct} - \text{Base}) \times \text{Energy}_{\text{total}} \times \$100$$

$$\text{Tier 2 RU} = \text{Annual GFI}(\text{Base} - \text{Attained}) \times \text{Energy}_{\text{total}} \times \$380$$

Data-Driven Operational Analysis for Energy Efficiency Improvement

Improving energy efficiency requires an accurate understanding of a vessel's actual performance, which in turn depends on how effectively shipping companies utilize available data. Typically, shipping companies manage three categories of operational data: annual fuel consumption, daily fuel consumption, and high-frequency measurement data. All shipping companies collect annual fuel consumption data for IMO DCS and EU MRV reporting, while

daily fuel consumption data comes from Noon Reports compiled by navigators. High-frequency measurement data are available only on vessels equipped with smart-ship solutions, where sensors record precise data at high sampling frequencies. The following section examines what each type of data can reveal — and how these insights can guide decision-making to improve operational efficiency and support decarbonization strategies.



• Annual Fuel Oil Consumption

Annual fuel consumption data includes voyage distances, sailing times, and actual fuel consumption by type. This dataset is directly applied in CII (Carbon Intensity Indicator) rating calculations and is essential for evaluating annual environmental performance. However, it only provides macro-level information. For instance, ships of the same type may still show differences in CII ratings, but the precise causes cannot be fully explained, as annual data do not sufficiently capture detailed variables such as operating conditions, weather, speed profiles, or loading status.

• Daily Fuel Oil Consumption

Daily fuel consumption data are segmented by operational status (e.g., port stay, port entry and departure operations, voyage), allowing for a clearer understanding of energy consumption patterns at each stage of operation compared to annual fuel consumption data. By utilizing this

data, it is possible to distinguish between fuel consumption during port stay and during the main voyage, thereby identifying which segments are causing inefficiencies. Furthermore, when synchronized with KR's ocean environmental data, daily fuel consumption can be segmented and analyzed by various key factors. However, since a single daily value is used as a representative figure, this inherent limitation prevents detailed variability from being captured, resulting in low accuracy.

• High-Frequency Sensor Data

Modern ships equipped with smart-ship solutions collect high-frequency measurement data through various sensors. This data, recorded at short intervals (seconds or minutes), provides time-series information that includes both navigational data and engine data.

By analyzing this data statistically, it is possible to identify operating conditions that affect vessel performance — such as speed, draft, and rudder angle. When synchronized with KR's ocean environment data, external factors (including wind speed, wave height, and sea temperature) can also be statistically assessed. In addition, performance variations under different wave and wind conditions, as well as rudder angle data, make it possible to assess the navigator's operational habits.

By filtering the measurement data to include only segments where sea conditions are calm and navigation is stable, the vessel's pure technical performance can be estimated.

When sufficient long-term data are accumulated, voyage-based analysis enables the determination of technical performance degradation over time — such as hull and propeller fouling or engine efficiency decline — helping ship operators identify the optimal timing for maintenance.

In cases where sister ships exist, performance comparisons between vessels are also possible. By classifying parameters such as ship performance, maintenance condition, and engine efficiency decline as technical performance, and factors such as port waiting, sea conditions, and navigational practices as operational performance, operators can identify the optimal measures to improve energy efficiency for each vessel.

Among the three types of data available to shipping companies, high-quality measurement data collected through smart ship solutions are essential for accurately assessing vessel

performance. Furthermore, long-term data accumulation is indispensable for analyzing performance degradation over time.

Regulatory Impacts on WAPS Performance and Case Studies

In environmental regulations, incentive schemes are established to reward Energy Saving Devices (ESDs) that contribute to reducing greenhouse gas emissions. Among them, Wind-Assisted Propulsion Systems (WAPS) offer dual benefits compared to other ESDs — simultaneously lowering the GFI and improving energy efficiency, thereby reducing carbon costs.

The dual benefits of WAPS are designed somewhat differently under each regulation. For example, under EEDI, only the top 50% of WAPS performance conditions are reflected, resulting in efficiency values estimated at

nearly twice the actual level. In contrast, FuelEU Maritime introduces a reward factor called f_{wind} , which provides an additional 1–5% incentive if WAPS achieves energy savings of 5%, 10%, or 15% or more. Meanwhile, the IMO Net-Zero Framework is designed to provide dual benefits by adding the contribution of WAPS to the vessel's total energy use when calculating the GFI. Accordingly, KR has developed a procedure for calculating WAPS efficiency in accordance with the relevant regulations, and has conducted comparative analyses to verify consistency and reliability across different evaluation methods.

EEDI	GHG Intensity Fuel EU Maritime	GFI IMO Net-Zero Framework(Mid Term)								
$\frac{CO_{2,ME} + CO_{2,AE} - CO_{2,reduction,ESD}}{Capacity \times Speed}$	$f_{wind} \times \frac{\sum_{j=1}^J EI_j \times Energy_j}{Energy_{total}}$ (WwT + TtW)	$\frac{\sum_{j=1}^J EI_j \times Energy_j}{Energy_{total}}$								
Weighted average over global shipping route's wind condition	f_{wind} Reward factor for WAPS based on EEDI performance <table><tr><th>f_{wind}</th><th>Criteria</th></tr><tr><td>0.99</td><td>$0.05 \leq P_{wind} / P_{ME} < 0.10$</td></tr><tr><td>0.97</td><td>$0.10 \leq P_{wind} / P_{ME} < 0.15$</td></tr><tr><td>0.95</td><td>$P_{wind} / P_{ME} \geq 0.15$</td></tr></table>	f_{wind}	Criteria	0.99	$0.05 \leq P_{wind} / P_{ME} < 0.10$	0.97	$0.10 \leq P_{wind} / P_{ME} < 0.15$	0.95	$P_{wind} / P_{ME} \geq 0.15$	$Energy_{total}$ Fuel Oil, Electric From Shore +Zero-emission Energy Source
f_{wind}	Criteria									
0.99	$0.05 \leq P_{wind} / P_{ME} < 0.10$									
0.97	$0.10 \leq P_{wind} / P_{ME} < 0.15$									
0.95	$P_{wind} / P_{ME} \geq 0.15$									

The target vessel was assumed to be a Very Large Ore Carrier (VLOC) equipped with either five rotor sails or five wing sails. As a first step, WAPS performance was evaluated through Computational Fluid Dynamics (CFD) analysis, and the results were presented in the form of a performance polar chart. The rotor sail showed

limitations in utilizing maximum wind speeds due to the need to maintain an optimal ratio between rotor rotation speed and wind velocity. However, it generated strong thrust under beam and crosswind conditions thanks to the Magnus effect. In comparison, the wing sail requires approximately four times the surface area to produce the same

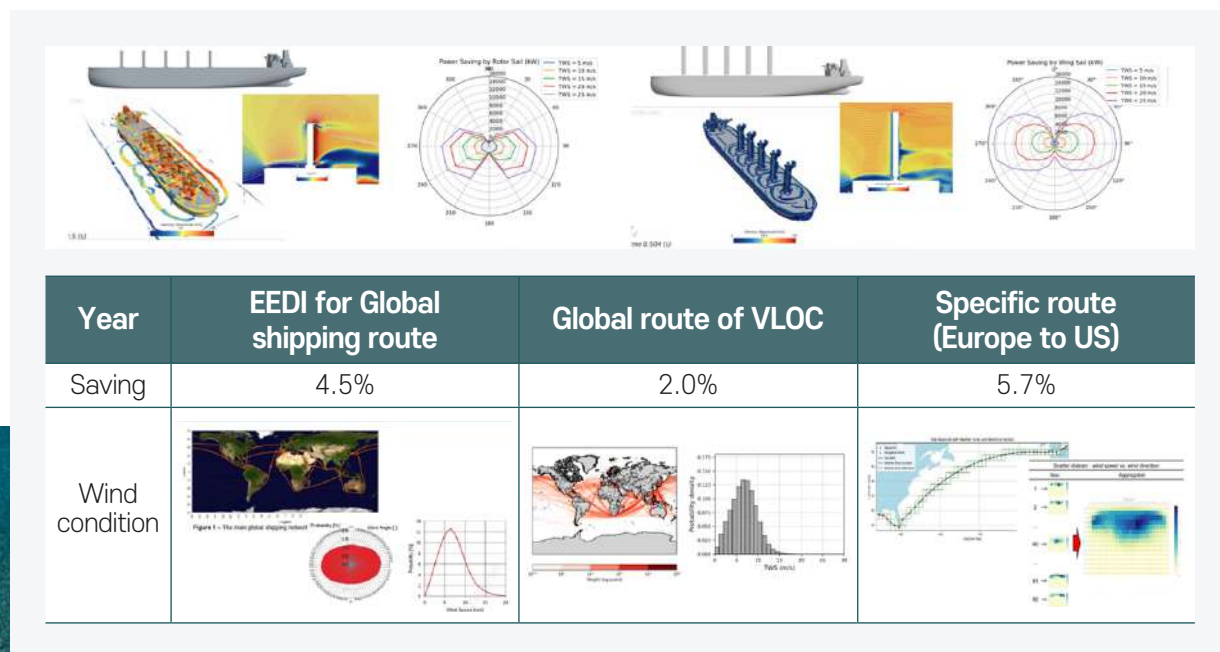
thrust as a rotor sail, but it is not restricted by wind speed and can also generate propulsion under tailwind conditions by harnessing both lift and drag forces. If space efficiency and gust-response safety associated with its larger surface area can be ensured, the wing sail has the potential to deliver superior long-term performance.

KR calculated WAPS efficiency using three evaluation methods based on the rotor sail performance polar chart. The first method applied the EEDI evaluation approach, which estimates efficiency during the design stage without considering the vessel's actual route. It uses the global route wind direction and speed distribution (Wind Matrix) provided by MEPC. The analysis identified approximately 4.5% power savings; however, since the vessel's actual route was not reflected, this figure is difficult to interpret as a practical operational effect.

The second method analyzed efficiency by extracting global routes based on the AIS data of the VLOC and synchronizing them with ocean environmental data to construct a Wind Matrix. This analysis showed a power saving of about 2.0%, which is about half the level estimated by the EEDI evaluation method.

Lastly, to verify the maximum effect of WAPS, a Wind Matrix was developed for the North Atlantic route where wind conditions are strong. In this case, efficiency increased by up to 5.7%, even for a very large vessel.

In summary, the performance of WAPS varies significantly depending on the evaluation method and route conditions, highlighting the necessity of precise analysis that reflects actual routes and environmental factors.



Third-Party Verification Guidelines for ESDs

Although WAPS offers dual benefits under environmental regulations, many shipping companies are still reluctant to invest. The main reason is that the high initial installation cost and uncertainty regarding efficiency make it difficult to objectively assess the ROI (Return on Investment). Accordingly, KR is establishing a rational efficiency calculation procedure from a third-party perspective, reflecting actual routes and environmental conditions as examined in

the previous case. This initiative is intended to help shipping companies assess investment feasibility based on more realistic criteria. In addition, KR is expanding its scope of services by developing efficiency estimation procedures not only for WAPS but also for various other energy-saving devices — including Onboard Carbon Capture Systems (OCCS), Waste Heat Recovery Systems (WHRS), and passive Energy Saving Devices (ESDs) of Category A type attached to the hull.

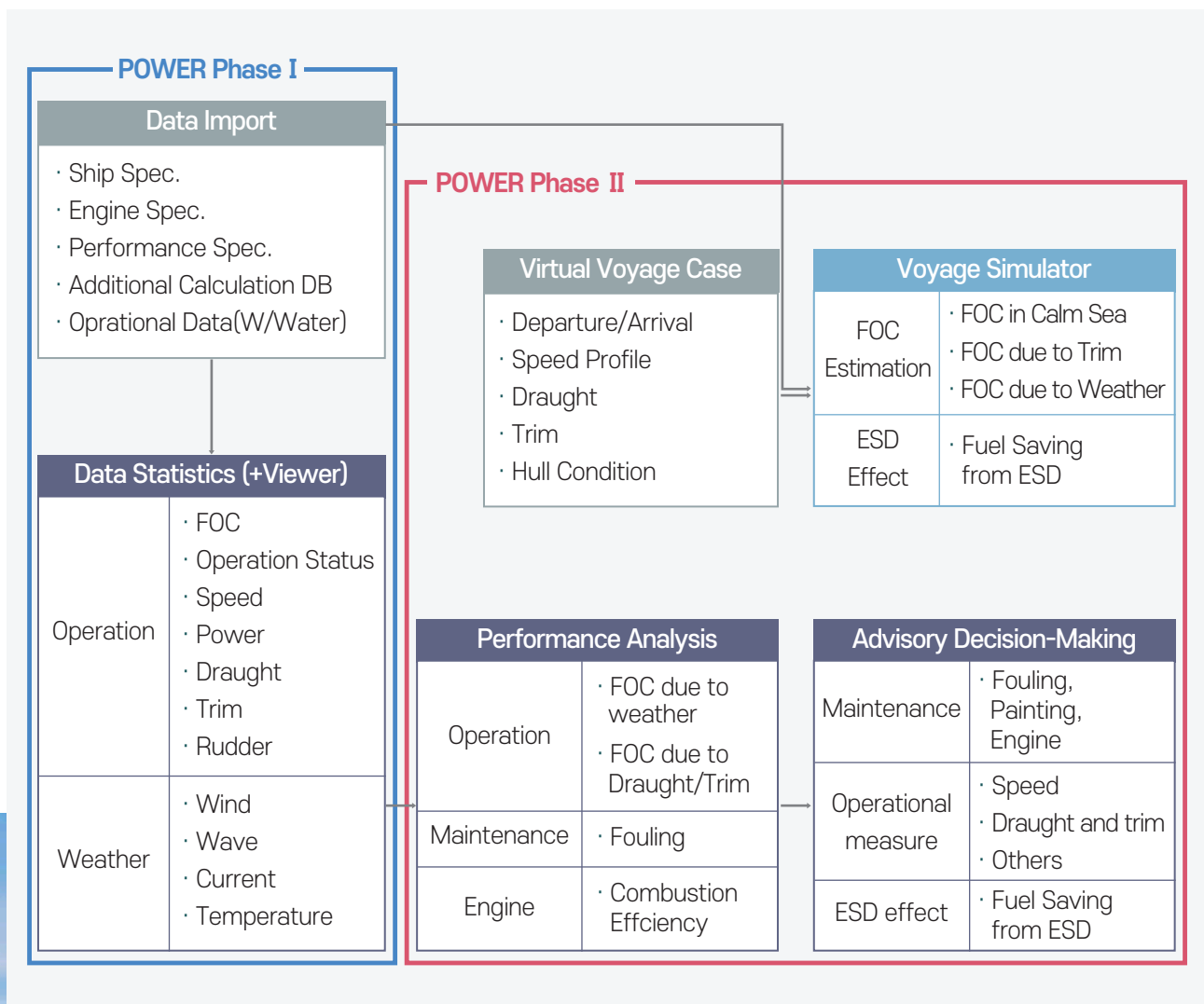
Decision Support for Energy Efficiency Improvement

KR is developing an operational data analysis solution called KR-POWER, designed to support data-driven decision-making for energy efficiency improvements. The system analyzes operational performance and estimates the actual effectiveness of various Energy Saving Devices (ESDs). The development is being carried out in two phases. Phase 1, scheduled for release at the end of 2025, will integrate shipowners' operational data with KR's environmental and AIS data to provide statistical visualization of operational characteristics, weather conditions, and fuel consumption.

Phase 2, scheduled for release by the end of 2026, will further expand its functions to data visualization and performance analysis based on measurement data. Through this enhancement, the system will enable the quantification of fuel consumption by contributing factors, as well as the identification of performance degradation resulting from hull fouling and

declining engine combustion efficiency. Building on these analysis results, the system will provide capabilities to predict fuel consumption under hypothetical operating conditions such as draft, trim, and speed, and to simulate the effects of ESDs.

This enables shipping companies to pre-evaluate energy efficiency improvement strategies under various operating conditions. They can assess hull and propeller fouling, coating condition, and engine efficiency from a maintenance perspective; evaluate performance in relation to speed, draft, and trim from an operational perspective; and review the effectiveness of ESDs from a technical perspective, thereby supporting more rational decision-making. In addition, KR is working to integrate shipyard smart ship solutions and shipping companies' Fleet Control Center data with the KR Smart Ship Platform as part of this implementation. 

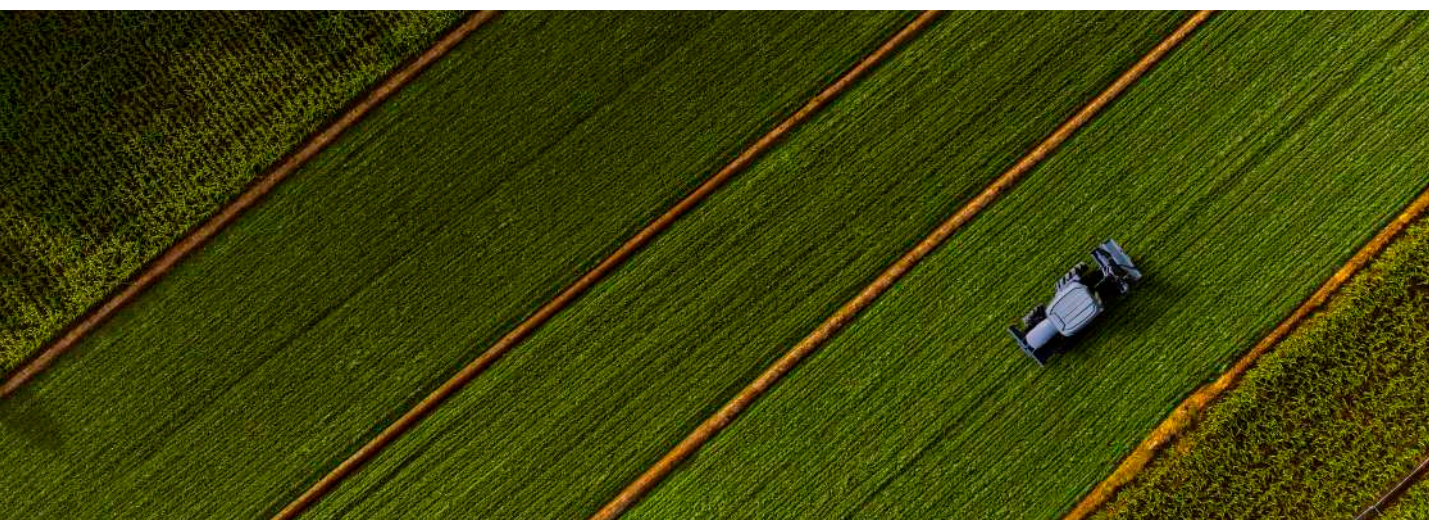


Biofuel Series – Part I

Biofuels in the Pathway to Net-Zero: Technical Challenges and Operational Perspectives



HA Seungman Principal Surveyor of KR Machinery Rule Development Team



This is the first installment in KR's Biofuel Series. Coming up in the next issue, Part 2 — co-authored with VISWA Group — will take

a closer look at the operational challenges, quality issues, and case studies of biodiesel blends in marine fuels.

A New Pillar in Shipping Decarbonization: Biofuels

Biofuels are fuels derived from biomass—such as vegetable oils, agricultural residues, and waste-based materials—through processing and refining. In the maritime sector, they are attracting increasing attention as alternative fuels that share physical and chemical properties with conventional fossil fuels while contributing to the achievement of Net-Zero targets.

Currently, the main types of biofuels under consideration include Fatty Acid Methyl

Ester (FAME), Hydrotreated Vegetable Oil (HVO), bio-methanol, bio-LNG (Liquefied Bio-Gas), ethanol, Straight Vegetable Oil (SVO), Fischer-Tropsch diesel (F-T diesel), upgraded pyrolysis oil, and Dimethyl Ether (DME). Among these, FAME and HVO stand out as the most promising options for international shipping, as they can be used as drop-in fuels without requiring major modifications to existing ship fuel systems.

In other words, biofuels can either fully replace conventional fuels or be blended in varying

proportions, making short-term transitions more feasible.

- FAME: Already relatively widespread, with an increasing number of cases where it is blended with conventional fuels, but requires careful management due to its lower oxidation stability and poor long-term storability.

- HVO: Chemically similar to diesel, offering excellent compatibility with existing engines

and higher oxidation stability suitable for long-term storage. However, cost factors remain a constraint.

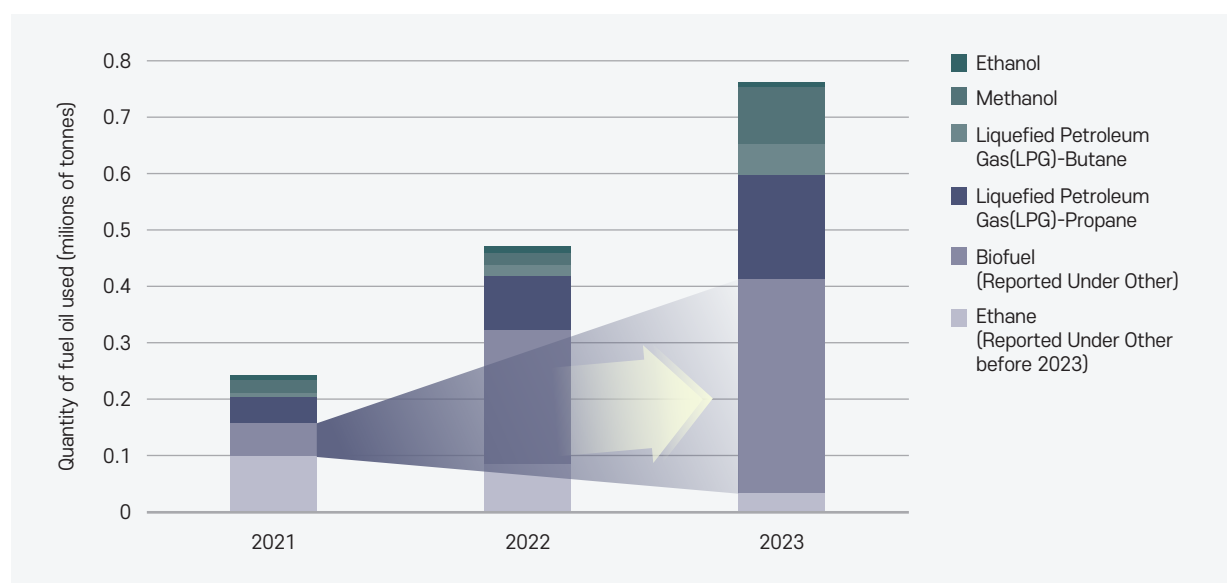
Biofuels thus present a wide spectrum of types and characteristics, and their respective strengths and weaknesses will directly influence future fuel choices and regulatory strategies in the maritime sector.

Status of Biofuel Use in Shipping: Still at an Early Stage, but Growing Rapidly

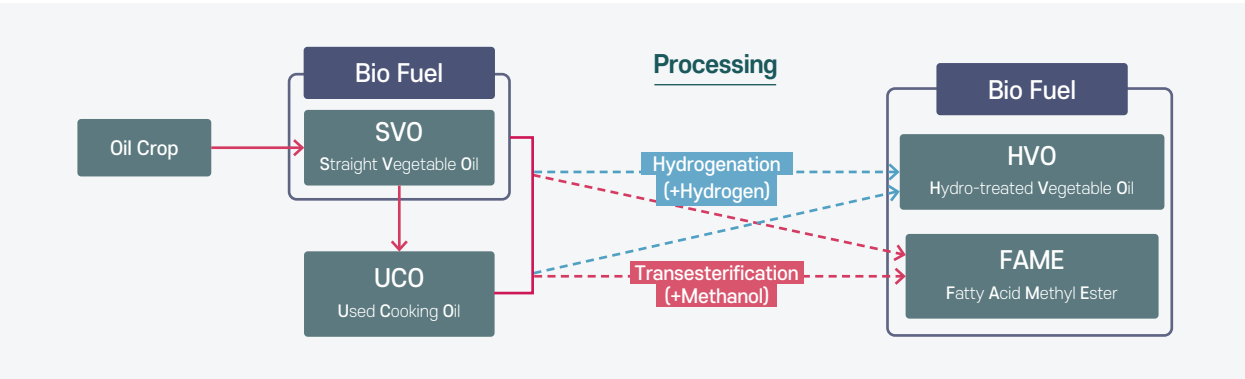
As of 2023, the vast majority of global biofuel consumption — around 99% — remains concentrated in road transport, with aviation accounting for about 0.5% and shipping only 0.6%. In terms of total marine energy use, this translates to a share of just 0.3%.

Although the volume is still marginal, it is noteworthy that since the IMO DCS (Data

Collection System) reporting began in earnest in 2021, biofuel use in shipping has shown a steady year-on-year increase, as illustrated in the bar chart below. This indicates that, while biofuels currently represent only a small piece of the overall maritime energy mix, their share is expected to expand rapidly as regulatory discussions intensify and shipping industry interest grows.



Production Processes and Characteristics of FAME and HVO



Among the various types of biofuels, those being most rapidly applied in the shipping industry are Fatty Acid Methyl Ester (FAME) and Hydrotreated Vegetable Oil (HVO). Both are derived from oil crops, straight vegetable oil (SVO) or used cooking oil (UCO), but their production processes differ significantly.

- FAME is produced through a transesterification process in which methanol is added to the feedstock oil. Because the resulting ester bonds retain oxygen atoms, the fuel exhibits polar characteristics and is highly susceptible to oxidation and degradation. Consequently, it deteriorates easily during long-term storage and is considered less stable.
- HVO, on the other hand, is produced via hydrogenation, in which hydrogen is added to the feedstock oil to remove unsaturated bonds and oxygen. This process converts the oil into a structure of saturated hydrocarbons, chemically almost identical to petroleum diesel. As a result, HVO is non-polar, highly resistant to oxidation, and well suited for long-term storage.

	Main Characteristics	Molecular Structure
SVO	·Carbon Double Bond (C=C): Unsaturated ·Ester Bond (-COO-): Contains oxygen atom	$\begin{array}{c} \text{H}_3\text{C} - \text{O} - \text{C}(=\text{O}) - \text{R} \\ \text{H}_3\text{C} - \text{O} - \text{C}(=\text{O}) - \text{R} \\ \text{H}_3\text{C} - \text{O} - \text{C}(=\text{O}) - \text{R} \end{array}$
FAME	·Polar Oils	$\begin{array}{c} \text{H}_2\text{C} - \text{O} - \text{C}(=\text{O}) - \text{R} \\ \\ \text{H} - \text{O} - \text{C}(=\text{O}) - \text{R} \\ \\ \text{H}_2\text{C} - \text{O} - \text{C}(=\text{O}) - \text{R} \end{array}$
HVO	·Saturated Hydrocarbons (No Carbon Double Bond and No ester Bond)	$\text{C} - \text{C} - \text{C} - \text{C} - \text{C} - \text{C} - \text{C} - \text{C} - \text{C} - \text{C}$
Distillate Oils	·Non-Polar Oils	

These structural differences have important implications for actual ship operations:

- ▶ FAME offers advantages in terms of cost and supply availability, but its lower oxidation stability and storability demand strict management.
- ▶ HVO provides excellent stability and compatibility, but its feedstock requirements and higher production costs remain barriers to wider market adoption.

A further challenge in the adoption of biofuels lies in the competition between international shipping and aviation. Aviation has limited alternatives for decarbonization, making the use of Sustainable Aviation Fuel (SAF) indispensable. Within SAF, HVO is widely recognized under the name Hydroprocessed Esters and Fatty Acids (HEFA) and has become the primary feedstock pathway. Because aviation

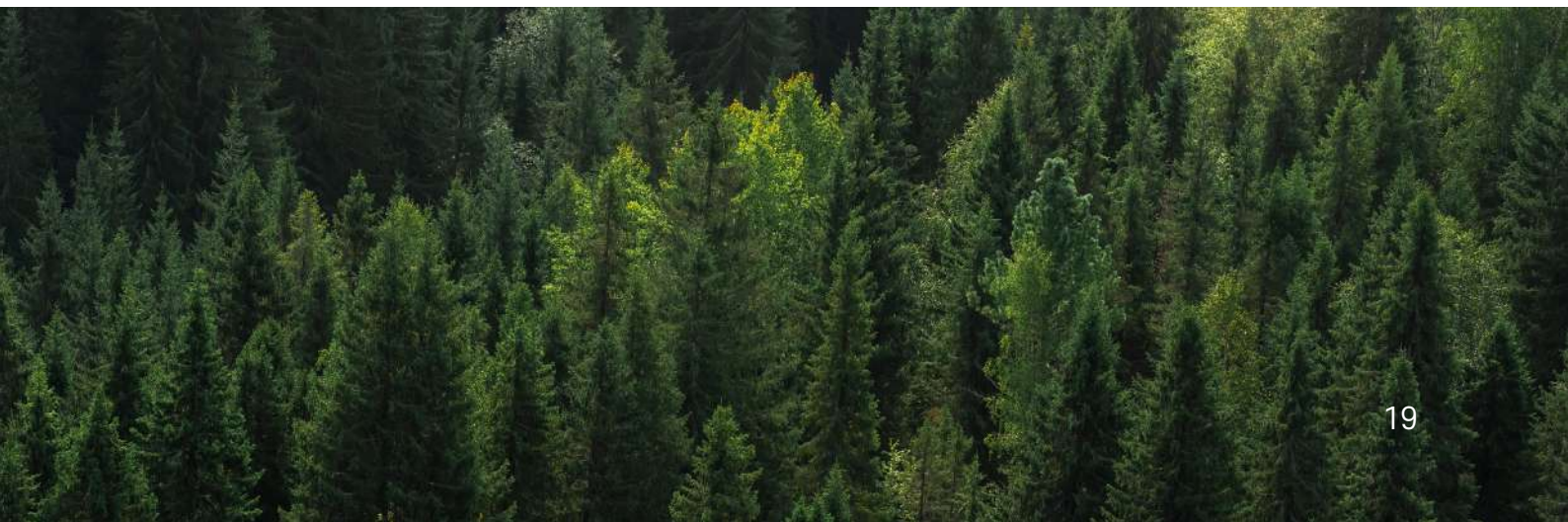
has fewer alternatives and greater willingness to pay premium prices, the large-scale introduction of HVO into shipping faces significant practical constraints.

For this reason, this article will focus primarily on the technical and operational considerations of FAME, which is more likely to see wider application in shipping.

Technical Considerations: Guidelines for the Safe and Efficient Use of Biofuels

To ensure the safe and efficient use of biofuels in ships, it is essential to carefully examine and manage the potential risks arising from their inherent fuel properties. Unlike conventional fossil fuels, the distinct chemical characteristics of biofuels directly affect engine performance and fuel system integrity.

In particular, FAME contains oxygen atoms in its molecular structure, which introduces a range of technical risks. Identifying these risks in advance and implementing appropriate preventive measures is the key to stable ship operations.



Key Technical and Operational Risks of Biofuels and Mitigation Measures

1. Oxidation Stability and Long-Term Storage Issues

FAME is chemically prone to oxidation, which can cause the fuel to degrade and form sludge or acidic compounds. This leads not only to

reduced fuel quality but also to corrosion of engine components and filter clogging.

- Mitigation | Biofuels should ideally be consumed within three months rather than stored long-term. For extended storage, regular fuel quality analysis is recommended, and antioxidants should be added as needed to improve stability. Recently, NYK Group commercialized an antioxidant called BioxiGuard for biodiesel, demonstrating the shipping industry's efforts to tackle this issue.

2. Material Compatibility

Biofuels may react with rubber, plastic, or certain metallic components in the fuel system, leading to

damage such as fuel leakage or part failure.

- Mitigation | Review material compatibility before use and replace them with biofuel-resistant materials such as fluorocarbon rubber (Viton) or Teflon. Materials like nitrile rubber and neoprene should be avoided, as they may swell or weaken when exposed to biofuels.

3. Risks from Specific Compounds

Depending on the feedstock or production process, biofuels may contain unexpected reactive compounds that can severely damage fuel systems. For example, CNSL (Cashew Nut Shell Liquid) contains highly reactive substances such as cardol

and anacardic acid, which accelerate corrosion and wear of metallic parts and form polymers that clog filters. Other problematic compounds have also been reported, such as:

- Estonian Shale Oil: Risk of reduced fuel stability
- Phenolic Compounds: Can destabilize fuel properties
- Biodiesel Residues (e.g., free fatty acids, mono-/di-/triglycerides): Accelerate oxidation and degradation
- Rosin Acids: Highly reactive under oxidative conditions, reducing fuel stability

- Mitigation | Require full disclosure of feedstock and production process details from suppliers, and rigorously check Certificates of Quality (CoQ) before bunkering. If necessary, conduct detailed testing using GCMS (Gas Chromatography–Mass Spectrometry) to detect harmful compounds in advance.

4. Lube Oil Contamination and Performance Degradation

In four-stroke engines, FAME-based fuels can leak into the lubricating oil during combustion, lowering oil viscosity. This leads to reduced lubrication performance and accelerated engine wear.

- Mitigation | Regularly monitor FAME concentration in lube oil using FTIR (Fourier Transform Infrared Spectroscopy). Adjust oil change intervals flexibly, not just by fixed time schedules, but based on contamination levels and viscosity changes.

5. Sludge Formation and Filter Clogging

Because of FAME's instability and hygroscopic nature, sludge can accumulate more frequently in fuel tanks and purifiers. This increases the risk of filter clogging, which may disrupt operations.

- Mitigation | Drain tanks regularly to prevent water accumulation, adjust sludge discharge frequency in purifiers, and fine-tune gravity disk settings to match the characteristics of biofuels. In the early adoption phase, it is essential to stock sufficient spare filters to prepare for clogging incidents.

6. Engine Performance

FAME has a lower calorific value compared to fossil fuels, which can result in increased fuel consumption or reduced engine output at high loads. Mechanically controlled (MC) engines are more vulnerable to these effects than electronically controlled (ME) engines.

- Mitigation | Confirm calorific value before use, and optimize engine settings (e.g., ignition timing) if necessary to minimize performance loss. Lubricity improvers can also be used to prevent mechanical wear.

7. Need for Additional Testing and Risk Assessment

Unlike petroleum-based fuels, FAME contains oxygen, which can cause oxidation, corrosion, and microbial growth. Compliance with international

standards (e.g., ISO 8217) alone is not sufficient to guarantee safety; additional testing is strongly recommended.

Test Type	Distillate Fuel + FAME	Residual Fuel + FAME	Remarks
Microbial Growth (IP 385)	✓		To measure risk of microbial growth
Copper Corrosion (ASTM D130)	✓	✓	To measure corrosiveness effect (Especially for higher FAME content in the fuel)
Steel Corrosion (ASTM D665)	✓	✓	
Chemical Species (GCMS)	✓	✓	To detect methanol, Fatty acids, Glycerine
Combustion Quality (IP 541)		✓	To measure ignition/combustion quality
Fuel Compatibility (ASTM D4740)		✓	Before switching fuels

These technical considerations demonstrate that biofuels are not merely “green fuels,” but require systematic management and preventive maintenance to ensure safe and reliable operation. For this reason, KR recommends conducting

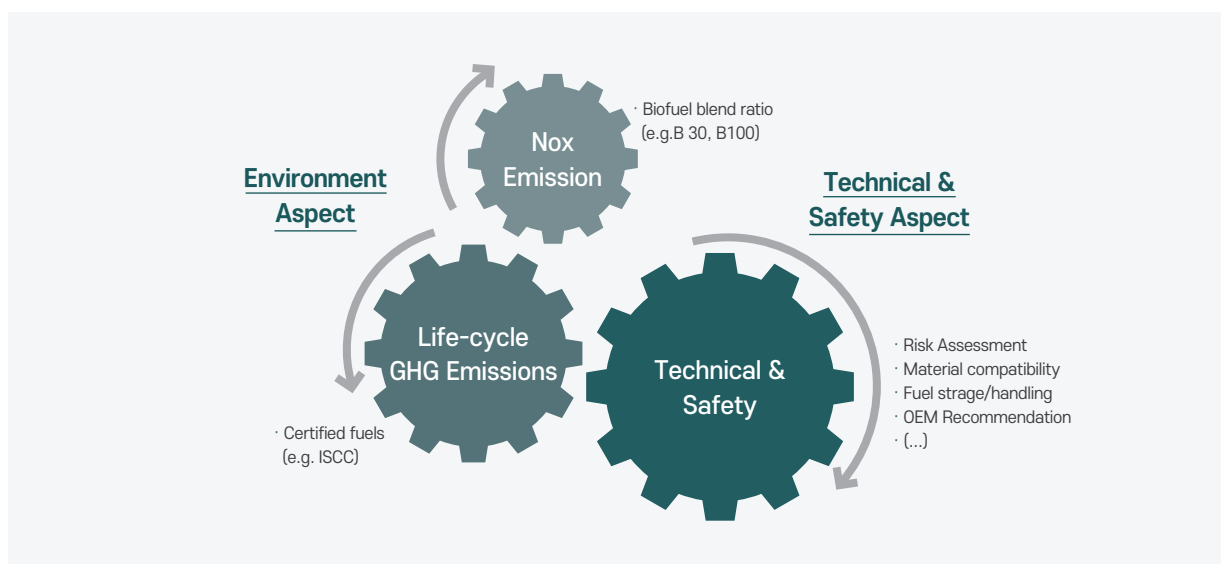
risk assessments. The table below summarizes key issues that should be considered during evaluation, and it is essential that shipowners and crew fully understand and prepare for these risks in advance.

	FAME / FAME + Distillate Fuel	FAME + Residual Fuel
Issue on Machinery Equipment	Manufacturer-recommended Measures	
	Material compatibility, e.g. Swelling of rubber components in the fuel piping system	
	Changes in viscosity, Density and Lower heating value	
Issue on Sludge and Fuel Deterioration	-	Asphaltene Sludge Generation
	Microbial Sludge Formation	
	Solidification of Biofuels	
	Sludge formation due to cleaning effect	
	Oxidative Polymerization (Fuel degradation by oxygen, Resulting in sludge formation)	

Safe Transition to Biofuels: KR Notation “SusBio”

In international shipping, the use of biofuels is no longer a choice but a necessity. However, the diversity of fuel characteristics and ongoing regulatory uncertainties continue to pose significant challenges for both shipowners and shipyards. Beyond the question of simple usability, the industry urgently requires clear standards that holistically address safety, environmental performance, and operational reliability.

To meet this demand, Korean Register (KR) is developing the “SusBio” (Sustainable Biofuel) notation. SusBio goes far beyond classifying fuels by blend ratios. It provides a comprehensive framework that encompasses life-cycle GHG verification, sustainability certification, NOx compliance, material compatibility, fuel storage and handling requirements, and risk assessment.



KR is also working in close collaboration with shipyards to prepare Standard Design Specifications optimized for biofuel use. By incorporating biofuel readiness at the newbuilding stage, this approach aims to preemptively reduce the additional costs and risks that could arise during future fuel transitions. In parallel, KR is strengthening its technical cooperation with VISWA Group, a leading marine fuel analysis company, to ensure that clients receive the latest insights

and data in a timely manner.

Ultimately, the successful adoption of biofuels cannot be achieved by any single player. It requires the alignment of multiple stakeholders: robust safety standards from classification societies, design standardization by shipyards, assured fuel quality from suppliers, and operational expertise from shipowners. 

KR Decarbonization Magazine

Interview

Navigating Decarbonization:
Danaos Shipping's Strategic Response

Ms. Evi Politi, R&D Director of Danaos Shipping





Navigating Decarbonization: Danaos Shipping's Strategic Response

Ms. Evi Politi R&D Director of Danaos Shipping



In this exclusive interview for KR's Decarbonization Magazine, Ms. Evi Politi, R&D Director of Danaos Shipping, shares her insights on the company's strategic response to evolving environmental regulations, alternative fuel adoption, digital optimization, and crew training. The discussion highlights Danaos' proactive approach to sustainability and innovation in the maritime industry.

How is Danaos responding to EU ETS, FuelEU Maritime, and IMO mid-term measures?

The maritime industry is currently navigating a rapidly evolving regulatory landscape with challenging new requirements such as FuelEU Maritime, EU ETS, and IMO's mid-term greenhouse gas reduction measures. For Danaos, the EU ETS applies to approximately 19 vessels that call at EU ports, translating into an estimated financial impact of around \$12 million for our clients in 2025.

Regarding FuelEU Maritime, the compliance cost for 2025 is estimated to be approximately 30% of the cost incurred under EU ETS. However, starting from 2030 and at five-year intervals thereafter, the cost trajectory increases exponentially, posing a significant long-term financial burden for operators and charterers. As of now, we have not observed any direct impact on vessel operations, and our commercial agreements remain unaffected.

Concerning IMO mid-term measures, these are expected to translate into an effective penalty of approximately \$200 per metric ton of VLSFO by 2030, increasing to around \$500 per metric ton by 2035. While these figures represent a substantial added cost, we consider them manageable, especially when compared to past fuel price inflation levels experienced during economic crises. We believe this cost can be handled by shipping companies up to 2035.

Do you think the financial burden of these regulations will be transferred to the end user?

Yes, we believe that ultimately the cost will be transferred to the end consumer. Under EU ETS, our clients are responsible for covering the cost, and the same polluter-pays principle applies to FuelEU Maritime. We are currently finalizing our contractual agreements with clients regarding FuelEU Maritime clauses. For IMO regulations, we expect the same principle to be valid.

What is Danaos' strategy for transitioning to alternative fuels such as biofuel, LNG, methanol, and ammonia?

Danaos has invested in newbuilding vessels that are methanol-ready and ammonia-ready from the design stage. In several newbuildings, we have prepared methanol tanks below the accommodation area to accommodate green fuel as soon as it becomes available. Our decarbonization strategy is detailed in our publicly available long-term carbon transition plan.

Currently, our clients are not absorbing the premium associated with transitioning to green fuels. Therefore, we have opted for methanol-ready configurations that allow us to retrofit vessels once green methanol becomes commercially available and financially supported by our clients. We are prepared to retrofit vessels to operate on either green or blue methanol, which, as advised by ExxonMobil, can significantly reduce our carbon footprint.

Given the rapid pace of technological advancement, it is not wise to invest in equipment that may become obsolete, especially when the corresponding fuel is not yet readily available. We have also used biofuels (B30) supplied by our customers without any issues. While we are positive about biofuels, they are considered a midterm solution rather than a radical decarbonization measure.

Which energy efficiency technologies are you applying or testing on your vessels?

Danaos has studied 38 energy efficiency improvement methods since 2013 and invested in many of them across our existing fleet. These include low-friction paints, propeller retrofits, propulsion improvement devices, engine tunings, and smaller measures in the engine room to enhance energy efficiency.

Regarding air lubrication, we have reviewed this measure but found its effectiveness limited, especially for container vessels. The fore and aft sections of the hull contribute most to frictional resistance, and maintaining a stable air layer is challenging due to vessel movements and rupture conditions. As a result, the limited performance benefits do not justify the required investment, and we have rejected this measure.

We also carried out bulbous bow optimizations years ago. It was among the first measures we applied, which yielded very good savings.

After implementing a wide range of retrofits and energy-saving measures across our existing fleet, we believe we've reached the limit of what can be achieved through incremental improvements. The next step involves more transformative changes, particularly the adoption of alternative fuels. Our priority is green methanol, followed by ammonia, although ammonia presents significant safety challenges due to its toxicity.

We are also actively exploring carbon capture systems as a midterm solution for decarbonization. In fact, we are developing our own system, which is currently undergoing the approval process.

Do you agree that increasing the carbon tax could accelerate the energy transition?

Yes, increasing the carbon tax would certainly mobilize stakeholders to proceed with necessary investments and finance the carbon transition. It would accelerate the transition process.

Can you tell us about Danaos' digital optimization efforts?

We have developed a sophisticated data analytics platform that incorporates proprietary algorithms for operational profile analysis, emissions monitoring, and forecasting. Additionally, we have implemented an internal carbon pricing tool to assess the financial impact of emissions and support data-driven decision-making.

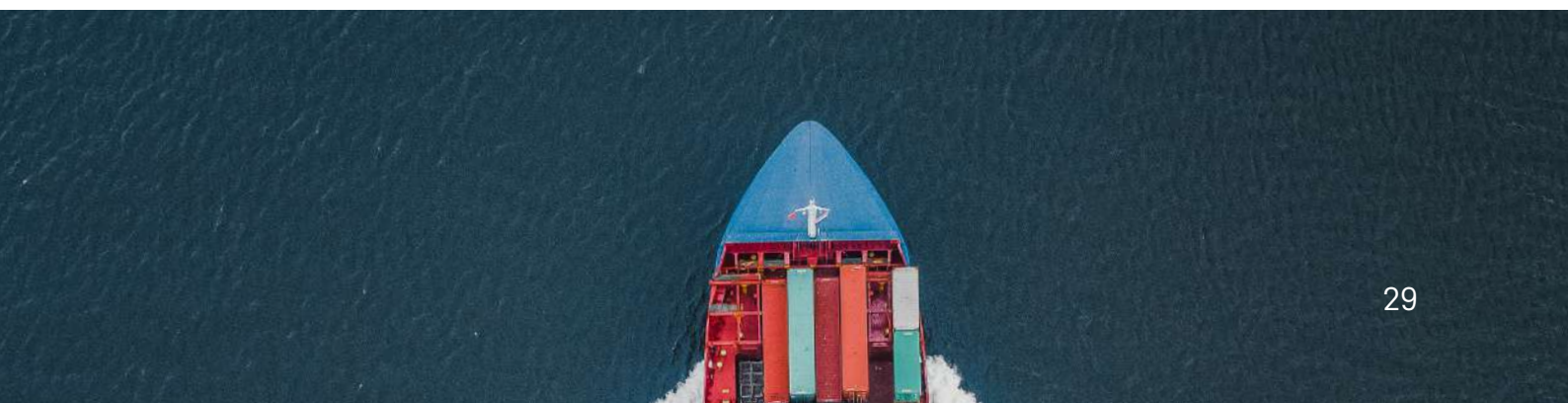
Our digitalization plan extends beyond environmental analytics. We are in the process of fully digitalizing all company processes, including technical operations, safety management, commercial operations, and accounting. Our goal is to complete this transformation by 2027 to enhance efficiency and transparency across all departments.

Regarding weather routing, we primarily follow our charterers' instructions. Our affiliate company has developed a weather routing software applied to several of our vessels.

How could the USTR-imposed fees and geopolitical developments affect Danaos?

For Danaos, the commercial impact of USTR-imposed fees is indirect. All our vessels operate under charter party contracts, meaning such fees are contractually borne by our charterers. The US container trade accounts for approximately 20% of global container volumes, typically served by vessels ranging from 6,000 to 13,000 TEUs. Liner companies can serve the US market using non-Chinese-built vessels if necessary.

"Any additional costs from these fees are expected to be passed through the supply chain to the end consumer. Regarding the dry bulk segment, Danaos exclusively owns and operates capesize vessels that do not engage in US-related trades, so there is no evident impact."



What is Danaos' view on the potential emergence of US-based shipbuilding and the MASGA initiative?

When participating in newbuilding bids, the preference of our charterers and the vessel price are key factors. Charterers may request specific vessel sizes and show preferences for certain yards, such as Korea, Japan, or China. Ultimately, it depends on the client's preference and the competitiveness of the price. If a US shipyard offers a competitive price, we would consider it, but we are not confident they can compete with Korean or Chinese yards.

What is Danaos' approach to small modular reactors?

Small modular reactors are gaining attention as a low-carbon solution. While we remain open to exploring nuclear energy, the current international maritime nuclear regulatory framework is complex and underdeveloped, posing significant legal, safety, and liability challenges. Additionally, nuclear propulsion faces strong public opposition and concerns about radioactive waste management, which hinder its near-term viability. It may be considered in the future, but we are not close to applying this solution onboard at present.

How is Danaos preparing its crew for new technologies and fuels?

Danaos' commitment to equip seafarers with necessary knowledge and skills is fulfilled through two primary channels. We have pre-boarding familiarization, and the key topics covered include regulatory impact overview, energy efficiency enhancements, digital optimization tools, and global policy updates.

We also have our online training platform. This is a dedicated platform that seafarers can access, offering a curated selection of both market-wide and Danaos-customized courses. Among these are introductions to new fuel types, the IMO greenhouse gas reduction measures, and the safe operation of exhaust gas scrubbers—for instance, when they were first installed, among other topics. In line with the established training framework we have, crew members will receive targeted training on green fuels and technologies once the decision to implement a green retrofit is made.

"Of course, I agree with you that comprehensive training is essential to ensure the successful and safe application of new fuels and technologies on board.

This is of imperative importance to us—the human factor and how we will be able to be part of the decarbonization process."

What kind of support or collaboration would Danaos like from classification societies such as KR?

Classification societies are strategic partners in the decarbonization effort. KR could support us during the newbuilding stage as a technical advisor and in the approval process of alternative fuel-ready designs. We are also interested in collaborating on joint industry projects related to carbon-neutral technologies and fuel lifecycle analysis. Additionally, we would be keen to explore digital notations for vessels that meet criteria related to digitalization and smart technologies.

We have also collaborated with KR on innovative training tools. For example, KR personnel recently visited one of our vessels to capture virtual reality imagery for the KR Real-360 platform, which supports crew training and vessel familiarization. We welcomed this initiative as it reflects the strong and constructive partnership between Danaos and KR.

Do you have any expectations or cooperation plans with Korean shipbuilders?

We have a long-term cooperation with Korean yards and have built many vessels there, including the latest Daehan vessels with KR. We are willing to continue our shipbuilding activity in Korea, provided the financial criteria are met.

In recent years, workforce challenges in Korean shipyards, together with the rapid progress of Chinese yards, have intensified competition. This has made cost an increasingly important factor in newbuilding decisions. However, beyond cost, our choices will also take into account a range of elements—such as quality, technology, reliability, and the specific nature of each project—with Korea continuing to stand out as a highly valued partner for advanced and high-value projects. 

[Editor's Note] This interview was conducted prior to the MEPC ES, where the adoption of the NZF was delayed.

KR Decarbonization Magazine

Regulatory Updates

| IACS Trends |





| IACS Trends |

IACS Trends

The IACS withdrew Unified Requirement (UR) H1 as of January 2025, following the completion of the draft IMO Interim Guidelines for the Safety of Ships Using Ammonia as Fuel at the 10th session of the Sub-Committee on Carriage of Cargoes and Containers (CCC 10), as the draft is expected to be approved at the 109th Session of the Maritime Safety Committee (MSC 109) and IACS UR H1 was found to have gaps compared to the provisions of the Interim Guidelines.

Currently, IACS is developing various URs and Unified Interpretations (UIs) to supplement the IMO Interim Guidelines for Ammonia-Fuelled Ships.

In addition, IACS has revised UR M77 to allow the use of aqueous ammonia as a reductant in Selective Catalytic Reduction (SCR) systems based on risk assessment and in consideration of the IMO Interim Guidelines. This amendment provides a regulatory basis for utilizing aqueous ammonia generated on ammonia-fuelled ships as a reductant for emission control.

Furthermore, IACS is developing guidelines that cover a wide range of alternative fuels and technologies, including methanol, hydrogen, batteries, carbon capture, and gas dispersion analysis. 

KR Decarbonization Magazine

Inside KR

KR Approves Ammonia-Fueled Ship Safety Solution
'Hi-CLEARs' Developed by HD Hyundai

KR Grants AIP to HD Hyundai's LNG Boil-off Gas Treatment System

KR Approves 'IMO Type-C Tank Design Based on Engineering Critical Assessment'
Jointly Developed by HD Hyundai Mipo and HD KSOE

KR and HD Hyundai Samho Launch Joint Development of
Ammonia Fuel Piping Safety System

KR Grants Approval in Principle (AIP) for SHI's "SnapWindFloat", a 15MW Floating
Offshore Wind Substructure

KR Grants Approval in Principle for Hanwha Engine's Ammonia Fuel Supply System



INSIDE KR

Gastech 2025 Highlights ◆

KR participated in Gastech 2025, the world's largest energy exhibition and conference, held in Milan, Italy, from 9 to 12 September 2025. During the event, KR achieved multiple cooperation outcomes, including Approvals in Principle (AIPs) and joint agreements with shipyards, equipment manufacturers, and flag administrations.

KR Approves Ammonia- Fueled Ship Safety Solution 'Hi-CLEARs' Developed by HD Hyundai



KR has granted Approval in Principle for the ammonia-fueled ship safety solution 'Hi-CLEARs'. The system was developed in collaboration with HD Hyundai Heavy Industries and HD Korea Shipbuilding & Offshore Engineering and was announced at Gastech 2025.

The approval is the result of a joint development project aimed at overcoming safety and regulatory barriers to the commercialization of ammonia-fueled vessels and at laying the groundwork for future international technical standards. The newly developed Hi-CLEARs is a safety-enhancing system that swiftly captures any ammonia gas leaked during operation, converts it into aqueous ammonia, and uses it as a reductant in an SCR (Selective Catalytic Reduction) system. This innovative solution not only eliminates potential ammonia leakage but also achieves a 'Zero Discharge' of ammonia to the atmosphere and sea, earning recognition as a breakthrough technology.

KR took a central role in amending IACS Unified Requirement M77, which governs the application of SCR systems on ships. The revision, based on risk assessment, now permits aqueous ammonia and ammonia itself to be used as reductants, where previously their use was restricted. This change provides the technical foundation needed for the commercialization of Hi-CLEARs and demonstrates KR's commitment to shaping international safety requirements. 



KR Grants AIP to HD Hyundai's LNG Boil-off Gas Treatment System

KR has granted an Approval in Principle for an LNG Boil-off Gas (BOG) Treatment System jointly developed by HD Hyundai Heavy Industries and Donghwa Pneutec at Gastech 2025. The AIP, awarded in cooperation with the Liberian Registry, is based on a concept proposed by HD Korea Shipbuilding & Offshore Engineering (HD KSOE).

The newly developed BOG treatment system is designed for installation and operation both onboard vessels and along quays during berth. It can process up to 0.5 tonne of BOG per hour, converting it into city gas for onshore energy use.

This enables shipyards to recover BOG generated during vessel construction, thereby reducing both greenhouse gas emissions and fuel losses. Shipowners, in turn, can safely manage surplus gas during extended port stays or when Alternative Maritime Power (AMP) is required, ensuring compliance with increasingly stringent environmental regulations.

The joint development project was completed through close cooperation between the shipyard, equipment manufacturer, classification society, and flag administration, building upon HD KSOE's concept design. In June 2025, the system was applied to an 8,000 TEU LNG dual-fueled containership under construction, where it successfully completed demonstration trials, verifying its performance. 



KR Approves 'IMO Type-C Tank Design Based on Engineering Critical Assessment' Jointly Developed by HD Hyundai Mipo and HD KSOE

KR has awarded Approval in Principle to HD Hyundai Mipo and HD Korea Shipbuilding & Offshore Engineering for their IMO Type-C tank design applying Engineering Critical Assessment (ECA). The AIP was announced during the Gastech 2025.

This project is part of ongoing efforts to address the growing demand for eco-friendly fuels and cargoes such as LNG, ammonia, and hydrogen. These fuels are stored and transported under high-pressure and cryogenic conditions, and in particular, for small and medium-sized gas carriers and bunkering vessels, achieving both efficiency and safety in tank design has become a critical challenge.

To meet these technical challenges, the three parties have developed procedures to apply ECA-based structural integrity assessment methods from the early design stage of IMO Type-C independent tanks. This methodology enables the prediction of crack propagation in metallic structures and provides a structural safety analysis throughout the tank's operational lifetime under real service conditions.

As part of the project, HD Hyundai Mipo evaluated the structural and fatigue strength of the tank, while HD KSOE led the tank design and structural integrity assessment. KR conducted a comprehensive review of the design in accordance with its classification rules and international regulations, which enabled the issuance of the AIP. 



KR and HD Hyundai Samho Launch Joint Development of Ammonia Fuel Piping Safety System

KR signed a Memorandum of Understanding with HD Hyundai Samho at Gastech 2025. The two companies will jointly develop a water circulation system for the double-wall pipe annular space of ammonia-fueled vessels, aiming to enhance the safety of next-generation ships powered by ammonia.

Ammonia fuel pipes are designed with a double-wall structure, leaving a ring-shaped annular space between the inner and outer pipes. This joint development project seeks to circulate freshwater through this space to enhance the safety of fuel supply piping and minimize potential leakage risks to the atmosphere during operation. Under the collaboration, HD Hyundai Samho will be responsible for system design and development, while KR will verify its safety.

Once completed, HD Hyundai Samho plans to apply the system to its ammonia-fueled ship designs and advance its commercialization. KR, for its part, intends to propose the need for relevant safety standards to the International Maritime Organization and continue its role as a proactive contributor to international rulemaking on alternative fuels. 



KR Grants Approval in Principle (AIP) for SHI's "SnapWindFloat", a 15MW Floating Offshore Wind Substructure

KR has awarded an Approval in Principle (AIP) for Samsung Heavy Industries' newly developed "SnapWind Float", a next generation floating offshore wind substructure capable of supporting 15MW turbines.

Leveraging its extensive offshore project experience, SHI has designed the "SnapWindFloat," a floating substructure capable of supporting up to 15MW offshore wind turbines. The design incorporates lightweight and modular features for easier construction and installation. It is stabilized by a minimum of three mooring lines fixed to the seabed, ensuring safety, and is designed to maintain sufficient stability even under slightly inclined conditions. The structure is also compatible with various turbine capacities, enabling a high degree of versatility.

KR conducted a comprehensive review of the "SnapWind Float", evaluating its safety, structural strength, and mooring system in accordance with international standards and classification rules. 



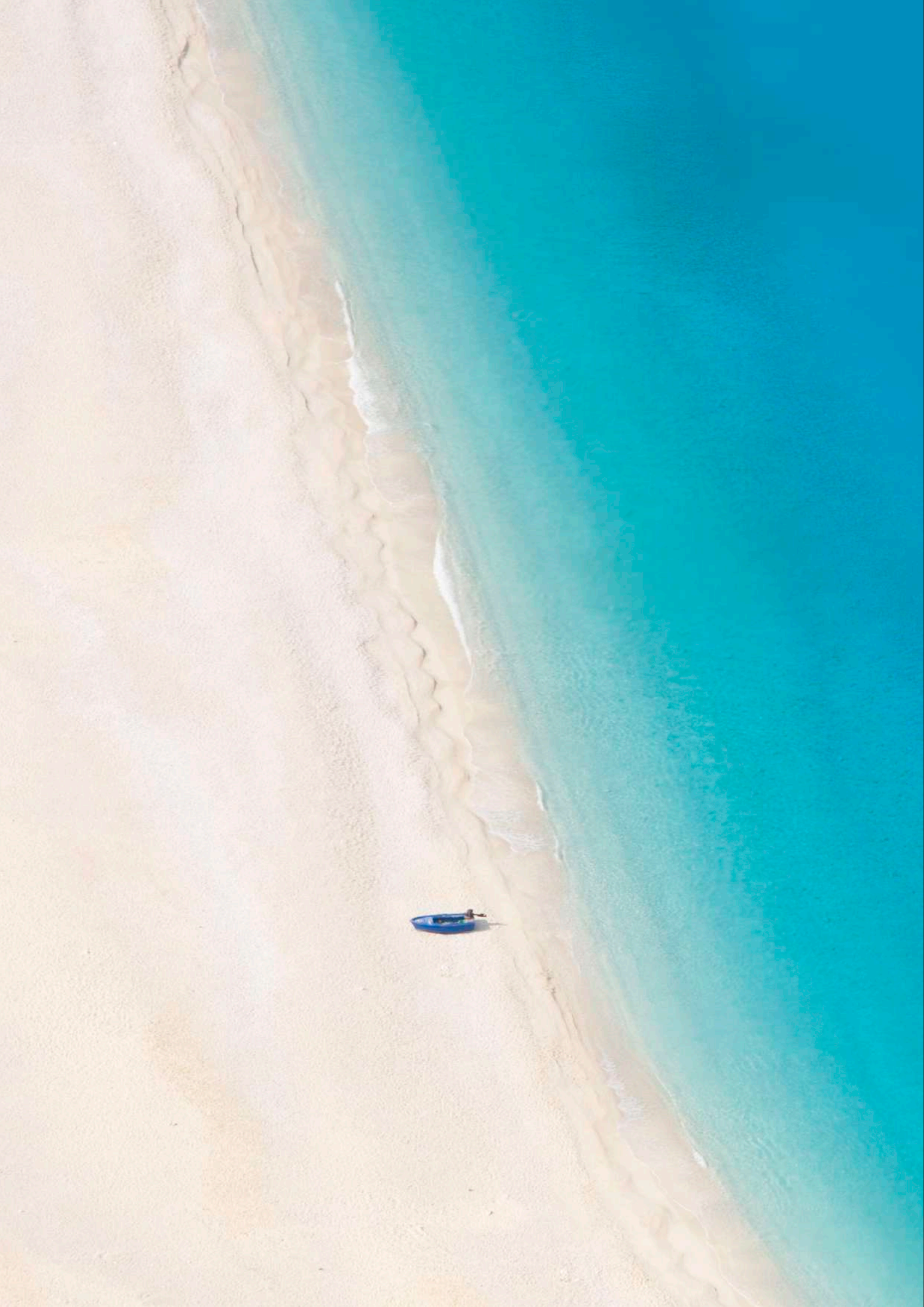
KR Grants Approval in Principle for Hanwha Engine's Ammonia Fuel Supply System

KR grants Approval in Principle (AiP) for the 93K VLAC Ammonia Fuel Supply System (AFSS) developed by Hanwha Engine.

The AFSS is a core system that ensures the stable supply of ammonia fuel to the engines of ammonia-fueled vessels at the required temperature, pressure, and flow rate. It is an essential system for the operation of ammonia-powered ships.

Hanwha Engine's AFSS, which has received AiP, enhances operational efficiency through optimized component layout and applies purging technology to minimize residual ammonia within the system. This significantly reduces the risk of harmful substance exposure for workers during maintenance.

KR granted the AiP after a comprehensive review of the system's design in accordance with class rules and international regulations. 



In line with our enduring commitment to protecting the natural environment, KR provides comprehensive survey and certification services for renewable energy sectors, including wind and ocean power.

At the same time, KR continues to advance green ship technologies aimed at reducing emissions and optimizing fuel efficiency — helping our customers achieve their environmental goals through practical, sustainable innovation.

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KR Decarbonization Portal



GHG Data Management System
KR GEARS