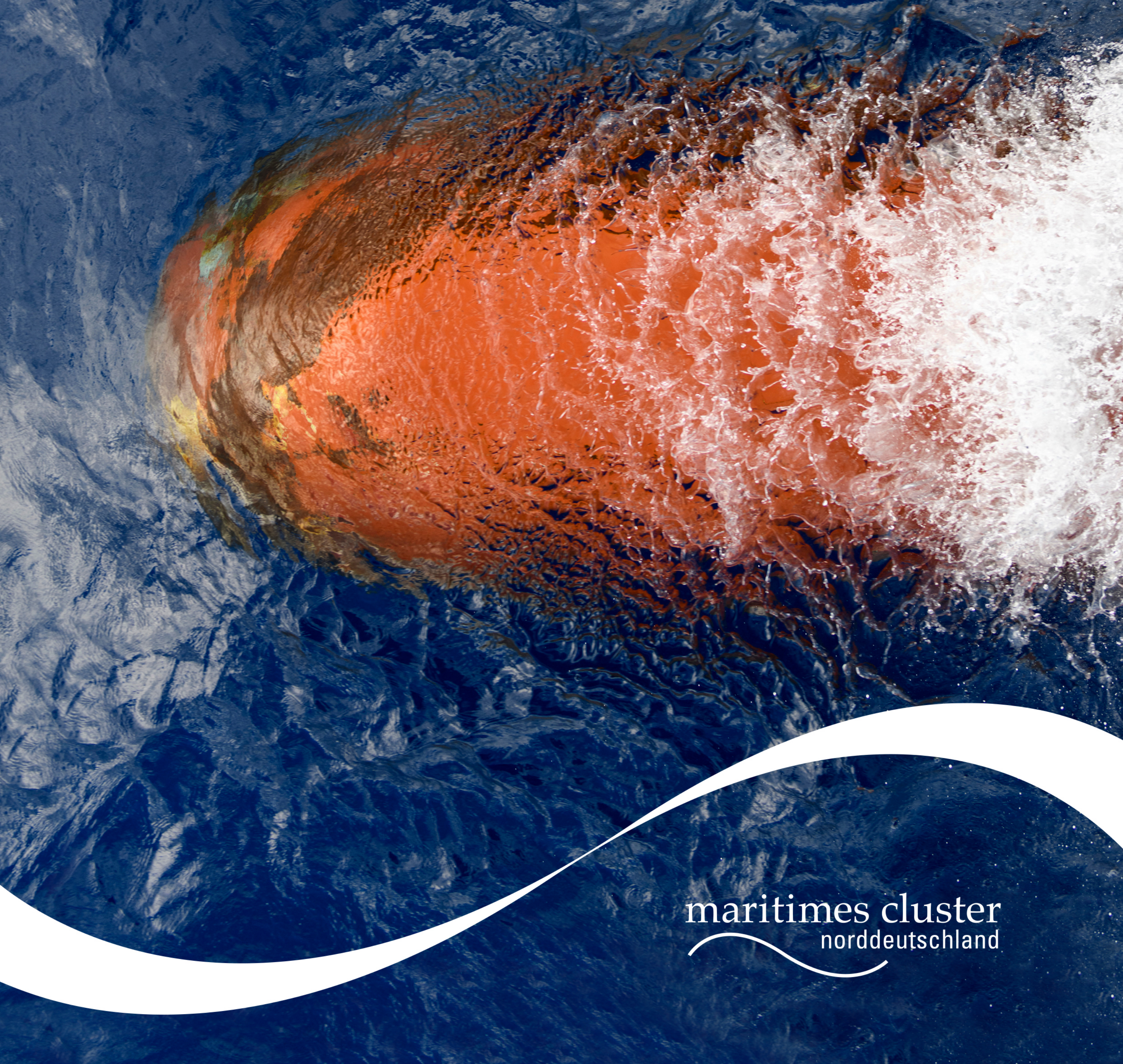
The MCN 2024 Guide

Ship Efficiency in the Context of international Emission Regulations



maritimes cluster
norddeutschland

Content

1. Opening statement from the Chairman and the Managing Director of the Maritime Cluster Northern Germany

Dear readers

The maritime industry encompasses a diverse range of sectors, including shipbuilding, suppliers, marine technology, shipping, offshore and more. It holds immense potential for future growth and development. The maritime industry is a key sector in Northern Germany and will play a significant role in shaping the region's future economic development.

The Maritime Cluster Northern Germany (MCN) is committed to fostering collaboration within this industry through the promotion, facilitation and consolidation of cooperation. We facilitate collaboration between partners across state and federal borders. We promote cross-industry collaboration and innovation. We assist with the identification of innovation partners, provide guidance on funding opportunities and arrange contacts within the maritime industry.

The MCN is a maritime network comprising more than 350 members from a range of business, research and political backgrounds. Our regional offices in Bremen, Hamburg, Lower Saxony, Mecklenburg-Western Pomerania and Schleswig-Holstein provide comprehensive local presence and convenient access to our services.

The issue of climate change is currently a topic of great concern for all. Climate change represents one of the most significant challenges facing the world today, and this also applies to international shipping. At MCN we are actively engaged in the pursuit of a more sustainable and environmentally conscious global fleet. In the coming years a number of new sustainability and climate-focused regulations will come into force. In light of the ongoing advancement of technology, it is essential to conduct regular reviews of the policy in order to ensure its continued relevance and effectiveness.

Considering these challenges, the MCN, in particular the MCN Ship Efficiency specialist Group, has taken the initiative to develop this Ship Efficiency Guide in 2022 for the first time. This document, which has been created through a joint effort by members of the specialist group, technology providers and external experts, provides an overview of technical options for improving ship operations. It is intended to serve as a basis for fulfilling the IMO's regulatory requirements and in the interests of more efficient and sustainable shipping and is aimed at shipping companies, ship operators and other key stakeholders.

We would like to extend our gratitude to all the authors who reviewed the existing guide and to the new authors, who learned about the guide and were willing to contribute. We would also like to thank the MCN specialist group on Ship Efficiency for their commitment, knowledge, time, strength and energy in creating this second update of the guide.

Prof. Bastian Gruschka
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2. Editorial

Shipping, and in particular the technical aspects of shipping, are highly represented by the members of the Maritime Cluster Northern Germany. Among these are companies with a long tradition and high expertise as maritime suppliers, engineers or naval architects working on the technical enhancements of ship-related technologies within international projects. The field of sustainability in shipping and the active support for all members on the way towards a reduction of emissions is part of the vision and mission of the MCN and is an integral part within MCN's current strategy. To facilitate collaboration, MCN established the specialist group Ship Efficiency in 2014. Such concentrated expertise is crucial for achieving ambitious environmental goals set by authorities and shipping companies.

The shipping industry still faces significant pressure to meet stringent international targets by IMO and other regulations set by the EU and other entities. Regulations such as EEXI, EEDI, and CII aimed to enhance the efficiency of transport operations, resulting in vessels sailing 10-30% slower than in previous decades depending on their size and type. However, the adoption of new fuel types has been slow. Traditional fuels like Heavy Fuel Oil and Marine Gas Oil remained in the recent years more cost-effective compared to biofuels or e-fuels. Regulatory efforts, such as including shipping in the EU Emissions Trading System (ETS), have had some impact. Additionally, several proposals at IMO level suggest imposing fees on each ton of greenhouse gas emissions, providing more financial incentives to decarbonise - as every gram of CO_2 counts.

The upcoming FuelEU Maritime initiative in 2025 will further encourage shipping companies to prioritise their fuel sources, gradually increasing the use of alternative fuels. However, this shift may lead to higher energy prices in the future. As a result, the applicability of linear Business Case models for Efficiency Retrofits becomes questionable. Energy prices are expected to rise throughout the next decade and the industry needs to prepare for this.

In 2021 the steering committee, consisting of Dr. Lars Greitsch, Sigurd Hildebrand and Peter Mackeprang, initiated the development of a guide providing an overview of ship efficiency and associated regulations. The first version of the MCN Guide was released in September 2022. Since we, the current steering committee of MCN specialist group Ship Efficiency, took over in 2022, we have been working on several additions and updates concerning the document. While our goal is to create a comprehensive overview of most relevant technologies, it is important to note that our matrices are not exhaustive. In general, decarbonisation can be achieved by transitioning to less carbon-intensive or carbon-neutral fuels, avoiding emissions and by operating the vessels more energy efficient. As technology advances there is a need for updating this guide over time and we strive to conduct updates in regular intervals.

We decided to change the title of the document to 'The MCN 2024 Guide' to better reflect our intention to provide a detailed roadmap for stakeholders in the maritime industry. This title communicates our aim to facilitate actionable improvements in ship operations.

The MCN 2024 Guide covers the FuelEU regulation and provides an update of our fuel matrix. It introduces a chapter on alternative decarbonisation methods, including emissions capture. Ship efficiency remains the main topic with a new section detailing its evolution over recent decades, helping ship owners understand differences between today's vessels and those from a decade ago. Several technologies have been added to our technology matrix. Quantifying savings requires robust data strategies; thus, we've included a chapter on this topic. It is essential to consider various factors, rather than stating "X% saved," we focus on "X% of Y" saved."

On behalf of the author's collective the Steering committee of MCN specialist group Ship Efficiency

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3. Introduction – Shipping in the Context of Greenhouse Gases

As our economic world fully relies on international delivery chains and demands high transportation volumes, the shipping sector is an important backbone of the economy and has experienced significant growth in the past decades. Coming from about 0.2 billion tons in 1990, the container vessel fleet for example loaded 1.85 billion tons in 2020 [1]. This growth has been in parallel with a growth of cargo capacity of each vessel, seeing nowadays very large container vessels with a loading capacity of more than 24,000 containers (TEU). A similar shift in vessel sizes can be reported for other vessel types.

This leads to a favourable relation between transport volume and energy demand respectively emission volume. The shipping sector carries 90% of the worldwide transport volume and is responsible for about 3% of greenhouse gas emissions. This indicates a high efficiency compared to other modes of transport.

Nevertheless, the evaluation of ship efficiency and technologies for enhancing it were important key aspects in modern ship design. Long before talking about regulations, the shipping sector faced a significant challenge due to high fuel prices within several periods, for example the oil crisis in the early 1970's.

Looking back in history, the understanding of ship hydrodynamics targeting optimal transport efficiency led to numerous technical developments and in the end resulted in larger ship units under the key word "efficiency of scale".

However, to understand the influence of the supply chain as we rely on today, the structure of trade routes and their complexity must be considered. The large-scale vessels operating the main routes need to be supplied by smaller vessels from all sub hubs. So, to reduce the overall emissions, energy efficiency of all vessel sizes need to be assessed and finally optimised.

Moreover, everything happens under the influence of weather situations that cannot be compared with our theoretical understanding of ship hydrodynamics while observing a ship model just in its own wave pattern in the model basins. The consideration of even rough sea conditions forces the industry to prepare its vessels for the worst thinkable. This circumstance and the special safety regulations for an oceangoing vessel is the technical antipole to a single point-optimised design.

But ship design has learned how to deal with this multigoal design challenge, and the consideration of operational matrices has become a basic principle within the initial design process. This may limit the flexibility of certain ship designs when planning to operate them on different trade routes, but it certainly helps to increase efficiency.

In addition to all cost-driven factors and regulations, awareness of the significant impact of man-made emissions is bringing pressure on the issue of ship efficiency and transport-related emissions. It is the private customer who requests climate neutral transportation of the goods he intends to buy. Nowadays, also larger companies want to offer carbon neutral transportation to their end customers. A service that has started within smaller business sectors.

As a result, shipping companies must offer such transport capacities by using carbon neutral fuels with higher prices. And again, the demand for higher ship efficiency is a clear consequence.

It may be a mixture of all these different influences and the fact that a vessel built today will be in service for 20 up to 30 years, but efficiency was, is and will be a key topic of ship design and ship operation.

4. Existing and upcoming Regulations in International Shipping – an Overview

Rules for the shipping sector with a focus on ship efficiency have been discussed for many years within the International Maritime Organisation (IMO). Especially the situation that there was a demand on same rules for all flag states made the discussion more complex to avoid that ships would change flag towards flag states with lower standards. Unlike the Kyoto Protocol with it´s clear focus on CO_2, here the regulations are based on energy efficiency.

In 2011 three instruments to reduce CO_2 emissions were introduced by IMO with becoming mandatory on 1st January 2013. First, the Energy Efficiency Design Index (EEDI) which indicates the potential energy efficiency of a ship and is determined during the design phase of a new ship. Usually, it is determined based on model test data. Here just the technical standard of the vessel design is evaluated regardless any other influences on real fuel consumption, such as efficient operation. The EEDI is the ratio between the theoretical air pollution and the theoretical transport work capacity. The vessel must achieve a certain level of this ratio, as the required EEDI is and will be further reduced in several steps.

After launching of the vessel, the Ship Energy Efficiency Management Plan (SEEMP) is mandatory as well since 1st January 2013 and is set in order to monitor the continuous enhancement of energy efficiency in operation. Here, the IMO recommends the Energy Efficiency Operational Indicator (EEOI) in order to monitor the operational energy efficiency and to evaluate the effectiveness of the SEEMP.

Following the idea behind the EEDI and related to the EEDI reference lines, the Energy Efficiency Existing Ship Index (EEXI) was introduced to cover almost all existing vessels in service. The EEXI will be mandatory from 1st January 2023 and for all cargo and cruise vessels larger than 400 gross tonnage under MARPOL Annex VI. There are different reduction values for different vessel types and sizes leading to different required EEXI values with some corrections for special requirements such as ice class-based vessels [2].

Vessels not being EEXI compliant demand measures to make them compliant by 1st January 2023, with the most likely option being an engine power limitation (EPL) to meet the required EEXI level. Obviously, the remaining maximum speed of the vessel will be reduced by this measure which could require further measures in order to keep the vessel applicable for the desired purpose by enhancing efficiency.

The rules allow to consider this efficiency gain within the EEXI evaluation either based on model test or hydrodynamic simulations reported and approved by a technical file.

At MEPC 76 (June 2021), the IMO adopted amendments of the MARPOL Annex VI regulation. The amendments include a new regulation 28, which requires the demonstration of operational carbon intensity reduction through the Carbon Intensity Indicator (CII). The CII judges the carbon intensity of a merchant vessel based on the Annual Efficiency Ratio (AER]). The AER is defined as:

$$AER = \frac{Annual\ Fuel\ Consumption\ \cdot\ CO_2\ Emission\ Factor}{Annual\ Distance\ Sailed\ \cdot\ Capacity}\left[\frac{gCO_2}{tnm}\right] \quad (1)$$

It shall be noted that the capacity is generally defined as the summer deadweight. Only for cruise passenger ships, vehicle carriers and RO/RO passenger ship the technical cargo-carrying capacity is used. The rating of CII is determined by comparing the vessel’s individual AER in the year of compliance with the vessel’s baseline values. The baseline values are the average AER values for that vessel class in 2019 reduced by a certain factor which is defined by the year of compliance.

Depending on the outcome of this comparison, a vessel is rated as A, B, C, D or E. Where A stands for a very carbon efficient vessel, vessels rated as D or worse must agree an action plan with the regulators. Figure 1 illustrates the rating scheme and the limits set by the IMO. Figure 1 illustrates the rating scheme and the limits set by the IMO.

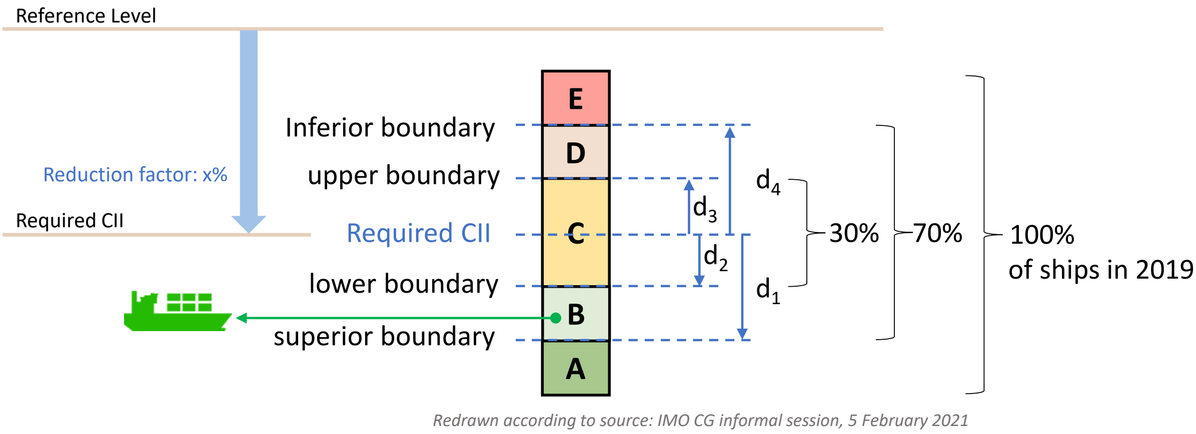

Figure 1: CII evaluation scheme [3]

The AER baselines are becoming more stringent over time, making it increasingly difficult to comply with the regulation. Table 1 shows the reduction factors of the current decade as they are defined by IMO so far (Jan. 2022).

Table 1: Reduction factors for CII compliance

Year	Reduction factor from 2019
2023	5 %
2024	7 %
2025	9 %
2026	11 %
2027-2030	To be decided

An AER value that would be as “C” in 2023 would receive a D rating in 2025 as figure 2 shows. In order to comply with the requirements, the vessel would need to undergo some measures. A study by the Korean Register indicates that more than 75% of the KR verified tanker and bulk carrier vessels would be rated as C, D or E in 2023 [4]. So, for a large part of the world fleet, it will be challenging to comply to the regulation and vessel operation will have to change to be compliant in the coming years.

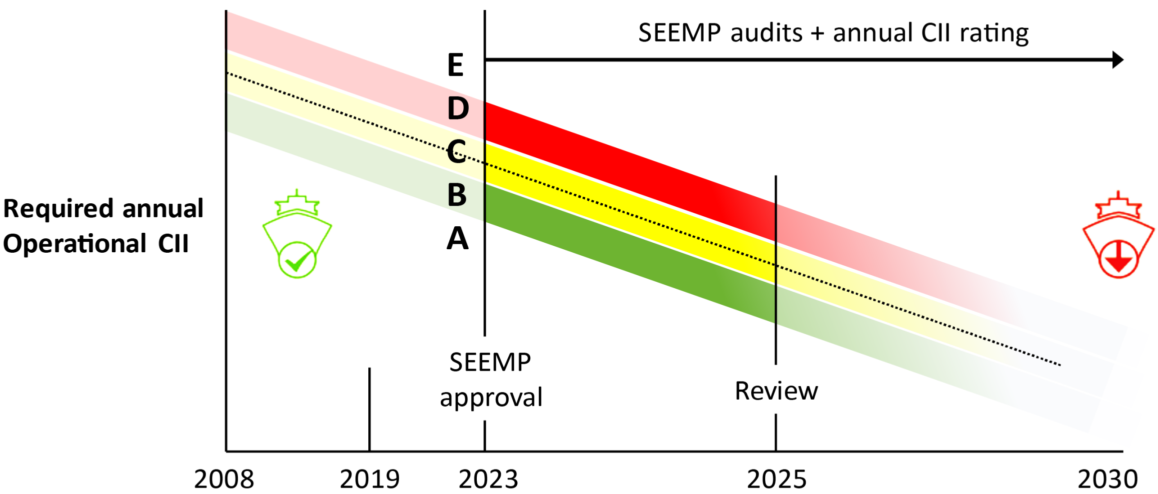

Figure 2: CII development scheme [5]

The annual CII and the recording of the annual rating is again based on the SEEMP. In case a vessel is rated D for three consecutive years or rated E, a corrective action plan has to be set up to show how the required CII rating (C or above) can be achieved. This could require different measures in order to boost the efficiency to subsequently become CII compliant.

As the CII is evaluated based on a theoretical cargo capacity and not based on the transported cargo as the EEOI, some countermeasures will not affect the rating. Nevertheless, there are numerous technical or operational measures that can be taken to make the vessel compliant again. This guideline tries to show and evaluate some of these measures within the Assessment Matrices Ship Efficiency.

In July 2023 the 80th, session of the IMO's Marine Environment Protection Committee (MEPC 80) adopted the 2023 IMO Strategy on Reduction of GHG Emissions from ships with enhanced targets to tackle harmful emissions. The revised IMO GHG Strategy includes an enhanced common ambition to reach net-zero GHG emissions from international shipping close to 2050, a commitment to ensure an uptake of alternative zero and near-zero GHG fuels by 2030 as well as indicative checkpoints for 2030 and 2040. The new targets include a 20 percent reduction in emissions by 2030, a 70 percent reduction by 2040 (compared to 2008 levels), and the ultimate goal of achieving net-zero emissions by 2050. New regulations are expected to enter into force around mid-2027. [6]

Impact of the European ETS on the shipping sector

The EU Emissions Trading Scheme (ETS) sets a price for greenhouse gas emissions. The aim of the measure is to significantly lower shipping emissions. The shipping industry will be incentivised to reduce their emissions and invest in climate-friendly technologies.

From 2024 all ships over 5,000 gross tonnes calling at European ports are included in the ETS. There is a three-year introduction phase. In 2024 40 percent of vessel emissions will require ETS certificates. In 2025 it will be 75 percent. From 2026 100 percent of the vessels greenhouse gas emissions will require corresponding EU ETS certificates. Voyages within the EU will need ETS certificates for all carbon dioxide emissions, whereas for voyages between EU and non-EU ports 50% of the emissions will be included in the ETS.

Whether smaller cargo ships or trawlers will also be included in the ETS is to be reviewed. In addition, the greenhouse gases methane and nitrous oxide will also be included in emissions trading from 2026.

The polluter-pays principle is applied. Ship operators will have to purchase emission allowances, either via the primary market which is through auctions at the European Energy Exchange or via the secondary market which means between market partners. The third way is to purchase derivatives from banks. There will be no free emission allowances! The inclusion of shipping in the EU ETS means that between 80 to 100 million additional emission allowances will come onto the market. The auctioning proceeds of 20 million emission allowances will go to the newly created Innovation Fund which will be used for shipping-specific projects. The remainder of the revenue will go to the EU member states and is allocated only for climate and energy-related activities. [7, 8]

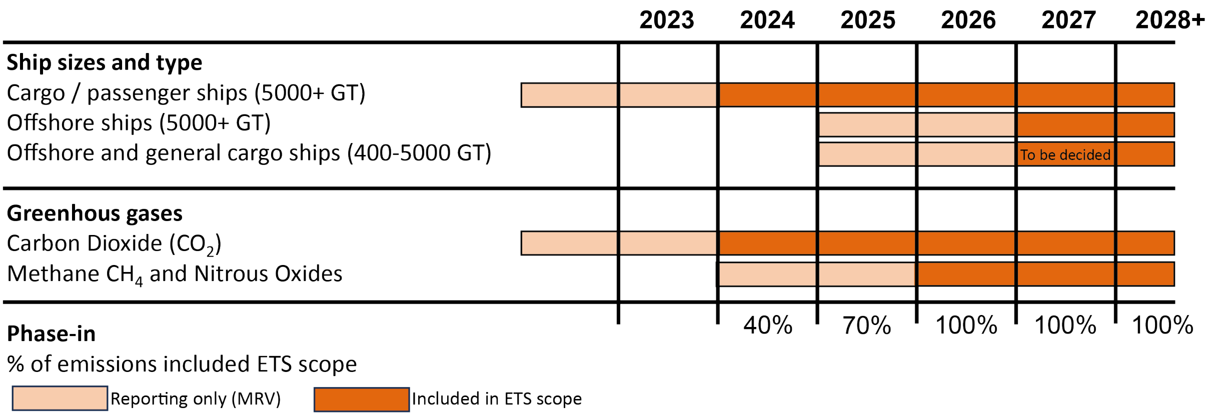

Figure 3: ETS schedule, according to [9]

The EU ETS measure is based on the EU Monitoring, Reporting, Verification (MRV), which entered into force on 1 July 2015, and was implemented from 2018. The main objective of the EU MRV regulation was to measure and to reduce CO_2 emissions from maritime transport.

Exemptions: Not included in the EU ETS are naval vessels, certain ice-class vessels, ships calling at islands with small populations or calling at islands in remote sea areas. Furthermore, ships performing public service tasks are excluded.

Assessment of alternative fuels: The EU ETS allows using a zero CO_2 emission factor for biofuels, renewable fuels of non-biological origin as well as fuels with recycled carbon that meet the sustainability and GHG emission saving criteria of the EU Renewable Energy Directive (RED). However, the EU has not yet finalised the delegated act which defines the rules for such fuels under the RED.

Companies that do not redeem their allowances will have to pay a penalty of EUR 100 per tonne of CO_2. However, they still must surrender their allowances. Companies that fail to comply with the EU MRV for two or more consecutive periods may be banned from accessing the EU for all their ships. Vessel emissions are going to have an increasing significance in chartering arrangements. Collection and exchange of data between shipowners and charterers to enable the compliance with the obligations imposed by the EU ETS will need to be addressed in charter party agreements. An allocation of responsibility for bearing the costs of compliance with the EU ETS, particularly in relation to the purchase of allowances under the scheme, will also need to be in place.

FuelEU Maritime

Background

While the inclusion of shipping in the EU ETS delivers a market-based measure that promotes improvements in energy efficiency, the European Commission understood that some instruments – such as carbon pricing or targets for the carbon intensity of activity – are not suited to bring about a significant shift towards renewable and low-carbon fuels, in the short and medium term.

Increasing the supply and distribution of such fuels is addressed by the EU Renewable Energy Directive (RED III) and Alternative Fuels Infrastructure Regulation (AFIR), the European Commission recognised that a tool that establishes increasing levels of demand for renewable and low-carbon maritime fuels was also necessary.

The FuelEU Maritime initiative is part of the Fit for 55 package aiming to enable the EU to reduce its net GHG emissions by at least 55% by 2030, compared to 1990 levels, and to achieve climate neutrality in 2050. The regulation lays down uniform rules imposing:

- a limit on the GHG intensity of energy used on board by a ship arriving at, staying within or departing from ports under the jurisdiction of an EEA country; and
- an obligation to use onshore power supply (OPS) or zero-emission technology in ports under the jurisdiction of a member state.

The FuelEU regulation was passed into law on 25 July 2023 and applies from 1 January 2025, with the exception of articles related to the required monitoring plan, which apply from 31 August 2024.

Application

To incentivise the use of renewable and low-carbon fuels on ships over 5,000GT, FuelEU sets targets that reduce the GHG intensity of energy used on ships based on 2020 reference levels. The energy use within the scope of FuelEU is similar to the scope of emissions covered under the EU ETS: half of energy use on voyages to and from EEA ports and all emissions for intra-EEA voyages and while at berth at EEA ports.

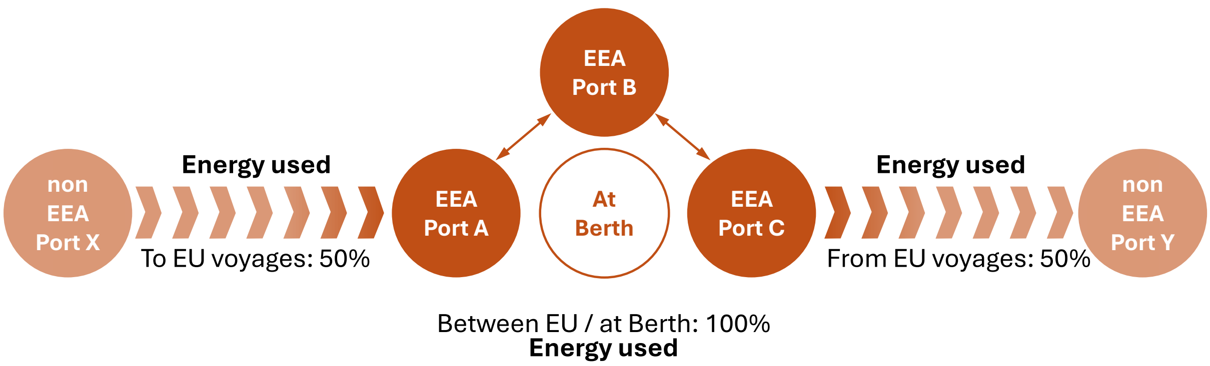

Figure 4: FuelEU basic principles © Lloyd's Register

The reduction required in the lifecycle GHG intensity of fuels under FuelEU – measured based on reported fuel consumption similar to EU MRV and the emission factors of the fuels used on a well-to-wake basis – will gradually increase over time, by 2% in 2025 to 80% by 2050. There will be a financial penalty for each quantum of energy used above the reference level.

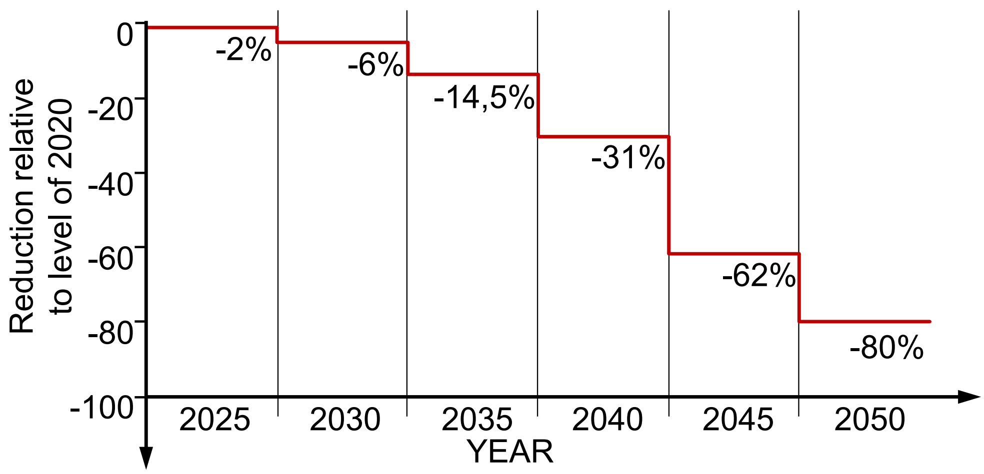

Figure 5: Reduction of GHG intensity © Lloyd's Register

The regulation includes a special incentive regime to support the uptake of Renewable Fuels of Non-Biological Origin (RFNBO). It not only clearly excludes fossil fuels, but also biofuels based on food or feed crops, allocating them an emission factor with no deductions.

To incentivise zero-emission port stays, passenger ships and container ships will be required to connect to onshore power supplies at major EU ports (TEN-T ports required to provide shore power under Article 9 of AFIR) from 2030 and all EU ports with onshore power supply from 2035. This will not be the case for stays of under two hours or if the ship uses zero-emission technology whilst at berth, amongst other derogations. Any port contraventions will also be subject to financial penalties.

FuelEU includes a voluntary pooling mechanism, under which ships will be allowed to pool their compliance balance with one or more other ships. Pooling can be done regardless of shipping companies, meaning it applies to a company's fleet or to pools of vessels owned and/or chartered by several companies. The pooling option in FuelEU means that companies investing in a low-carbon fuel capable ship could not only reduce their own exposure but would also be in a very strong bargaining position when offering to pool with other non-compliant vessels. However, depending on the type of charter party agreement the vessels were under, and especially where charterers are responsible for buying the fuel, care will be needed.

Like the EU ETS, FuelEU will also offer time-limited exceptions for the specific treatment of the outermost regions, small islands, and areas economically highly dependent on their maritime connectivity.

At the time of publishing there remain several unknown details around FuelEU compliance. Up to a total of 14 delegated and implementing acts are under development and will clarify specific elements of FuelEU Maritime.

Table 2: 6-Month schedule for FuelEU compliance © Lloyd's Register

Deadline	Event	Description
By January 31	FuelEU Report submission	shipping companies submit ship-specific FuelEU reports to the verifier
By March 31	Ship-specific FuelEU reports verified	submitted reports will be assessed and recorded in the FuelEU database by verifier
By April 30	Banking, borrowing and pooling request	shipping companies can bank, borrow or pool vessels and record it in the FuelEU database subject to approval by its verifier
	Requests approved / record updated	the selected verifier shall record in the FuelEU database the definitive composition of the pool and allocation of the total pool compliance balance to each individual ship.
By June 30	FuelEU Penalties payment	shipping companies shall pay FuelEU penalties to the administering authority resulting from 1) GHG intensity limit 2) non-compliant OPS port calls, and/or 3) RFNBO subtarget.
	FuelEU document of compliance issued	the verifier shall issue a FuelEU document of compliance (DoC) for ships without the need of paying any FuelEU penalties.
		administering authority shall issue a FuelEU DoC for the ships concerned, provided that an amount equal to the FuelEU penalties has been paid.
	A valid FuelEU DoC onboard	ships calling at an EEA port, arriving at, staying within or departing from an EEA port, or which have carried out voyages during the corresponding reporting period, shall hold a valid FuelEU document of compliance.

5. Performance Monitoring

5.1 Successful data measurement onboard

In times of AI and Machine Learning accurate data is of outmost importance for correct Vessel Performance Analysis. This chapter highlights critical aspects of sensors and communication system, as robust communication both within ships and between ships and land is essential and one should note that high data quality is a constant effort, as environmental conditions can change. Figure 6 shows the survey result from HullPIC (Hull Performance & Insight Conference) 2023, where 84 experts in the field participated. It clearly highlights the importance of regular calibration processes for important vessel sensors.

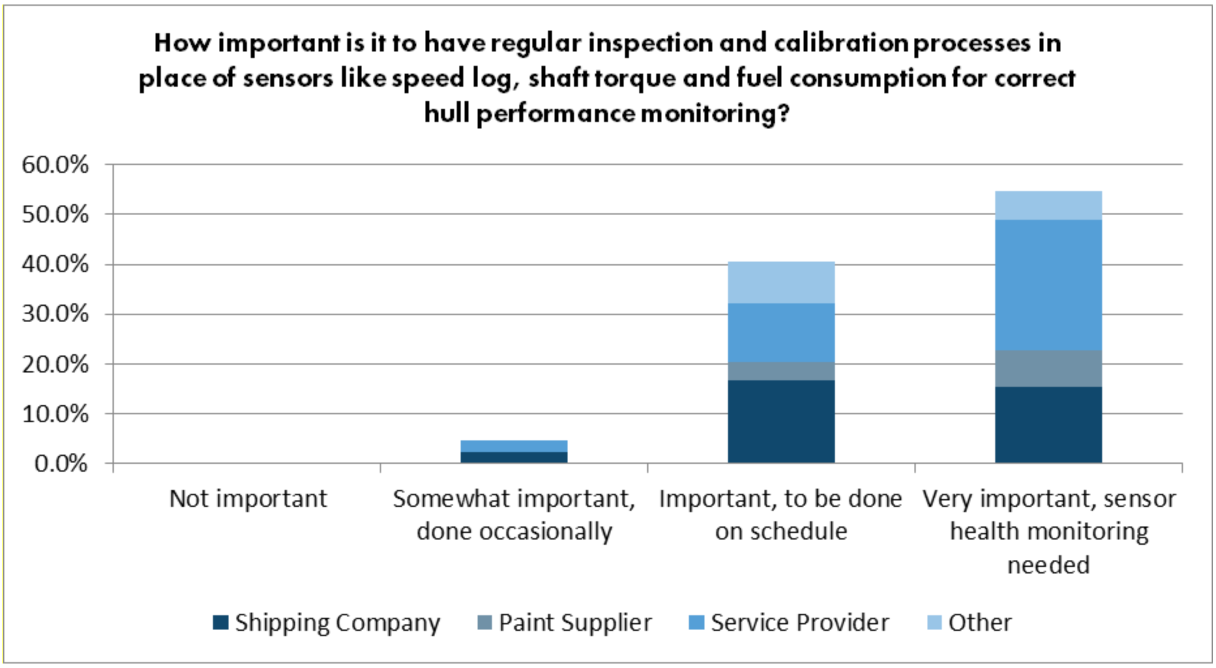

Figure 6: Importance of calibration processes ©Idealship

In the following the most important sensors onboard and the communication processes are explained.

5.1.1 Shaft power measurement

Shaft power measurement is an important part of marine engineering that makes sure the ships work well and safely. There are several established methods available for torque measurement and, by linking torque and shaft speed, for power measurement on ship shafts and each has its own benefits. Typical systems are using strain gauges, magnetic belts, steel wire sensors (vibrating strings) or optical techniques (Laser or LED). A key feature is the relative ease with which such devices can be retrofitted to ships already in service. All methods have in common that they use the ship's shaft directly as an elastic deformation body. The angle of twist, which will be generated by a deformation of the shaft during operation is the basis.

Accurate torque measurement on a ship's propeller shaft is challenged by alignment issues and shaft bending, which can distort the readings. One needs to understand that the harsh marine environment, including varying temperatures and high humidity, can affect sensor accuracies. Moreover, vibrations and noise from the ship's operation complicate measurements, requiring effective vibration isolation and noise filtering. Hence a regular maintenance and calibration as well as proper installation of the torque meter sensors, are crucial to ensure reliable data.

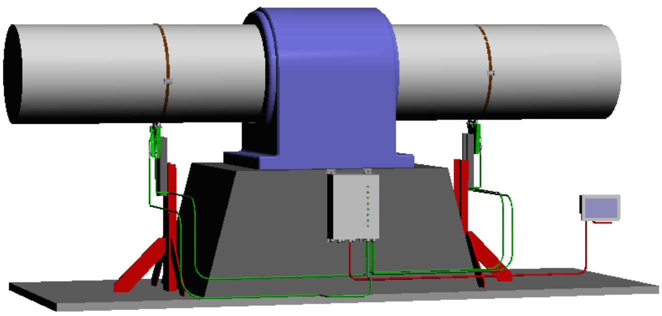

Figure 7: Example shaft power meter with magnetic belts, type TORXmeter by TX Marine Messsysteme GmbH

5.1.2 Fuel flow measurement

Fuel flow measurement is a critical component in the maritime industry, enabling efficient fuel management and optimisation of engine performance. For precise fuel flow monitoring, different measurement principles are used, each with their own benefits and applications. One either measures the volume or the mass of the fuel flow. In the field of volumetric fuel meters Positive Displacement Meters are renowned for their accuracy, when calibrated. These fuel flow meters are ideal for low flow rates because they divide fuel into fixed volumes. Direct mass flow measurement is possible with Coriolis Flow Meters. They accurately measure fuel density and flow rate, providing fuel management data and have been installed more and more frequently over the last decade.

Figure 8: Example of a Coriolis flowmeter manufacturer

Figure 9: Installation example Endress und Hauser

Accurate fuel flow measurement on a ship faces challenges due to variable operating conditions like changing engine loads and speeds. Also, these devices are impacted by the marine environment and vibrations issues mentioned above. So, a proper installation, regular maintenance, and calibration of sensors are crucial to ensure precise data collection over time.

5.1.3 Logged speed

According to the regulations of International Maritime Organization (IMO), ships are required to have a speed log on board to ensure safe navigation. Marine Doppler speed log, electromagnetic log and satellite speed log are three common speed measurement tools. The doppler speed log is known for its high accuracy. Many speed log devices require calibration on a regular basis, speed log measurement error. To determine the actual vessel performance the speed through water is of a much higher importance than the speed over ground. Also, ocean currents from satellite providers have a limited accuracy [10]. The logged speed measured onboard of the vessel is typically showing the performance trend of a single vessel in the best manner [11].

5.1.4 Data transmission Understanding Bus Systems in Maritime Operations

In the complex world of modern maritime operations bus systems and communication technologies are integral components that ensure the smooth functioning and safety of various types of vessels. Bus systems are essential for the efficient and reliable transmission of data and control signals across different systems and components on a ship. They must be robust enough to withstand harsh maritime environments. A bus system consists of data lines and control units. Information in the form of digital bit combinations is transmitted between individual control units via data lines. The control units filter out the information that is suitable for you and process it. Here are some reasons why bus systems are used:

- Simplification of Wiring and Connections: Bus systems reduce the amount of required wiring by allowing multiple devices to use the same transmission paths. Instead of connecting each device individually, all devices can communicate over a common bus.
- Cost Efficiency: By decreasing the number of physical connections needed, costs can be saved.
- Flexibility and Scalability: Bus systems offer flexibility when expanding systems.
- Standardisation and Compatibility: Many bus systems are based on industry standards.
- Efficiency in Data Transmission: Bus systems can be designed to provide efficient and fast data transmission between connected devices.
- Error Diagnosis and Management: In many bus systems, errors and issues can be centrally diagnosed, simplifying maintenance and troubleshooting.

These reasons make bus systems an attractive solution in many technical and industrial applications, from factory automation to communication within and between computers.

5.1.5 Data Transmission from Ships to Land

- Satellite Communication provides nearly global coverage.
- Cellular Networks (4G/5G) are effective near coastlines.
- HF Radio is useful for long-distance communication without satellites.
- LRIT and AIS support monitoring and coordination of ship traffic.

Security and privacy are paramount when transmitting data from ships to land. Encryption is essential to protect data from unauthorized access during transmission, especially over open networks. Furthermore, robust privacy policies are needed to regulate data storage, usage, and sharing.

Various problems can occur during data transmission, impacting efficiency and security:

Modern ships rely on bus systems for efficient and reliable data transmission, which must withstand environmental challenges.

- Electromagnetic Interference (EMI): Interferences that affect data integrity.
- Loosening Connections: Vibration can cause cables and connectors to loosen, resulting in intermittent or permanent transmission disruptions.
- Signal Attenuation: Signal loss over long distances, often requiring amplifiers.
- Congestion and Bandwidth Limitation: Too many devices or high data volumes can overload networks.
- Latency: Delays that are particularly problematic in real-time applications.
- Security Risks: Risk of cyber-attacks and data breaches with inadequate security.
- Hardware Failures: Defects in transmission media and failures in network components.
- Compatibility Issues: Difficulties integrating different systems.
- Weather Conditions: Impact on wireless transmission during poor weather.
- Transmission issues of wireless data transfer

Effective planning, technological solutions, and regular maintenance are crucial to addressing these challenges.

5.1.6 Conclusion about measurements

Determining the actual power on a ship's propeller shaft can be a challenging task as it depends on the environmental conditions, how well the system is made and how it was maintained in the past. Engineers need to take these aspects into account when calibrating the sensors or defining the maintenance schemes. This requires skilled personnel and training in how to take care of the specific sensors like flow meters, torque meters, speed logs and others. Collecting accurate data comes with an effort.

Furthermore, data communication needs to be reviewed. The choice of appropriate technologies and systems is dictated by specific operational needs, environmental conditions, and the necessity for integrating various onboard and shore-based systems. The evolution of bus systems and communication technologies in maritime operations reflects the industry's increasing reliance on digitalization and connectivity. As these technologies continue to develop, they promise to further revolutionize maritime operations, ensuring ships operate more safely, efficiently, and independently.

5.2 Guidance to benefit tracking of energy saving devices (ESDs)

5.2.1 Understand the current vessel’s performance prior to retrofit

When assessing ESD business cases, the impact on EEXI is often used as a reference. The EEXI relates to the Sea Trial performance of a vessel, reflecting the hull and propeller performance of the new build. The effect of the ESD is usually predicted through Computational Fluid Dynamics (CFD) calculations. This predicted effect can be considered in the EEXI calculations, and it is expected that the same impact will be observed on the vessel in operation. However, older vessels often operate under different engine conditions compared to when they were at sea trial. This difference is due to both biofouling and the natural aging process of the hull and propeller, such as wear and tear caused by sea impact over time. It should not be expected that the hull and propeller performance will return to its Sea Trial condition after dry-docking, though the impact of biofouling can be reduced through the application of a new paint. Instead, the actual condition of hull and propeller should be assessed in the main engine diagram. If the propeller is found heavy running or a heavy running condition is likely to occur due to the effect of the new ESD, such as a shaft generator retrofit, appropriate actions need to be taken. These actions may include a propeller retrofit or a trailing edge modification, as described in this document (chapt. 12.4).

5.2.2 Choosing the right performance indicator

The objective of any retrofit benefit tracking process is to conduct a fair comparison between the pre-retrofit and post-retrofit conditions. This necessitates the availability of high-quality data for both periods and the application of a performance indicator, a measure to determine the performance differences.

For some retrofits it is sufficient to use the average of the measured values, such as the change of the electric load, when an Energy Saving Device is in use. However, determining the effect of ESDs that aim to improve hull and propeller performance is more complex. Due to varying environmental conditions, the data needs to be filtered and corrected. Additionally, changing operational conditions, draughts, and speeds must also be accounted for.

Several different performance indicators have been developed in the past to determine the change of hull and propeller performance over time. ISO 19030 (2016) describes a standard methodology of hull and propeller performance assessments to analyse retrofit, maintenance and dry-docking effects [12]. This document uses Percentage Speed Loss as a hull performance indicator. There are several other methods and indicators available to track changes in hull and propeller performance, each with its own advantages and disadvantages, which are discussed in the literature [13].

Most performance indicators compare the observed performance with a baseline value. To determine the actual fuel savings, one first computes the average performance indicator during the pre-retrofit stage (reference period) and then the performance indicator during the post-retrofit stage (evaluation period). The difference in these performance indicators can be converted into fuel consumption savings.

5.2.3 Choosing the right periods

A hull and propeller retrofit is mostly done during a dry docking with a new paint. The biggest impact on the hull and propeller performance is usually imposed by the paint. Different paint types will show different performance characteristics within a dry-docking cycle. The paint performance characteristics can also vary enormously considering the fouling likelihoods of different operational profiles. To account for paint effects, appropriate periods must be selected for retrofit assessment and reference. ISO 19030 recommends to compare the average performance indicators from post-previous dry-docking with the values post-retrofit dry-docking, as illustrated below.

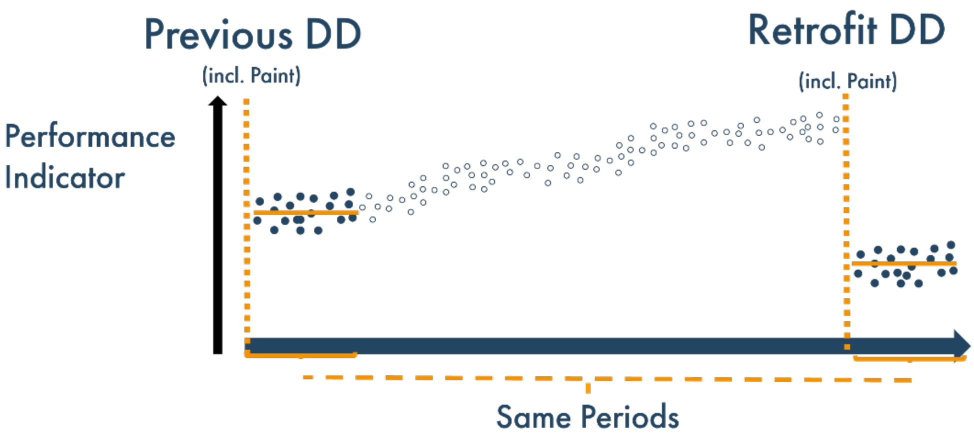

Figure 10: Periods to be used for hull and propeller improvements as per ISO 19030 [12]

When paint characteristics are similar, this approach can largely mitigate the impact of the paint. However, the availability of valid data from the previous dry-docking, typically five years ago, poses a challenge, especially when the vessel ownership has changed.

How to choose the reference and evaluation periods depends on several factors. This can be the type of retrofit, data validity, sufficiency of reference data and changes in operational conditions. If such data are unavailable, data from the last hull and propeller cleaning should be used as biofouling effects can have a large impact on the saving calculation. The chosen reference and evaluation period and how much paint effects are included needs to be clearly communicated to all stakeholders.

Typically, hull and propeller ESDs are installed during dry-docking events combined with new paint applications, making it challenging to separate savings between the paint and ESDs. Only Wind Assistance Propulsion Systems (WAPS) and ESDs that can be switched on and off, such as air lubrication systems, allow for performance comparisons by toggling the systems on and off.

5.2.4 Assessing the business case

In the context of an ESD installation it is important to achieve alignment within the various stakeholders on the ability to demonstrate the improvement benefits claimed. The time it takes to gain certainty on a retrofit success is often underestimated. The achievable levels of accuracies are well described in ISO 19030, considering different types of measurement technics. Measurement accuracy levels vary, and transient savings from devices like wind assisted propulsion require longer evaluation periods. Awareness of these timelines is crucial for setting realistic expectations.

Any business case is created with a certain expectation about the financial impact to the business. For ship operation this means that one needs to make an estimate of the fuel consumption profile that the vessel will have as well as the operational profile of the future. After the installation of the retrofit, the vessel will be operated depending on the new market conditions, which can lead to a different operational profile. Reviewing the business case by computing expected savings based on the actual operational profile helps to identify discrepancies between expected and actual savings, considering both propulsion performance and operational changes.

6. New training requirements

The purpose of the guideline is to understand and consider different approaches to reach the IMO 2050 target and reduce greenhouse gas emissions.

A missed link in all these considerations is, that there is still a crew on board that should take care of all new technologies and alternative fuels. This crew has to be well trained and skilled. Especially in the transition phase there is a big gap between knowledge and experience. To reduce the risks for crew and operator, changes in education and training have to take place. Therefore, during the commission of new systems, all stakeholders have to be included to guarantee safe operations. These stakeholders are:

- universities,
- academies for further education and training,
- the manufacturer of new technologies,
- the operators,
- the policy and legislator including NGO's.

These stakeholders must be involved about new hazards and the gaps between existing legislation and training requirements. Furthermore, it is important to stay up to date with forthcoming developments that may arise in the near future. This chapter is used to aware all players, to suggest solutions and to minimize gaps while transition phase and beyond.

Gap-Analysis

There are well-established courses for the usage of LNG according to the IGF-Code. But this code is only tailored for LNG as low flash point fuel. Only a few remarks are adoptable, e.g.:

- Ship construction (tank structure, pipelines...)
- physical/ chemical characteristics of the different fuels during
    - normal operation
    - bunkering
    - emergency preparedness
- IGF treats fuels with a low flash point below 60°C

Beyond these points IGF does not treat toxic gases and/or products of biofuels.

Beside the fuel a rising number of new technologies conquer the market. That covers electrification, storage of high voltage energy, exhaust gas treatment systems or wind assistant propulsion, without claiming a complete list. All these points lead to a new profile of competencies. They require new and widener knowledge coupled with a complex system understanding.

Currently, even the number of trained crew members for handling LNG is hard limited. Studies from IMO and other NGOs like classification societies point out a clear the existing gap between demand and availability of well-trained staff.

Suggested solutions

A two-level approach is necessary to overcome that problem. First of all, an acknowledged regulation framework must be created which is usable during training and work scenarios. Following the establishment of such regulations, it's crucial to develop specialized training courses to qualify available and experienced staff with the advanced technologies and fuels. That programme must be globally accessible and based on international standards from IMO.

Simultaneously, a second, more sustainable approach needs to start. Fundamental concepts of handling knowledge and skills must be implemented in the STCW's regulation as a fixed part.

Based on the diversity of solutions we need a coordinated schedule for universities/academies and companies. Currently, the universities/academies could only impart the basic knowledge for shipping and could not be complied with the permanent growing complexity of processes on board. Therefore, it is necessary to implement specific training courses that enable the crew members to fulfil the new requirements in connection with e.g. digitalisation and alternative fuels.

To train the large number of crew members we must launch that programme urgently due to the strongly limited quantity of training academies. The acceleration of implementation of alternative fuels highlights the next challenge in the race to become climate neutral.

Another important point about training is the information technology. More complexities within the network on board, the increased automation level and the linking to shore-based decision support lead to more and more requirements concerning the skills and knowledge in that field. Effective data protection is essential to ensure continuous security, safeguarding both the vessels and their crews. The threat of cyber piracy is set to play a significant role in the near future, especially as automation and computer-based processes become seamlessly integrated into everyday operations. To manage these processes, highly qualified staff are needed. The complexity and nature of these roles exceed the capabilities of the current crews and highlights again the need of training. For those business processes high qualified staff is necessary because such jobs cannot be performed by the currently existing crews.

Are we really ready for the future in shipping?

7. Effect of various Marine Fuels on more efficient and greener shipping

7.1 Overview

Seaborn transport is an integral part of our global society and provides prosperity, economic growth and global supply security for example through the transport of mineral resources, raw materials as well as semi-finished and finished products. In addition, luxury holidays and marine security, lifeguards and military protection are among the aspects of marine issues. From an economic and environmental perspective, maritime transport is the most effective and efficient way to move goods around the world. But: The global maritime transport sector is responsible for about 2.9% of global CO_2 emissions. In other words, more than one billion tons of CO_2 were released into the atmosphere in 2019 from shipping alone. Shipping also faces other types of emissions such as Sulphur dioxide, Nitrogen oxides, soot (a modification of Carbon) and other particle matters. The industry is making many efforts to get shipping cleaner. New IMO regulations on Sulphur and Nitrogen oxides, implemented in the MARPOL Annexes, are forcing ship owners to act to achieve a cleaner future. Existing and future regulations will help industry, operators and authorities to meet the ambitious targets of the Paris Climate Change Conference, COP 26, the

Kyoto Protocol, the Carbon Intensity Indicator (CII) and many others. All these commitments require intensive action in a short timeframe, but the solutions currently available are severely limited.

Actions: The use of alternative fuels reduces Sulphur dioxide emissions and particle matter. The use of selective catalytic reactors (SCR) plus urea-injection reduces Nitrogen oxides emissions by converting NO_x into water and Nitrogen. However, one component of exhaust gas is very hard to reduce or remove: Carbon dioxide. Carbon is one of the most important elements and a good energy carrier in combustible fuels. Liquid, carbon-based fuels are easy to handle, easy to store and to use within the combustion process. Low toxicity and reduced handling risks are very big advantages of using carbon-based fuels. Nevertheless, this element gets harmful to our climate when burned with oxygen and converted into CO_2.

CO_2 emissions can be reduced in several ways:

The first is to reduce gross consumption of carbon fuels. This can be achieved by increasing the efficiency of engines and equipment, maximising the use of fuel close to the highest possible efficiency. But these measures are severely limited by physics.

Another option is to capture the Carbon dioxide from the exhaust-gases and store it on board (Onboard Carbon dioxide Capture and Storage, OCCS) or in the plant for further options. Carbon dioxide capture and storage technologies (CCS) are already available. This type of emission reduction serves to remove the gas CO_2 from the exhaust gas. An open/remaining question is how to store and transport CO_2 on board a ship. Example: Burning one ton of carbonaceous fuel produces more than three tons of CO_2. This is also a payload and storage issue, and it consumes additional energy, e. g. when compressed or liquefied and for transportation. Finally, the problem is not yet solved, because the captured CO_2 has to be stored safely and in the long term.

The third solution are alternative fuels, either carbon-free fuels such as hydrogen or ammonia, or fuels made with Carbon dioxide from the air through direct air capture (DAC) or indirect air capture via growing crops and converting biomass into "bio-based" fuels. These fuels are so called “net-zero” emission fuels, meaning they don´t emit additional fossile CO_2. These types of fuels of course emit CO_2 (if they are carbon-based), but the total amount of CO_2 in the atmosphere remains nearly constant.

In selecting the fuels described in the matrix, the feasibility of each fuel for use on seagoing vessels was taken into account. However, the 2050 targets require a stronger pioneering spirit from all stakeholders in this challenge. The matrix aims to identify the key characteristics that are important for achieving the global goal of reducing CO_2 emissions in the first instance while maintaining competitiveness in current maritime transport.

Marine fuels have to fulfil many requirements, e.g.:

- high safety potential in regard of flash point, low explosion limits, non-toxic, no or low impact on crew and environment in case of leakage
- high energy density, small bunker volume
- easy bunkering, storage and handling up to the point of combustion
- worldwide availability, requiring a complete network of bunker stations and the corresponding fuel quantities
- no or less impact on the environment when it comes to emissions

- competitive fuels must be cheap to achieve low transport costs.

These aspects represent a challenge for shipping that must be successfully overcome to meet the above-mentioned requirements of global society.

7.2 Assessment Matrix Marine Fuels

The following fuels were used for comparison:

HFO, MDO, LNG, LPG, Methanol, Ethanol, Biofuel Oil (FAME), HVO, Ammonia cooled, Ammonia pressurized; Hydrogen liquid (LH_2), Hydrogen gaseous (GH_2).

In addition to the distillates and residual fuels as the conventional standard and LNG, which is already in use, the selection is limited to the fuels that are currently being discussed as alternatives and are fundamentally suitable for use in shipping.

For each of the fuels considered, material properties, components, characteristics and handling were summarised and examined for the following effects:

- EEDI/EEXI: In calculating the Formula for EEDI, the conversion factor (CF) between fuel consumption and CO_2 emission will apply. CF is a dimensionless conversion factor between fuel consumption and CO_2 emissions.
- CII: The Carbon Intensity Indicator (CII) applies to all cargo, RoPax and cruise ships above 5,000 GT and is expressed in grams of CO_2 emitted per cargo-carrying capacity and nautical mile.
- ETS: Shipping companies must buy and surrender Allowances from the Emission trading system for their emitted Greenhouses Gases based on the MRV. In 2025 40% of emissions reported in 2024 must be covered. This share increases to 70% in 2026 and to 100% in 2027.
- FuelEU is a a key part of the EU's Fit for 55 package with increasing reduction targets for the greenhouse gas intensity of energy from 1 January 2035 with fixed penalty payments and introducing measures to encourage the use of the so-called renewable fuels of non biological origin (RFNBO).
- Availability of combustion engines: For the time being, the combustion engine remains the standard energy converter onboard. Therefore, it is essential that the fuel type can be used practically.
- Required space for tanks / machinery & components / payload.
- Calorific value per volume [MJ/l] and calorific value per mass [MJ/kg] are criteria for ship design. All alternative fuels have lower calorific values as the MDO reference. Furthermore, additional technical components such as gas handling units and protected spaces/areas, might be required.
- Bunker availability: the transport industry requires a good network of refilling locations, which is generally given by hydrocarbon fuels. In particular, HFO, LSHFO and MDO/MGO are available worldwide at short notice.
- Ship's endurance (range): A lower calorific value means that more bunker tank volume is needed and the endurance is reduced. The endurance of the vessel is crucial especially for deep-sea shipping. Retrofit (from DO) available/possible: As the path of decarbonisation

and the availability of alternative fuels is uncertain, verification for fuel oil flexibility shall be based on the possibility of retrofitting the engines.

- Bunker procedure: Local constraints and restrictions could limit the flexibility and bunker location.
- Onboard storage/handling: Increased risks and physical properties like pressure, temperature, flammability and toxicity require additional safety precautions.
- Legislation/Issues: The IMO's initial strategy on the reduction of GHG emissions from shipping sets key ambitions. This is a policy framework. The main goals are:
- Cutting annual greenhouse gas emissions from international shipping by at least half by 2050 compared to 2008 levels, and work towards phasing-out GHG emissions from shipping entirely as soon as possible in this century.
- The initial GHG Strategy envisages a reduction in the carbon intensity of international shipping (reduction of CO_2 emissions per transport service), as an average across international shipping, with a target of 70% by 2050, compared to 2008. The strategy was revised in 2023 to the current target of "net zero" by 2050.
- Key stakeholders in the maritime sector as ship owners, operators, ship managers, banks and investors, shipyards and suppliers reaffirmed their commitment and corporate actions in implementing measures to decarbonise shipping. Corporate actions and prioritization on global market measures, the development of alternative fuels and propulsion technologies, and the need for development and access to clean fuels will raise the industry's reputation for clean shipping. The image of shipping brands will be enhanced in the view of customers if they offer alternative shipping strategies to minimize their carbon dioxide footprint.

Summaries of important characteristics of the marine fuels considered as well as the evaluation by the author collective can be found in chapter 12.1. These evaluations form the basis for the following marine fuels assessment matrix.

Assessment Matrix Marine Fuels

Table 3: Assessment Matrix Marine Fuels

Fuel Type	Origin	Effect on: CII	EEDI/EEXI	ETS	FuelEU until 2034	Availability of Combustion Engines*	Space required/ tanks & machinery & components/Pay-load	Bunker availablity of Fuels	Ships Endurance (range)	Retrofit (from DO)	Bunkering procedure	Storage/ Handling on board	classification rules in power	IMO Goals 2050	Reputation / Image
HFO	fossil	--	--	--	--	++	+	++	++	n.a.	+	+	++	--	--
MDO	fossil	--	--	--	--	++	++	++	++	n.a.	++	++	++	--	--
LNG (content of CH_4 varies)	fossil	+	+	+	--	+	-	-/0	-	-	0	-	++	--	0
LPG (C_3H_8 + C_4H_{10})	fossil	-/0	-/0	-/0	--	-	-	0	-	-	+	0	++	--	0
METHANOL fossile	fossil	-	-	-	--	+	0/+	0/+	0	-	++	0	+	--	+
LNG** (pure CH_4)	biobased	++	++	++	+	+	-	-/0	-	-	0	-	++	0/+	0
LPG** (C_3H_8 + C_4H_{10})	biobased	++	++	++	+	-	-	-	-	-	+	0	++	0/+	0
METHANOL**	biobased	++	++	++	+	+	0/+	-	0	-	++	0	+	0/+	0
ETHANOL**	biobased	++	++	++	+	+	0	-/0	0/+	-	++	0	+	0/+	+
Bio Fuel Oil (FAME)**	biobased	++	++	++	+	++	++	-	++	0	++	+	+	0/+	--
HVO Hydrogenated Vegetable Oil**	biobased +E-Hydrogen	++	++	++	+	+***	++	--	++	++	++	++	+	0/+	++
E-Methanol and other PtL-Fuels*	E-fuel	++	++	++	++	+	0/+	-	0	-	++	0	+	+	0
Ammonia,cooled, from green H_2	E-fuel	++	++	++	++	-	-	-	-	--	-	--	--	++	-
Ammonia, pressurized, from green H_2	E-fuel	++	++	++	++	-	-	-	-	--	-	--	--	++	-
Hydrogen, liquid (LH_2) from electrolysis	E-fuel	++	++	++	++	--	--	--	--	--	--	--	--	++	+
Hydrogen, gaseous (GH_2) from electrolysis	E-fuel	++	++	++	++	--	--	-	--	--	--	--	--	++	+

* using green/biobased CO_2

** All completely biobased and non-fossile hydrogen added fuels based on biofuel origin will considered CO_2 emission as "zero emission" according to legislation and therefor have "no" impact on GHG, EEDI/EEXI and CII.

*** Engines under development or already in sea trials, releases for HVO and other fuels expected shortly

8. Alternative way to Zero Emission – Carbon Dioxide Capture in the Maritime Sector

Introduction overview

Shipping contributes 3% to the total global greenhouse gas emissions. To meet the International Maritime Organization's (IMO) target of reducing greenhouse gas emissions from the global fleet by 50% by 2050 compared to 2008 levels, it is essential to implement technology that mitigates the emissions from heavy fuel oil (HFO), marine diesel oil (MDO), marine gas oil (MGO), or even ultra-low sulphur diesel fuel (ULSD) [14].

This initiative signals a transformative journey towards a greener, more resilient future for the shipping industry. Although alternative low and zero carbon fuels are gaining attention, the industry, supply chain, and technological infrastructure are not yet prepared for an immediate transition. Onboard Carbon Capture (OCC) presents a viable solution by capturing fossil fuel emissions before they are released into the atmosphere. This technology is currently available and can serve as an interim measure until the widespread adoption of green fuels can be ready [15].

The need for carbon capture in the maritime industry

As emissions soar in maritime transport, the industry faces significant challenges in curbing its environmental footprint. Carbon capture technologies offer a promising solution, yet implementation poses logistical and technological hurdles. Overcoming these challenges is crucial for the maritime sector to meet sustainability goals and navigate towards a cleaner future.

Key carbon capture technologies in the maritime sector

To enhance comprehension of the role of Carbon-Neutral vessels in maritime decarbonization and evaluate the business viability of OCC across various vessel types and sizes, one conducted an analysis of its applicability within the largest shipping segments, both for retrofitting to existing vessels and for incorporation into newbuild vessels.

The three main types of CO_2 capture systems for the maritime sector are post-combustion, pre-combustion and oxyfuel combustion. Direct Air Capture & Carbonate Looping Process are two technologies to watch.

<u>Oxy-fuel & Pre-combustion Technologies</u>: extract Carbon from the fuel prior to its utilisation. These systems typically necessitate a complete engine redesign, as they must be seamlessly integrated into a vessel's fuel supply and power generation system. Given their high cost and time-intensive implementation, they may pose challenges for adoption within the shipping industry [16].

<u>Post-combustion Processes</u>: capture CO_2 from flue gas generated after combustion and can be integrated into traditional engine designs without significant modifications. The technology allows vessels to capture up to 40% of CO_2 emissions, with the potential of exceeding 90% in the future. As these systems are on the market today and is a somewhat “plug-and-play” solution, OCC technology can be more cost-effective and appealing for ship owners. OCC with chemical absorption is technically feasible and expected to reach commercial availability by 2030 [17].

OCC on large vessels has the best business cases while smaller vessels have the most challenges. Alternatively, if CO_2 is to be transported as a liquid, it would need to be maintained at approximately minus 50 degrees Celsius. Storage space presents a challenge. Approximately 1 ton of liquefied CO_2 occupies about 1 cubic meter, necessitating precise calculations to allocate the necessary space for anticipated CO_2 capture volumes. Furthermore, increased ship weight correlates with higher fuel consumption, necessitating consideration of these costs in owners' or operators' planning [18].

Direct Air Capture (DAC): is another Carbon capture solution that works by directly captures CO_2 from ambient air using sorbents or chemical reactions. While not commonly used in large-scale applications yet, DAC is currently being developed as a potential solution for decarbonization efforts across various sectors, including maritime. The current main bottleneck is the power consumption of these systems. For DAC to make sense, energy used in the process must come from low-cost and low-carbon sources to ensure economic feasibility and negative emissions. DAC is increasingly transitioning from concept to reality, with support from governments, industries, and investors. Currently, subsidies totalling approximately US$1.9 billion annually are available to bolster DAC projects success in the future [19].

Carbonate Looping Process (CLC): is a promising chemical looping process where CO_2 is captured through an air/fuel reaction of a metal oxide with the flue gas to form metal carbonate. The metal oxide is then regenerated by heating the carbonate, releasing a pure stream of CO_2. While still in pilot research, carbonate looping has the potential applications in carbon capture for various industries, including maritime. One of the bottlenecks for commercial implementation of OCC on a large scale in the maritime sector is mainly due to the high energy-efficiency penalty associated with the current systems on the market. With the preliminary test data of CLC, the energy needed will be lower than that of for example Direct Air Capture (DAC) [20, 21, 22].

Environmental and economic impacts

As previously mentioned, the maritime industry is accountable for 3% of global CO_2 emissions. As regulatory bodies intensify their focus on reducing emissions, OCC offers a proactive approach to address environmental concerns. By capturing CO_2 directly from a vessel's powertrain or exhaust gases, OCC prevents these harmful emissions from entering the atmosphere, thereby curbing the industry's carbon footprint.

As recently as March 2024, 47 countries garnered support for imposing a charge on greenhouse gas emissions from the international shipping sector at an International Maritime Organization (IMO) meeting, favouring four proposals that advocate for levying of a fee of \$150/ton CO_2 produced by the industry.

Implementing Onboard Carbon Capture (OCC) technology on vessels will have an added investment costs when retrofitting to existing vessels or when ordering new vessels. Even though the extra cost may seem excessive currently, it may well be offset by savings from avoiding the CO_2 fees of the future that might rise in significantly price until the net zero deadline of 2050 [23].

Regulatory landscape and future outlook

The International Maritime Organization (IMO) ambitious goals reflects a collective commitment to mitigating emissions from the shipping industry. The targets of reducing emissions by 30% by 2023, 70% by 2040 and achieving net-zero emissions by 2050 underscore the urgency and determination to combat climate change now. The decision to implement an emissions price from next year represents a significant step towards bridging the gap between traditional fuels and cleaner energy sources, while also generating revenue to facilitate a seamless transition to greener and cleaner fuels and technologies. This initiative not only demonstrates international cooperation but also underscores the maritime industry's role in driving sustainable practices for a more environmentally responsible future [24].

Conclusion

In conclusion, the imperative to reduce greenhouse gas emissions in the maritime industry has sparked a transformative journey towards a greener future. Despite significant challenges, such as logistical and technological hurdles, Carbon capture technologies, particularly Onboard Carbon Capture (OCC), present promising solutions.

Post-combustion processes based OCC systems are being installed in vessels now and will be more prevalent in retrofits and new vessels as we get closer to 2030. Emerging methods like Direct Air Capture (DAC) and Carbonate Looping Process (CLC) may not be on vessels now but are offering a proactive approach to curbing emissions and aligning with ambitious regulatory targets set by the International Maritime Organization (IMO).

As countries move towards imposing charges on emissions and with regulatory frameworks emphasizing emission reduction targets, OCC technology stands as a vital tool for ship owners and operators. While initial investment costs may appear steep, they are offset by future savings and regulatory compliance. Overall, the adoption of OCC underscores the maritime industry's commitment to sustainability, international cooperation, and driving forward greener practices for a more environmentally responsible future.

9. The evolution in ship design continues within the past two decades

or what has been changed in ship design within the past two decades?

Ship design has always been evolving, not least through the integration of new technologies. This evolution began with the dugout canoe and continues to progress continuously. Sails and its different types, the steam engine, the propeller, later the diesel engine and many more have been milestones in that development.

Looking back at the last two decades, there have also been some groundbreaking milestones and trends. What they all have in common is the fact that it is always about improving the general efficiency of the ships. Less about their pure appearance.

This has been true up to now for the undisturbed evolution of ships. But there are external factors that have a strong influence on ship's evolution:

- The safety of ships and the national and international rules and regulations that have arisen from the ship's safety or rather for it (e.g. a probabilistic damage stability calculation for passenger and cargo ships, the 'Stockholm-Agreement' for RoRo Passenger vessels, 'safe-return-to-port' regulation for passenger/cruise vessels).
- The infrastructural development of harbours and seaways (e.g. the St. Lorentz seaway, the Kiel Canal and of course the Panama)
- And nowadays, new regulations aiming to decarbonise shipping which are mentioned in chapter 4 of this document and which are influencing the ship design more and more.

Efficiency driven design evolution

Ship efficiency may simply be defined as fuel consumption per ton-mile transported. The main innovations of the last two decades can be divided into two categories: reducing fuel consumption and increasing cargo intake.

Rules have come into force recently which had the intention to speed up the efficiency evolution and therefore have a direct impact on the ship design. Even if criticism of the technical implementation of the aimed intention at one place or another may be appropriate, regulations such as EEDI, EEXI and CII described in chapter 4 serve their purpose. They push newbuildings and the fleet in service towards a better overall efficiency achieved e.g. by:

Hull lines optimisation

The input parameters for the hull line development have been changed drastically leading to different hull lines for newbuildings.

One of these input parameters is the design speed. It is a well-known fact that the required engine power thus fuel oil consumption is increasing with an exponent of about 3 or even more with the actual ship's speed. That means by reducing the speed by e.g. 10% from 15kn to 13.5kn, the daily fuel oil consumption may be reduced by about 30%. Since the fuel oil price increased over the past two decades the actual speed of the fleet in services and the design speed for newbuildings has been reduced significantly. A lower design speed has resulted to different hull lines for newbuildings and triggered a boom of bulbous bow retrofits (see chapt. 12.4) on the vessels already in service.

Another design aspect that changed within the past decades is the assumption of an operation profile for the lines development instead of sticking to a certain speed on one single (design) draught. Nowadays, the hull optimisation will be done by means of CFD for the whole, simplified, operation profile weighted by the probability of occurrence. That means ballast draught and laden draughts will be considered as well as 2-5 different operation speeds. The hull lines resulting in the overall best performance will be chosen as the most efficient one

Main engine dimensions

In addition to the weight and the length of a main engine, the height of the main engine also has a certain influence on the ship's design. This means that developments by engine manufacturers such as long- or giga-stroke engines or the newly developed short-stroke engine design influence the required height of the engine room and thus the adjacent decks and compartments.

Wind assisted ship propulsion

Newly developed devices based on well-known concepts such as sails, kites, wings or rotors can occasionally be found on new ship designs to reduce the fuel oil consumption in general. There is currently no silver bullet in sight and ship designers need to investigate pro's and con's of the different systems. However, the trend to install or being prepared to install such devices is obvious and reasonable with increasing costs for fuels and CO_2 emissions.

Figure 11: Wind assisted ship propulsion by Flettner Rotor [25]

Diesel electric (DE) propulsion

The development of better performing electric motors, DC-Circuits and power management systems made Diesel electric propulsion concepts more favourable. Ships having an operation profile with highly varying power requirements may be designed today with a DE-propulsion system. It enables the ship to run smaller generators in their most efficient load instead of running a large engine in an unfavourable low load.

The operation profile needs to be investigated carefully and the higher specific fuel consumptions of smaller engines need to be taken into consideration as well as losses in the electric power generation.

An obvious advantage is that smaller generators can be substituted easier by other means in future, which are producing electric power for the electric propulsion engine (e.g. fuel cells, generators driven by an alternative fuel)

Alternative fuels

The topic of alternative fuels is today's most discussed issue. To reduce tank to wake or well to wake emissions, in future other fuels than fossil fuels will need to be used. The aggregate state of the fuel in ambient condition has a major impact on its storage thus the ship design. A clear trend is not yet foreseeable, but in view of the long lifetime of the ships it is advisable to be prepared for a fuel change in some way. In particular, the storage of gaseous fuels in pressurised tanks has significant influence on general arrangement of ships. Other fuels like Methanol require specific safety measures due to their toxicity, which also influences layout of fuel systems, ventilation, etc. more about this can be found in chapter 12.1.

Deckhouse in front

The location of the deckhouse in ships length is a compromise between the international rules for a line of sight, safety and the crew comfort. Ships designed for project cargo or high deck cargo (light containers) can be loaded more flexible having a deckhouse in front. The crew comfort in higher sea states, slamming impacts on deckhouse and windows need to be investigated and distances between living quarters and working areas to be considered. However, cargo demands, especially the growth of project cargo in size and amount rules certain design decisions.

Figure 12: Heavy goods vessel with deckhouse in front [26]

There are many other measures to increase the overall efficiency of the vessel, but not having a major impact on the ship design, e.g. coating, propulsion improvement devices, frequency-controlled e-motors, LED-lights and much more, many of them can be found in chapter 12.4.

This chapter does not claim completeness on the topic. Other, special types of ships and sailing areas may have undergone other developments or been impacted by other drivers.

Alternative fuels will continue to have a significant influence on the design of ships in the coming years but technical achievements regarding AI, autonomous shipping will also lead to ships being more efficient and appearing differently in years to come.

Thus, designing ships remains one of the most creative and versatile disciplines in the industry and the ship's evolution continues.

10. Technical solutions for better Ship Efficiency

When talking about ship efficiency, the first decisive moment is obviously the ship design and all related optimisation steps before the vessel is built. Within this development phase of the new vessel there are many design constraints to be considered.

All requirements requested by the future ship owner are defined within the ship building specification. This description summarises all influences of the desired operating conditions and valid regulations. The vessel´s basic design must follow these design rules to be compliant with the building contract. Traditionally, one operating point is defined within these contractual rules, the so-called design point with a clear request to a minimum achievable vessel speed based on defined environmental conditions like a specific sea state and a certain factor considering different resistance increasing influences. This sea margin shall consider additional resistance for example caused by hull fouling, propeller fouling and additional wave resistance. However, the understanding of this additional consideration varies. In any cases, the basis is the resistance measurement or calculation considering the hull form and its resistance due to friction effects on the surface and the pressure effects on the surface due to its own wave system.

The optimisation potential here is given by a minimum of friction losses at the surface for the specified transportation task and the reduction of the wave resistance. Some technical solutions focus on the reduction of frictional losses. For example, special hull coatings lead to lower friction and less subsequent fouling on the hull surface. Air lubrication systems reduce frictional losses by applying a layer of air bubbles and nevertheless, the evaluating of the friction increase on the hull due to fouling effects and the on-time execution of countermeasures such as hull cleaning as an operational measure are some of the efficiency-driving solutions.

Today, the hull optimisation process takes the entire operating matrix and, in some cases, already the added resistance due to sea waves into account. In doing so, the results show possible penalties for the smooth water condition, but on average should come out with advantages for the whole operating range. In latest projects, this has led to significantly different bow shapes and less pronounced bulbous bows compared to single-point optimised hull shapes. This shows that there is a clear potential for the re-design of bulbous bows based on a new operational profile of the vessel and consequently a market for retrofitting bulbous bows as the bow modification is technically possible and economically reasonable.

Following the hull shape optimisation, the next step is the optimisation of the propulsion layout. After pre-calculations of propeller main dimension based on the speed profile of the vessel and possible main engine types, which were already a basis for some design constraints of the aft body within the hull optimisation process, the detailed design process of the propeller begins. Here, the resistance curves of the specified draughts, the final engine layout and the inflow conditions at the propeller plane are to be considered. The most important design task is the identification of the optimal propeller main dimensions. Here, the propeller diameter and the number of blades can be varied by fulfilling all other design constraints such as cavitation safety, blade strength and vibration behaviour of the propeller. Over the years, the optimal propeller diameters have been directly influenced by changes in main engine layout. The trend towards lower engine speeds demanded an increase in propeller diameters, which clearly increased the efficiency of the propulsion system.

However, as the inflow field of the propeller is influenced by the hull shape and the operating conditions, the detailed propeller design also includes the optimisation of the blade characteristic. This leads to an individual propeller design for all vessel classes.

This individuality is the reason for the clear potential of a change in propeller design based on a changed operational profile. A shift in the speed profile and definitely a change in maximum power limit of the main engine will lead to a different propeller design when heading for the optimum. The large numbers of propeller retrofits, especially for the container vessels with the largest shifts in operating conditions in the last decade gives evidence for the effectiveness of this measure.

In addition to the propeller optimisation itself, there are different propulsion improvement devices that can be applied to enhance the efficiency of the propulsion system. In principle, a distinction can be made between frictional losses, axial losses, rotational losses and the vortex losses. The frictional losses on the propeller can be reduced by the area of the propeller surface and the roughness of the surface. Both influences are considered in propeller design and in the technical requirements for the surface. The axial losses are mainly influenced by the difference of the axial speed within the propeller stream before and behind the propeller. Here, a larger propeller diameter will lead to less axial losses considering the same propeller thrust. The most common propulsion improving device to reduce the rotational losses in the rudder is placed within the slip stream of the propeller. In addition, there are further devices enhancing the propulsion system placed before the propeller, providing a certain pre-swirl to the propeller. There are blade systems as part of the hull, single or combined with some kind of duct, with the aim of contra-rotation of the inflow and equalising the inhomogeneous inflow field. These devices can be included in the vessel design already during the new building phase and can be applied as a retrofit, whereby a possible shift in propeller and main engine characteristic should seriously be considered.

For the main engine itself, there are numerous measures available to optimise fuel oil consumption and to reduce CO_2 emissions as well as to align the main engine characteristic with possible shifts in the operational conditions of the vessel. Even turbo charger modification or at least changes in fuel are considerable measures.

As an external optimisation measure, any kind of wind assisted systems form a group of efficiency enhancing solutions. There are different types of systems on the market. Sails, as the oldest solution, are interpreted considering today´s usability requirements and come into the market as steerable foils or as a rotating column as the Flettner rotor. These solutions can be applied for new buildings as well as retrofits considering a holistic view and possible influence on the propulsion system.

Ultimately, the complex system ship can only be as efficient as the operation is planned and carried out. In this respect, seamanship is the decisive factor for keeping the efficiency on the highest level by fulfilling the transportation task. Modern data-driven approaches help the crews to find the most efficient transit between the waypoints, for example by use of weather routing systems, performance management systems and other utilities to support the crew’s experience in finding the optimal operation.

The pressure on today’s shipping business is obvious. Reasonable solutions or combinations are to identify to boost vessel´s efficiency for a clear reduction of fuel oil consumption and related CO_2 emissions. This guideline can only provide a small picture of what is possible and applicable, and it is still fascinating how many new solutions or modern interpretations of well-known solutions enter the market.

11. Assessment matrices Ship Efficiency

Ship owners, ship managers, designers, shipyards – they all feel the technical and commercial pressure to reduce GHG emissions over the lifetime of the vessel. Radical solutions, such as all-electric propulsion drives, may be suitable for small ships in coastal waters, but those in charge of sea-going commercial vessels must assess what is feasible and affordable. They are confronted with a variety of options offered by individual companies. Classification societies and engineering companies also offer and disseminate summaries and overviews.

The MCN was asked by its members to develop this guideline with a particular focus on existing technologies, systems and services provided by MCN members and other companies.

Within the established MCN Expert Group Ship Efficiency, several experts have volunteered to elaborate an assessment matrix as a suitable and convenient tool for all decision makers to evaluate and compare different technologies. This matrix is intended to demonstrate possible solutions offered on the market in an objective way. In addition, the technology providers were invited to describe their systems and services with their marketing know-how.

The editors of the matrix are aware that such an overview can only show the current status of technology development. Other systems available today or in the future could be added.

In detail, the first and foremost objective is to reduce the Green House Gases (GHG) as stipulated for example, by various regulatory frameworks. Secondly, new or additional technologies should be components, or systems that can be installed on board, are available at least as a prototype, and suitable for new builds and/or refits. Software solutions for on-board operations can also be considered as well as engineering processes to optimise onboard operations.

The headlines in the matrix show the following evaluation criteria:

- Effects on: CAPEX, energy costs / savings, ROI, operational effort, GHG, CII, EEDI / EEXI, cargo capacity
- Application range: speed, ops hours, sailing area, other dependencies
- Impact on: payload, installed power, space / ship design, ship & fuel handling, reputation & marketing
- A short explanation has been defined for each criterion e.g.
- CAPEX: Capital expenditures for system, installation, commissioning and training
- Operational effort: Operational expenditures for power, reduced payload, maintenance
- Sailing areas: e. g. ECAs, SECAs…
- Other Effects: e. g. environmental labels such as Blauer Engel, PR-work
- Ship Handling: e. g. bunkering, safety aspects

All definitions and evaluation criteria used in the assessment matrix are compiled in the tables behind the matrix.

As the matrix is not intended to serve as sales promotion for individual systems, no absolute figures such as ROI and savings were used. Instead, we opted for qualitive values such as low, medium or high. Again, all these expressions have been precisely defined in a table that is part of the spreadsheet. Only the budget for the system itself was stated as named by the supplier.

The first version of the matrix was reviewed and commented on by selected shipowners. Based on their feedback and suggestions, further technology suppliers have been invited to participate and complete the matrix. For more clarity the matrix in this updated version was divided into the following three sections:

Matrix 1	Operational Measures	Mostly digital assistance/software solutions like weather routing, dynamic trim/draught a.s.o.
Matrix 2	Periodical Measures	Like hull cleaning/blasting, new anti-fouling solution
Matrix 3	Technical Retrofits	Technical add-ons and/or retrofit solutions like propeller retrofit or wind assisted ship propulsion

The belonging detailed solutions and product descriptions can be found in the chapters 12.2, 12.3 and 12.4.

11.1 Assessment Matrix – Operational Measures

Table 4: Assessment Matrix Ship Efficiency – Operational Measures

Operational Measures		Effects on																		Application range							Influence on					
Technology	Ship type / size	CAPEX			Energy savings			ROI		Operational effort		GHG		CII		EEDI / EEXI		Cargo capacity		Speed		Ops hours		Sailing area		Other dependicies	Pay load		Installed power		Space / ship design	Ship & fuel handling
		New build	Refit	Remark	Propulsion	Aux.	Remark	Rating	Remark	Rating	Remark	Rating	Remark	Rating	Remark	Rating	Remark	Rating	Remark	Rating	Remark	Rating	Remark	Rating	Remark	Remark	Rating	Remark	Rating	Remark	Remark	Remark
Dynamic Draught and Floating Monitoring	Length > 80m	50 KUSD	50 kUSD	-	-	-	-	low	-	low	-	low	-	low	-	-	-	-	-	fully applicable	-	during transit	-	global	-	Data Logging / Performance monitoring in addition recommended	-	-	-	-	-	-
Numerical wave tank	any ship	10k – 100k USD	10k – 100k USD	depending on number of calculations	high	-	By knowing the optimum trim of the vessel	high	-	low	-	high	-	medium	-	-	Unless speed vs. power reference curves was missing	-	-	fully applicable	-	no restrictions	-	global	-	-	-	-	low	-	-	flexible bunker arrangements
Onboard measurements - Hull and propeller performance management	any ship	5k-100k USD	5k-100k USD	strongly depends on suppliers and scope	medium, through better ME efficiency, maintenance and hull cleaning decisions	-	Fuel savings of propulsion based on articel - Hansa 07/2019	high	depending on the improvement of decisions	medium	sensors to be maintained, data to be assessed	medium	-	medium-high	-	-	-	-	-	-	-	-	-	global	-	hull maintenance decisions and better operation lead to savings.	-	-	-	-	-	cleaning jobs can be an operational hazzle.
Onboard measurements - Common condition based efficiency assistance	any ship	5k-100k USD	5k-100k USD	strongly depends on suppliers and scope		medium	increase status, detailed process and ship operation information > identify cost reasons	high		medium	sensors to be maintained, data to be assessed		-		-	-	-	-	-	-	-	-	-	global	-	maintenance decisions and better operation lead to savings.	-	-	-	-	-	Better mangement of engine maintenance, work force and reduced downtimes.
Onboard measurements - Fuel Performance assessments to fulfill energy efficiency SEEMP regulations	any ship	30-50k USD	30-50k USD	-				medium		low	-		-		CII reporting	-	-	-	-	-	-	-	-	global	-	better operation lead to savings	-	-	-	-	-	-
Onboard measurements - Searecs - the electronic Record Book	any ship	< 9k USD	< 9k USD	cost for Installation (Server + Workstations+ approval)				high		low	training + updates, but effort of record book keeping is reduced by automatic entries		-		improve monitoring, plausibility checks, in time counter measures	-	-	-	-	fully applicable	-	fully applicable	-	global	-	-	-	-	-	-	-	Less crew efforts. significantly improved documentation
Weather Routing	any ship	2-5 kUSD	2-5 kUSD	cost per year and vessel, depending on supplier	high	-	savings depend on length of transit, geographic area, cost of fuel, and cost of hire	very high	minimal cost compared to fuel and time savings	-	recommendation provided directly to the master	medium - high	-	medium-high	-	-	-	-	-	no restrictions	-	anywhere	most effective for trans-ocean voyages, areas of heavy weather, or strong currents	global	-	-	-	-	-	-	-	-

11.2 Assessment Matrix – Periodical Measures

Table 5: Assessment Matrix Ship Efficiency – Periodical Measures

Periodical Measures		Effects on																		Application range							Influence on					
Technology	Ship type / size	CAPEX			Energy savings			ROI		Operational effort		GHG		CII		EEDI / EEXI		Cargo capacity		Speed		Ops hours		Sailing area		Other dependicies	Pay load		Installed power		Space / ship design	Ship & fuel handling
		New build	Refit	Remark	Propulsion	Aux.	Remark	Rating	Remark	Rating	Remark	Rating	Remark	Rating	Remark	Rating	Remark	Rating	Remark	Rating	Remark	Rating	Remark	Rating	Remark	Remark	Rating	Remark	Rating	Remark	Remark	Remark
Full blasting of the hull before paint application	any ship	-	50-250k USD	depending upon size and type of vessel as well as docking location.	high-very high	-	depending on state of hull at in-docking.	high	vessel specific but typically within 12 months.	-	some additional time in dock should be planned for	medium	-	medium	-	-	unless vessel undergoes a new seatrial.	-	-	-	-	during transit	-	global	-	to be conducted during docking. Availability of grit-blasting may be limited.	-	-	-	-	-	-
High performance antifouling solutions	any ship	250-550k USD	200-500k USD	depending on size, type of vessel, specific trade and alternative antifouling solution.	high-very high	-	savings shall be documented and quantified longterm by hull performance analytics (e.g. ISO 19030)	high	vessel specific but typically within 12-36 months.	-	-	medium - high	1-15% reduction	medium-high	-	-	none, unless vessel undergoes a new seatrial.	-	-	minor limitations	depending on trade, some antifouling systems may be limited in performance in case of prolonged idling.	during transit	-	global	most relevant solutions are designed for a global trade.	to be applied during docking.	-	-	-	-	-	-
Proactive hull cleaning without capture	any ship	300k - 600k USD	300k - 600k USD	cost can be considered to be an OPEX and will depend on vessel size and type.	high	-	solution designed for fouling intense areas. Saving depends on trade and antifouling solution.	high	vessel specific but typically within 12-36 months.	low	1-2 crew members required during operations and once every 4-6 weeks for vessels in a challenging operation.	medium - very high	depending on fouling, coating status and operational profile.	medium-high	-	-	none, unless vessel undergoes a new seatrial.	-	-	cleaning operations can be conducted when vessel is idle.	-	during transit	typically once every 4-6 weeks for vessels in a challenging operation.	cleaning operations only in ice free waters	operational limitations at sub-zero Celcius.	4G or 5G connection will be required as well as regulatory approval	-	-	-	-	some deckspace required.	-
Robotic hull cleaning with capture	any ship	-	10-40k USD	1 time operational measure! Cost depend on vessel size and fouling.	high	-	savings depending on fouling, coating status and operational profile.	high-very high	for each cleaning operation	low	some coordination, that's it	high-very high	depending on fouling, coating status and operational profile.	high	-	-	-	-	-	no restrictions	cleaning operations can be conducted when vessel is idle.	-	-	global	cleaning operations only in ice free waters	regulatory approval	-	-	-	-	-	-

11.3 Assessment Matrix – Technical Retrofits

Table 6: Assessment Matrix Ship Efficiency – Technical Retrofits

Technical Retrofits – Effects on

Technology	Ship type / size	CAPEX: New build	CAPEX: Refit	CAPEX: Remark	Energy savings: Propulsion	Energy savings: Aux.	Energy savings: Remark	ROI: Rating	ROI: Remark	Operational effort: Rating	Operational effort: Remark	GHG: Rating	GHG: Remark	CII: Rating	CII: Remark	EEDI / EEXI: Rating	EEDI / EEXI: Remark	Cargo capacity: Rating	Cargo capacity: Remark
Air Lubrication System	any ship	800k-1300k USD	1000k-1500k USD	Price indication Aframax vessels. It heavily depends on the vessel size.	high	n.a.	Saving depends on the size of the flat bottom.	medium	-	low	In operation very little, but some additional maintenance	high	-	high	-	high	-	-	-
Biofilm protection based on Ultrasound Technology	any ship	see remark	see remark	depending on ship size and area to be protected; example - shaft propeller: 15-20T€; pod drive: 20T€ per drive; bow thruster: 0-15 T€; freshwater generator: 10-15 T€	low-medium	very low	biofilm protection on rudder, propp, hull, cooling systems, fresh water systems …	low	-	-	maintenance- free	medium	-	medium	-	-	-	-	-
Bow Windshield Reduced Air Drag by aerdynamically shaped Bow	primarily container vessels	unknown	unkonwn	for new build aerodynamics should be considered, retrofits can only achieve a compromise	low	n.a.	after trial operation 2% fuel savings were confirmed	medium	depending of effort	-	maintenance free	low	up to ~2%	low	-	low	-	very low	depending on ship
Bulbous Bow retrofit	primarily fast and slender vessels (container)	-	400k - 2000 kUSD	Mainly steel work. Price highly depends on the ship size, type and shipyard.	medium-very high	n.a.	Depends on the difference between the actual operational profile and the Design condition of the vessel.	high	-	-	maintenance free	medium-very high	-	high	-	medium	-	-	Usually the hydrostatic tables do not need to be updated
Change from HFO to green Methanol	any ship	high	"high"	depending on conversion concept (approx 4.5 Mio. € for 8-10 MW main engine retrofit incl. fuel supply system & tank coating	+100%	+100%	depending on fuel pricing and CO_2 tax	medium	depending on CO_2 certificates	low	maintenance of additional fuel supply system	-90%	under consideration of well-to-propeller approach	high	under consideration of well-to-propeller approach	high	under consideration of well-to-propeller approach	low	depending on required additional tank volume due to lower heating value
Electric Propulsion - Dynafin™	costal operation, work-/tug-boats	unknown	unknown		very high	n.a.	up to 35% better propulsion efficiency compared to conventional propeller	high-very	awaiting a very quick ROI because of fuel saving rate	very low	system is operating automatically	very high	-	high	-	medium	-	-	no impact
Energy Saving Device: Becker Mewis Duct (MD)	Tankers Bulk Carrier Heavy-Lift MPP	80-300k USD plus Design Package	80-300k USD	depending on aft ship design, propeller diameter, and quantity	medium - 'high	-	depending on hull design / wakefield	medium-high	typically under 18 months (depends on fuel price and hull design)	-	maintenance- free	medium	-	medium	-	low	device increases the vref	-	-
Energy Saving Device: Becker Twisted Fin (BTF)	Container Vessels	200-300k USD plus Design Package	200-300k USD	depending on aft ship design, propeller diameter, and quantity	medium	-	dpending on hull design / wakefield	medium-high	-	-	maintenance- free	medium	-	medium	-	low	device increases the vref	-	-
Flume® roll damping solution	any ship	50kUSD -250k USD	50kUSD -250k USD	-	low	-	-	high	for a CV approx. 5-10 months	low	-	low	-	low	-	low	-	-	-
Frequency Inverter Retrofit	all	70-250 kUSD	90-300k USD	depending on vessel size	-	medium	depending on operational area and profile	high	5-15 months depending on vessel size	-	maintenance free	medium	2-8%	low	-	low-medium	-	-	-
Gate Rudder ™	any ship (single skeg)	>350k USD	>500k USD	depending on size, type of vessel, construction, specific trade	medium-very high	-	case specific	medium-high	Depending on capex, which depends on vessel design/size	-	-	medium - very high	-	medium - very high	-	high	-	-	-
Hybrid Power System	any ship	200-5000k USD	200-2000k USD	depending on battery size kWh and electric power of hybrid converter	high	high	depending on operational profile and battery size	low	45-70 months	-	nearly maintenance free	high	7-25%	high	7-25%	high	-	low	-
Integrated Propulsion and Maneuvering System	any ship	5-10% of propeller & rudder costs	350 – 500k USD*	*Depends on whether the propeller needs to be modified as well.	medium - very high	-	case specific, often lower for newbuilding than for retrofit.	medium	-	-	-	medium - very high	-	medium - very high	-	high	-	-	-
Marine ORC Waste Heat Recovery	any ship, min. 1000kW combustion engine power	250-300 USD per module	350-1000k USD	depending upon size heat source and how many modules installed	with shaft generator installed: high, depending on heatsource available and engine size	without shaft generator installed: very high, depending on heatsource available and engine size	ship specific	low-medium	depending upon fuel price and price carbon tax EU-ETS	-	no human intervention required, fully automatic	low-high	depending upon size heat source and vessel operating profile/DWT size	low-high	depending upon size heat source and vessel operating profile/ DWT size	low-high	depending upon size heat source and vessel operating profile/ DWT size	-	-
Modification of Trailing Edge	any ship	-	40-80k USD	An option for vessels with heavy running engines, excluding docking costs	low - medium	-	Depending on engine running condition prior modification	medium	-	-	-	low - medium	-	low - medium	-	-	-	-	-
Propeller Fin Cap	any ship	40-80k USD	40-80k USD	depending on copper price	low-medium	-	-	high	-	-	-	low-medium	-	low-medium	-	low-medium	-	-	-
Propeller Retrofit	CV 2500TEU	-	400k USD	depending on copper price, recycling included	high	-	-	high	-	-	-	high	-	high	-	high	-	-	-
	CV 13000TEU	-	900k USD	depending on copper price, recycling included	very high	-	-	high	-	-	-	very high	-	very high	-	very high	-	-	-
	Tanker / Bulker	-	400k USD	depending on copper price, recycling included	medium	-	-	high	-	-	-	medium	-	medium	-	medium	-	-	-
Reduction of parasitic losses on 4-Stroke Medium Speed Diesel Engine	any ship	5k - 150k	5k - 150k	depending on scope	-	high		high-very high	-	-	-	high	-	low	-	-	-	-	-
Schneekluth Wake Equalising Duct (W.E.D.)	Tankers, Bulk Carrier, Container	60-350k USD	60-350k USD	depending on Propeller diameter and block coefficient	medium - high	-	depending on wakefield and service speed of the vessel	medium - high	12 - 18 months	-	maintenance- free	medium	-	medium	-	low	device increases the vref	-	-
Shaft Generator - Inline	many ships	200-1000k USD	200-1000kUSD	500-7000 kW	-	high	-	low	36-48 months	-	nearly maintenance free	medium	-	medium	-	low-medium	device decrease aux. Consumption	-	-
Shaft Generator - Front End	any ship	400-1200k USD incl. VFD	400 - 1200k USD incl. VFD	500-2500 kW		high		low	36-48 months		nearly maintenance free	medium		medium		low-medium	device decrease aux. Consumption		
Variable Speed DC Drive and Distribution System	any ship with substiantial electrical power demand	medium (2-5% of newbuilt costs)	500k € - 5000k €	depending on complexity of electrical ship net and demand of power	very high	-	depending on operating profile	medium-high	depending on operating profile	-	-	very high	-	medium	-	medium	-	-	less space consumption compared to convential DE-System
Wind Assisted Propulsion: Flettner-Rotor	any ship	500k USD - 1000k USD	500k USD - 1000k USD	cost per installed unit	Medium - very high	-	depending on operating profile/ area/no. of devices	medium	depending on operating profile/area/ no of devices	very low	can work fully automated	medium-very high	depending on operating profile/ area/ equipment	medium-very high	depending on operating profile/ area/no. of devices	very high	-	-	depending on ship type
Wind Assisted Propulsion: Asymmetrical Air Foils	any ship	550k-800k USD	550k-800k USD	cost per installed unit		-		medium-high											depending on ship type
Wind assisted Propulsion: Parafoil Wing	any ship	unkown	unknown	at prototype status, test are ongoing		n.a.		unknown		very low-high	system is operating automatically	high-very high							System is mounted on a mast at the bow of the ship
Wind Assisted Propulsion: VentiFoils	any ship	300k USD	300k USD	cost for 2 Ventifoils, renting is optional		-		medium		low	-	medium-very high							space for 1 TEU taken by VentiFoils

Technical Retrofits – Application range / Influence on

Technology	Speed: Rating	Speed: Remark	Ops hours: Rating	Ops hours: Remark	Sailing area: Rating	Sailing area: Remark	Other dependicies: Remark	Pay load: Rating	Pay load: Remark	Installed power: Rating	Installed power: Remark	Space / ship design: Remark	Ship & fuel handling: Remark
Air Lubrication System	Works best up to 18 kn	Also works at faster speeds, but less effective	during transit	-	global	-	-	-	-	medium concerning AEs	Suffcient electric power needs to be installed onboard, usually that's the case.	Some space demand for compressors	-
Biofilm protection based on Ultrasound Technology	fully applicable	-	during transit	-	global	-	-	-	-	-	-	-	-
Bow Windshield Reduced Air Drag by aerdynamically shaped Bow	fully applicable	-	during transit	-	global	-	may have an negative impact on view in heading direction	very low	-	low	no remarks	add-on	Very high
Bulbous Bow retrofit	best savings at the given operation profile	-	during transit	-	global	-	-	-	-	-	-	-	-
Change from HFO to green Methanol	no restrictions	for high-performance retrofit concept	no restrictions	less wear, but higher system complexity - overall maintenance effort unchanged	global	SECA entry allowed	fuel availability	low	depending on required additional tank volume due to lower heating value	-	for high-performance retrofit concept	capability of integration into existing/typical ship design	flexible bunker arrangements, higher safety demands
Electric Propulsion - Dynafin™	<13 kts	wind speed < 17 m/sec	when sailing or positioning	-	global	-	none	-	-	none	depending on size	special ships	none
Energy Saving Device: Becker Mewis Duct (MD)	fully applicable	typically under 18 knots	during transit	-	global	-	RF installed during DD	-	-	-	-	-	small LRM reduction
Energy Saving Device: Becker Twisted Fin (BTF)	fully applicable	typically above 17 knots design speed	during transit	-	global	-	RF installed during DD	-	-	-	-	-	small LRM reduction
Flume® roll damping solution	fully applicable	effect increases with sea state	during transit	-	global	-	up to 4% fuel consumption decrease in heavy sea	low	approx. +1,5%	-	-	needs to be designed individually for each ship	better sailing conditions in waves
Frequency Inverter Retrofit	all	-	7860h/y	-	global	-	Main Engine load and Sea Water Temperature	-	-	gain	-	neglectable	-
Gate Rudder ™	fully applicable	-	during transit	-	global	-	-	-	-	-	-	Certain space requirement for the additional rudder machinery	Better maneuverbility
Hybrid Power System	fully applicable	-	10-50% reduction of op. Hours of gensets	-	global	-	-	low	-	smaller	exchange gensets against batteries	new rules for batteries are available, fuel cells still not	-
Integrated Propulsion and Maneuvering System	fully applicable	-	during transit	-	global	-	-	-	-	-	-	-	-
Marine ORC Waste Heat Recovery	no restrictions	-	no restrictions	as long there is a heatsource the system will work at sea and in harbour	global	as long there is a heatsource the system will work at sea and in harbour	-	-	-	-	less power for operations will be required form ME and/or AE's. ORC waste heat recovery will increase efficiency, however when inoperative, the power plant needs to be able to supply the required power	-	-
Modification of Trailing Edge	no restrictions	-	during transit	-	global	-	-	-	-	-	-	-	-
Propeller Fin Cap	fully applicable	-	during transit	-	global	-	-	-	-	-	-	-	-
Propeller Retrofit (CV 2500TEU)	fully applicable	-	during transit	-	global	-	-	-	-	-	-	-	-
Propeller Retrofit (CV 13000TEU)	fully applicable	-	during transit	-	global	-	-	-	-	-	-	-	-
Propeller Retrofit (Tanker / Bulker)	fully applicable	-	during transit	-	global	-	-	-	-	-	-	-	-
Reduction of parasitic losses on 4-Stroke Medium Speed Diesel Engine	fully applicable	-	during transit	-	global	-	possibly with engine de-rating	-	-	-	-	-	-
Schneekluth Wake Equalising Duct (W.E.D.)	'best efficiency for vessels with block coeffient above 0,8	best efficiency for slower vessels	during transit	-	global	High Ice Class is possible under certain circumstances	-	-	-	-	-	-	small LRM reduction
Shaft Generator - Inline	fully applicable	typically >10 knots	during transit	-	global	-	RF installed during DD	-	-	medium	one DG set less	little space demand	placed between main engine and thrust bearing
Shaft Generator - Front End	fully applicable	typically >10 knots	during transit		global					medium	one DG set less	very little space demand	placed at free front-end of main engine
Variable Speed DC Drive and Distribution System	no restrictions	-	always	-	global	-	electrical power for each drive is limited	-	-	-	-	~30% less space neeeded compared to AC	-
Wind Assisted Propulsion: Flettner-Rotor	no restrictions	depending on ship speed, relative wind speed and angle	during transit	-	global	-	simple, robust, can be operated fully automatically	very low	depending on ship type	-	less power for propulsion, system needs 50-100 kW electric power for rotating, depending on size	needs open deck space, depending on number of rotors	-
Wind Assisted Propulsion: Asymmetrical Air Foils							-	very low	depending on ship type	-	less power for propulsion, system needs 10-20 kW of electic power for adjusting sail position	needs open deck space, depending on number of sails, space to lay 36m to side	Automatic heeling control of the ship
Wind assisted Propulsion: Parafoil Wing							-	-	-	-	less power for propulsion, system needs a small amount of electricity	n.a.	Very high
Wind Assisted Propulsion: VentiFoils	<13 kts	relative wind speed < 17 m/sec					prefered wind direction from aside	very low	10 ts taken by Ventifoils	-	less power for propulsion, 15kW for the VentiFoils	needs open deck space and length > 50m	none, no air draft restrictions

Definitions

Table 7: Definitions Assessment Matrixes Ship Efficiency

Abbreviations	Full name	Short definition	Long definition
CAPEX	Capital expense	Capital expenditures for system itself, installation, setting-to-work and training	The money one spends to buy, maintain, or improve a fixed asset. Can usually be planned well in advance and is paid once. For higher invests financing costs are included or have to be considered as well. [27] [28]
Energy savings	Energy savings	Saving of energy. Costs (fuel costs).	The impact on the energy related costs is seperated in propulsion related costs and auxiliary engine related costs. For diesel electric propulsion systems the same percentage shall be used for both fields.
ROI	Return on investment	Duration after the savings are equal or higher then the investment (including CAPEX and OPEX)	The ratio between income and invest. Used to evaluate the efficiency of an investment. Often also indicated as the period after an investment has recovered its costs. [29] [30]
Operational effort	Operational effort	All extra handling or effort required for the technology (e.g. crew training/time)	The extra effort that this technology needs during operation. Could be for example aspects like higher educated staff, consideration of external factors like weather, limitation of flexibility or more difficult cargo handling
GHG	greenhouse gases	Gases which contribute the greenhouse effect	A gas that has influence on the earth temperature ans causing the greenhouse effect. Could be water vapor but often referred to gases emitted from industrial/human caused activities like carbon-dioxide, methane, nitrous oxides [31] [32] [33]
EEDI / EEXI	Energy Efficiency Design Index and Energy Efficiency Existing Ship Index	Defined by IMO. Indicating how much CO_2 per cargo ton and nautical mile is used (new built regulation)	A value calculated by a formula defined by the Internation Maritime Organisation indicating the energy efficiency of a specific ship. The EEDI indicates how much carbon dioxide (a GHG and directly correlated with fossil fuels consumption) per ton cargo per nautical mile is emitted. [34] From 2023 onwards ships are required to meet a specific required Energy Efficiency Existing Ship Index (EEXI), which is calculated as EEDI. The required EEXI is based on a regression formula for each ship type and reduction factors defined by IMO as a percentage. [35]
CII	Carbon Intensity Indicator	Upcoming regulation by IMO for 2023. Indicates a ship's performance level on emitting carbon dioxides based on measurements.	Annual operational carbon intensity indicator (CII). The CII determines the annual reduction factor needed to ensure continuous improvement of the ship's operational carbon intensity within a specific rating level. The actual annual operational CII achieved (attained annual operational CII) would be required to be documented and verified against the required annual operational CII. This would enable the operational carbon intensity rating to be determined. The rating would be given on a scale - operational carbon intensity rating A, B, C, D or E - indicating a major superior, minor superior, moderate, minor inferior, or inferior performance level. The performance level would be recorded in the ship's Ship Energy Efficiency Management Plan (SEEMP). [36]
Cargo Capacity	Cargo Capacity	The cargo capacity measured in tons or volumetric space (or lane meters or passengers).	The cargo capacity measured in weight or volumetric space (or lane meters or passengers). Less payload means lower income for a ship and a worse ratio for indicators that use the transported cargo capacity (like EEDI, EEXI). Also stability requirements have to be considered.
Speed	Speed	The ship's speed range at which a specific technology can be used or is well-effective.	The ship's speed range on with a specific technology can be used or is well-effective. The value may either be speed through water (e.g. propeller retrofits) or speed over ground (e.g. wind assistance).
Ops hours	Operating hours	The operating hours per year - how long a technology can be used or is effective.	The operating hours usually per year or as an non-dimensional factor for how long a technology can be used or is effective
Sailing area		The area in which a technology can be used or will usually be used (examples: Global, Only ECA, close to shore)	The area in which the technology can be usually used. There might be some restriction depending an nautical or operational requirements (speed, free sea-space, choosable course, manoeuvrability) or depending on environmental circumstances that can be expected usually in certain areas (like wind or solar-radiation)
Ship size / type		How ship size and type limits the application of a certain technology.	Ship size as a limitation for the application of a technology. Certain technologies may require sufficient room on deck or in cargo holds.
Other dependencies		Other aspects (boundary conditions) that have to be considered for application or availability of a certain technology.	Other aspects that have to be considered for application or availability of a certain technology
Pay load		The cargo capacity measured in tons or volumetric space (or lane meters or passengers).	The cargo capacity measured in weight or volumetric space (or lane meters or passengers). Less payload means lower income for a ship and a worse ratio for indicators that use the transported cargo capacity (like EEDI, EEXI). Also stability requirements have to be considered. [37]
Installed power		The influence on the installed power on board	the influence on the installed power on board – some technologies have none effect, some need extra power to be driven or lower the amount of energy available, some will gain additional power. [38]
Space		The influence on the available space on board	Tthe influence on the available space on board
Ship handling		The influence on the ship handling, (e.g. bunkering efforts, fuel swap at ECA, fuel heat & cleaning, safety aspects, etc.)	risks and influence on the ship handling, meaning all aspect that have to be considered for the operation of the ship – could be things like additional consumables, maintenance, limitations in speed or manoeuvrability, etc.
ECA	Emission Control Area	Emission Control Area defined by IMO with certain restrictions in this area	Regions defined by International Maritime Organization with specific regulations regarding exhaust gases and discharging substances into the water. An additional prefix can be given to clarify a region: SECA stands for a region with limits für sulphur, NECA for Nitrous. [39]

Rating Criteria

Table 8: Rating criteria of Assessment Matrix Ship Efficiency

Criteria	absolute value / remark	Impact Rating none	very low	low	medium	high	very high
additional CAPEX [% of newbuild costs]	*(optional)*		<1%	1-2%	2-5%	5-7%	>7%
additional CAPEX refits [USD]							
+/- Change in energy cost [% per year]	*(optional)*		<1%	1-3%	3-7%	7-10%	>10%
ROI [months]	*(optional)*		>48	36-48	12-36	6-12	<6
Operational effort [man-hours / day]	*(optional)*			0,5	0,5-2,0	>2,0	
GHG reductions [% per year]	*(optional)*		<2%	2-4%	4-8%	8-10%	>10%
EEDI [%]	*(optional)*		<2%	2-4%	4-8%	8-10%	>10%
CII [%]	*(optional)*			<2%	2-4%	>4%	
EEXI [%]	*(optional)*		<2%	2-4%	4-8%	8-10%	>10%
+/- Cargo capacity [% per year]	*(optional)*		+<1%	-1-2%	2-5%	5-7%	>7%
Reduction of installed power [% of main + aux. engines]	*(optional)*			<5%	5-10%	>10%	
Remark on space / ship design							
Remark on ship & fuel handling							

<u>Explanation:</u> (grey) *not quantifiable*

12. Short and detailed descriptions

12.1 Short descriptions of marine fuels

1. HFO (RME, RMG, RMK)
2. MDO (DMA, DMB, DMZ)
3. Liquified Natural Gas, Methane, SNG
4. LPG
5. Methanol
6. Ethanol
7. HVO
8. Bio Fuel
9. Ammonia
10. Hydrogen

1. HFO (RME, RMG, RMK) DIN ISO 8217

Specific Characteristics

Table 9: Specific characteristics of HFO — *Source: [40]*

Chemical Formula	$C_x H_y$ with X = 20-70 C/molecule		
	RME	RMG	RMK
Flashpoint	Min. 60 °C		
Toxicity	carcinogenic		
Explosion limits	n. a.		
Aggregate condition	Viscous		
Pour point	30 °C		
Storage	In regular but heated tanks		
Temperature	> 40 °C		
Density at storage pressure *and 15 °C*	991g/l	991 g/l	1010 g/l
Calorific value per volume	39.64 *MJ/l*	39.64 *MJ/l*	40.40 *MJ/l*
Calorific value per mass	39-40 *MJ/kg*		
Pressure	1.013 bar		
kinematic viscosity @ 50°C min/max	180 mm^2/s	180-380 mm^2/s	Max. 700 mm^2/s

General description

Heavy fuel oil is a residual product from oil refineries. This component is considered as non-vaporizable under ambient conditions. The chemical composition is a mixture of long chain alkane, alkene, cycloalkane and asphaltene, aromatics. HFO composed sulphur and metal particles like nickel, natrium, vanadium and calcium which are responsible for its dark black colour. HFO is practically always available and can be ordered in each port at each time and the application on board is the standard. The well to tank emission is for HFO settled for 14.8 g $CO_{2\ eq.}$/MJ [41]. This figure considers the supply chain from source, production, transport and distribution.

Alias name for HFO: IFO (intermediate fuel oil), Bunker C

Depending on the elementary composition combustion processes are creating a number of carbon dioxide. HFO is available in different qualities with different sulphur content. HFO with 3.5 % mass fraction is only usable in ships with scrubber technology. HFO with 0.5 % is called Very Low Sulphur Fuel Oil (VLSFO). VLSFO is confirming the MARPOL ANNEX VI /rule 14 request and is be used all around the world without exhaust gas treatment systems. Except the Sulphur Emission Control Areas SECA where only 0.1 % sulphur as fuel content is allowed. Those HFO is called Ultra Low Sulphur Fuel Oil (ULSFO).

Important specific physical characteristics

HFO is not a pure element. The chemical formular is not standardized and will be given as C_xH_y while x is bigger than 20 and less than 70. The CO_2 emissions are depending on the carbon fraction in the fuel. HFO is viscous and demands to heat to become liquid. The density is between 991 to 1010 $kg*m^{-3}$ depending on the quality. The flashpoint is located above 60°C to confirm the SOLAS regulations. Density and viscosity are specified in the ISO 8217. The NCV is depending on the fuels density but approx. to 39 MJ/kg.

Resulting specific handling/requirements for crew

Non specific requirements crew training.

Bunkering, storage and handling be subject to mature technologies and safe procedures. The handling requires continuous heating of tanks to prevent the HFO from solidifying. HFO needs additional treatment to achieve injection qualities. This treatment contains settling of fuel, purification, clarification, different filtering processes and final adjustment of viscosity. Tank arrangement require a heating system to avoid the cooling down the pour point. At sea the heat is provided by using exhaust gas boilers. In port auxiliary boilers, that need additional fuel, have to be operated. All handling procedures are parts of the STCW basic training. HFO can contain fines coming from catalyse process in the refinery. These cat fines can seriously harm the engine.

Matrix	Description	Valuation
CII	CII can only be improved by decreasing fuel oil consumption	--
EEDI / EEXI	The high fraction of carbon results in high CO_2 emission, EEDI or EEXI having a negative influence on both indicators	--
ETS	In power since 2024	--
FuelEU until 2034	In power from 2025	--
Availability of combustion engines	HFO is a standard fuel and can be used for almost all thermal engines	++
Required space for tanks/ machinery & components/ pay load	The efficient storage of HFO can be done by standard tank arrangements with additional heating systems.	+
Bunker availability	HFO is available globally, at every port	++
Ship's endurance (range)	The ship range is comparable to MDO	++
Retrofit (from DO) available / possible?	Not applicable	n.a.
Bunkering procedure	The bunker process is a standard procedure, with STCW basic training. The technology is available and mature.	+
Storage / handling on board	Storage of HFO on board is no technical matter, purifying and clarifying is necessary as well as adjustment of injection viscosity.	+
Legislation issues	Mature technology, standards and procedures are globally available and recognized.	++
IMO Goals 2050	Not comparable with the future climate goal of IMO.	--
Reputation / Image	HFO enjoys a good reputation in point of energy density, application and handling. The CO_2 emission potential, the fossil fuel source and the emissions of particles and sulphuric contents shifts the image down. The efforts are in order to reduce the application of fossil fuels like HFO.	--

2. MDO (DMA, DMB, DMZ) DIN ISO 8217

Specific Characteristics

Table 10: Specific characteristics of MDO *Sources: [42] [43]*

Chemical Formula	$C_x H_y$ with x >9
Flashpoint	60°C (43 °C for DMX)
Toxicity	carcinogenic
Explosion limits	0.6-7.5 [Vol.-%]
Aggregate condition	Liquid in norm condition
Storage	In regular tanks
Temperature	15 °C
Density at storage conditions	860-900 g/l
Calorific value per volume	Approx. 36-38.7 MJ/l
Calorific value per mass	Approx. 42-43 MJ/kg
Pressure	1 bar
kinematic viscosity @ 40°C min/max	2.00/11.00 mm^2/s

General description

MDO is a derivative, produced by refining crude oil. The chemical composition is a mixture of aromatics, naphthene and alkene. Depending on the quality it can be a pure derivative or a blended derivative with fraction of residual oils. MDO can contain sulphur in several grades from 1,0 %m/m high sulphur fuel oil down to 0.1 % m/m. Marine Diesel oil is practically always available and can be ordered in each port at each time and the application on board is the standard. MDO can be produced by power to liquid processes. Combustion processes are creating, depending on the elementary composition, number of carbon dioxide. MDO has the highest energy density of all marine fuels in norm conditions. The well to tank emission is for MDO settled for 14.9 g CO_2 eq./MJ. This figure considers the supply chain from source, production, transport and distribution. But it must be handled carefully because it is subjected to many uncertainties like, crude oil quality, refinery setting, different grades of desulphurization.

Important specific physical characteristics

MDO is not a pure element, the chemical formular is not standardized and will be given as C_xH_y while x is bigger than 9. the CO_2 emissions are depending on the carbon fraction in the fuel. MDO is always liquid in ambient conditions, with a density of 860 to 900 kg*m^{-3}. The flashpoint is located at 60°C to confirm the SOLAS standard, exception is DMX (Diesel Marine X) with a flashpoint at 43 C. Density and viscosity are recommended in the ISO 8217. The NCV is depending on the fuels density but approx. between 42 and 43 MJ/kg.

Resulting specific handling/requirements for crew

There are no specific requirements for the handling or crew training. Bunkering, storage and handling be subject to mature technologies and safe procedures. Tank arrangement is the easiest principle and MDO has the highest volumetric energy density. All handling procedures are parts of the STCW basic training. Depending on the fuel quality a preparation by purifying and or clarifying could be necessary.

Matrix	Description	Valuation
CII	CII can only be improved by saving of fuel oil.	--
EEDI / EEXI	The high fraction of carbon results in high CO_2 emission, EEDI or EEXI having a negative influence on both indicators.	--
ETS	In power since 2024	--
FuelEU until 2034	In power from 2025	--
Availability of combustion engines	MDO is a standard fuel and for almost all thermal engines usable	++
Required space for tanks/ machinery & components / pay load	The efficient storage of MDO can be done by standard tank arrangements.	++
Bunker availability	MDO is available globally	++
Ships endurance (range)	The ship endurance is assessed by Factor 1, all other fuels are based on MDO	++
Retrofit (from DO) available / possible?	Not applicable	n.a.
Bunkering procedure	The bunker process is a standard procedure, with STCW basic training. The technology is available and mature.	++
Storage / handling on board	Storage of MDO on board is no technical matter, based on the quality a purifying or clarifying could be possible, adjusting of injection quality is not necessary	++
Legislation / issues	Mature technology, standards and procedures are globally available and recognized.	++
IMO Goals 2050	Not comparable with the future climate goal of IMO.	--
Reputation / Image	MDO enjoys a good reputation in point of energy density, application and handling. The CO_2 emission potential shifts the image down. The efforts are in order to reduce the application of fossil fuels like MDO.	--

3. Liquified Natural Gas, Methane, SNG

Specific Characteristics

Table 11: Specific Characteristics of LNG *Source: [44]*

Chemical Formula	CH_4		
Flash point	-180 °C		
Toxicity	non-toxic		
Explosion limits	4.4-16.5 [Vol.-%]		
	Norm conditions	**Liquified natural gas**	**Compressed natural Gas**
Aggregate condition	gaseous	liquid	Gaseous
Storage	--	cryogenic	Pressurized
Temperature	0 °C	-162 °C	
Density at storage pressure	0.7-0.84 g/l	420-504 g/l	~ 200 g/l
Calorific value per volume	0.042 MJ/l	25.20 MJ/l	10.00 MJ/l
Calorific value per mass	36-50 MJ/kg		
Pressure	1.013	1	200

General description

LNG is the abbreviation for liquified natural gas. It occures as colorless, odorless and non toxic gas. It is a fossil gas mixture and can contain methane as major fraction up to 99 MOL %. In case the crude gas contains higher fractions of ethan (1-15 %), propan (1-10 %), butan, ethen and pentane, the gas is considered as wet also with higher fraction of water. Secondary components in the crude gase can be sulpher-hydrogen, nitrogen or carbondioxid. Those components must be removed in order to get a clean LNG with high quality. LNG can be also produced as synthetic natural gas (SNG) by electrified PtG processes or by biomass produced gas BtG. In comparison to MDO a reduction up to 25 % CO_2 emission can be achieved.

The emissions in context of Well-to-Tank WtT are settled between 17.7-24 gCO_2 eq/MJ [45] [46]. This figure considers the production, processing, transport, liquification and terminal operation.

Important specific physical characteristics

LNG becomes liquid below -162 °C and the flashpoint is located at approx. 600 °C. depending on the calorific value, LNG is divided in H (high) gas with high calorific value and high fraction of methan bigger 87 % up to 98 % while L (low) gas has a reduced calorific value and a higher fraction of secondary compositions including inert gases [47]. Based on the methane fraction the NCV differs from 50 MJ/kg for H gas down to 36 MJ/kg for L gas. The GWP_{100} is 28 times higher than CO_2.

Resulting specific handling/requirements for crew

For storage on board are special tanks required. Those tanks are not conforming with the standard tank, typically LNG tanks are known as IMO A, B or C tanks.

Handling on board required additional crew training and certified courses. LNG usage required explosion protection equipment. The manufacturers for LNG plants need special certification, including the producer. The piping system is double walled concepted with gas detectors and venting equiment to transfer the system soonest in a safe condition. A gasification unit is necessary. The complex tank system required space and payload and the maintenance procedures are limited for crew, regularly certified maintenance companies are necessarry.

Matrix	Description	Valuation
CII	Using of LNG reduces the CO_2 emission up to 25 %	+
EEDI / EEXI	The high calorific value and the small carbon content resulting in less emissions, even in sulphur oxides, particle matters and NO_x.	+
ETS	In power since 2024	+
FuelEU until 2034	In power from 2025	--
Availability of combustion engines	Engines using LNG are considered a mature technology and are available as two and four stroke engines in limited power segments.	+
Space required for tanks / machinery & components / pay load	Factor 3/5/2 compared with MDO	-
Bunker availability	Widely available	-/0
Ships endurance (range)	Factor 0,59	-
Retrofit (from DO) available / possible?	Available / possible / expensive	-
Bunkering procedure	Additional training required according to IGF-Code. Safety measures to be reviewed, 3 safety areas according IGF-code, tools and equipment must be anti-static and explosion approved.	0
Storage / handling on board	Ex-proven equipment. Gas detection equipment and venting masts to be installed. special tank arrangement in IMO tank type A or B or C	-
Classification rules in power	Mature technology, standards and procedures are globally available and recognized.	++
IMO Goals 2050	Bridging technology to achieve the future climate goal of IMO.	--
Reputation / Image	Good, however declining reputation due to the discussion about methane slip	0

** Fossil LNG was considered*

4. LPG

Specific Characteristics

Table 12: Specific characteristics of LPG

Sources: [42] [48] [49]

Chemical Formula	Prior C_3H_8 / C_4H_{10}	
substance	**Propane**	**Butane**
Flashpoint	470	365
Toxicity	(MAK) 1,800 mg/m^3	(MAK) 2,400 mg/m^3
Explosion limits [Vol %]	2.12-9,35	1.86-8.41
Aggregate condition storage	liquid	
Boiling temp (t_s) [°C]	-42	-0.5
Storage	pressurized	
Temperature [°C]	15	
Density at norm and liquide conditions (t_s) [g/l]	2.01/ (585)	2.709/(600)
Calorific value per volume (norm conditions) [MJ/l]	0.09318	0.12385
Calorific value per mass [MJ/kg]	46.3	44.7
Vapor pressure [bar]	7.3	1.8

General description

LPG is produced by refinery processes mainly from natural gas and partly from oil processing. LPG is a predominant mixture of propane and butane (normal and isobutane). It can contain a small fraction of unsaturated hydrocarbons (ethylene, propylene and butylene). Some traces of lighter hydrocarbons like ethane or heavier hydrocarbons like pentane are possible. LPG composition depends on the source from which LPG gas is produced (crude oil and natural gas production fields or oil refining). Mostly LPG is made of propane. Sometimes it consists of butane or of a mixture of both.

Important specific physical characteristics

Propane is a colourless and odourless gas, having a melting point at -187°C and a boiling temperature at -42,1 °C. The density is with 2g/l in gaseous form higher than air and increased up to 581.2 g/l in liquid form at the boiling point. Propane has a narcotic effect and leads in higher concentration to suffocation.

Butane is gaseous at ambient temperature, with a melting point at -138 °C and the boiling point is at -0.5 °C located. The density is 2.761 g/l in norm conditions, while the density increase by the factor of 222 in liquid form at the boiling point. Butane has a toxic effect with an MAK of 2400 mg/m^3. Butane is colourless and almost odourless.

Resulting specific handling/requirements for crew

Operational experience as Fuel Oil in shipping is very limited. Few LPG carriers are prepared for the utilization of cargo as a fuel on-board.

Special training for crew is required under the IGF-Code.

Matrix	Description	Valuation
CII	CII can only improve by saving of fuel oil consumption	-/0
EEDI / EEXI	The high fraction of carbon results in high CO_2 emission, EEDI or EEXI having worse influence on both indicators	-/0
ETS	In power since 2024	-/0
FuelEU until 2034	In power from 2025	--
Availability of combustion engines	2-stroke Combustion engines are available on the market. Otto cycle, lean-burn, four stroke engines are offered only for stationary power plants	-
Space required for tanks/ machinery & components / pay load	LPG is shipped in liquid form to keep the volume small and facilitate handling using pressurized tanks in practice. LPG is a low-flash-point liquid, and when used in a high-fire-risk space of the ship with a constant personnel presence, like in the engine room, a double walled pipeline must be used as secondary containment.	-
Bunker availability	LPG is portable and easy to handle; it can be stored in pressurized tanks, accessible across the world.	0
Ships endurance (range)	As Mass Energy Density is slightly higher but Volumetric Energy Density Lower. Larger tank space is required.	-
Retrofit (from DO) available / possible?	Retrofits for 2-stroke engines are successfully completed. No retrofits for 4-stroke diesel engines are offered from the market. Its high-octane number makes it suitable for spark ignition engines (SI), while its low cetane number makes it less favourable for use in compression ignition engines (CI) and de-rating to be considered.	-
Bunkering procedure	LPG bunkering can take place in many different ways, e. g. from terminals or truck on-shore or from bunkering vessels. Bunkering from terminals to LPG-carrying ships is today handled safely with proper specialized training.	+
Storage / handling on board	Generally, LPG can be transported as follows: - Refrigerated, typical at -50°C at close to ambient pressure - Semi-refrigerated - typically at -10°C at 4-8 bar pressure - Under pressure, typically at 17 bars, corresponding to the vapour pressure of propane at abt. 45°C The preferred way of storing LPG for use as propulsion fuel is in a pressurized tank at ambient temperature. Storage in a semi-refrigerated tank made of cheaper steel types than for LNG is also possible, but in order to such an arrangement to be sufficiently reliable, back-up systems must be in place to ensure low temperature in the tank. This makes pressurized tank storage a more reliable, affordable and simple solution. Double-walled pipelines must be used below the deck line.	0
Classification rules in power	Mature technology, standards and procedures are globally available and recognized.	++
IMO Goals 2050	Not comparable with the future climate goal of IMO.	--
Reputation / Image	LPG can contain close to zero sulphur and meets the requirements for Sulphur Emission Control Areas, while CO_2 and particulate matter emissions are lowered significantly at the same time. Downside to LPG as an alternative fuel is its environmental performance when produced from fossil sources.	0

** Fossil LPG was considered*

5. Methanol

Specific Characteristics

Table 13: Specific characteristics of Methanol — *Sources: [50] [51] [52] [53]*

Chemical Formula	CH_3OH
Flashpoint	9.7°C at 1,013 hPa
Toxicity	toxic when swallowed in quantities > 143mg/kg
Explosion limits	5.5-44 [Vol.-%]
Aggregate condition	liquid
Storage	regular tanks
Temperature	20 °C
Density at storage conditions	792 g/l
Calorific value per volume	15.50 MJ/l
Calorific value per mass	19.7 MJ/kg
Pressure	1.013 bar
Dynamic viscosity	0.6 mPa*s

General description

Methanol is the simplest alcohol and under normal conditions a clear, colorless liquid with an alcoholic odor. It is volatile, flammable and can be dissolved in water with any ratio. Methanol is used as a raw material in the chemical industry and has so far mainly been produced from natural gas. The production is carried out catalytically via the synthesis of carbon monixide and hydrogen. Regenerative production can also be carried out using green hydrogen and CO_2 from biogas plants.

Important specific physical characteristics

The molar mass of methanol is 32.04 g/mol. It has a vapour pressure of 128 hPa at 20 °C. [40] Its specific calorific value is 19.7 MJ/kg [54] and its energy density is 4.31 kWh/l. Methanol is insoluble in oils and fats. It can be mixed with water in any ratio. It is also highly soluble in other organic solvents. It burns with blue, almost invisible flame. Its flash point is 10 °C. The ignition temperature is 455 °C at 1,013 hPa.

Resulting specific handling/requirements for crew

Handling on board required additional crew training and certified courses. Since methanol preligates under normal conditions in the liquid state, storage is relatively easy in appropriate tank systems. However, care must be taken to ensure that explosive mixtures can quickly form in the air. When swallowed, toxic by-products such as formaldehyde and formic acid are formed in the body. Therefore, a limit of 143 mg/kg body weight applies. [40] When swallowed, abdominal pain, vomiting, loss of the position reflex, ataxia, a poisonous effect of the nervous system, convulsions, shortness of breath, loss of consciousness and blindness may occur. Inhalation may cause dizziness, coughing and headaches. It has a degreasing effect on the skin. The maximum concentration at the workplace (MAK) must be limited to 200 ml/m³! [54] From a concentration of > 15,400 mg/l, it has a toxic effect on fish. Methanol is classified as non-hazardous to the aquatic environment (according to 1272/2008/EC). Transport in bulk does not currently take place by sea.

Matrix	Description	Valuation
CII	Methanol has only one carbon atom. Thus, significantly lower amounts of CO_2 are emitted during efficient combustion.	+
EEDI / EEXI	With around 20MJ/kg and a C-factor of 1.375, the combustion of methanol emits less CO2 than compared to HFO.	+
ETS	In power since 2024	-/0
FuelEU until 2034	In power from 2025	--
Availability of combustion engines	There are currently a few manufacturers on the marked with correspondingly modified combustion engines. One example is the MAN LGIM engine, which is optimized for operation with methanol. [56]	+
Space required for tanks/ machinery & components/ pay load	Methanol has higher demands on the tank system. For example, a significantly larger construction volume must be maintained and protection against leakage of the fuel must be guaranteed. Systems must be protected against corrosion.	0/+
Bunker availability	Methanol is available for bunkering in some ports in the world. However, the refuelling infrastructure still needs to be expanded.	0/+
Ships endurance (range)	Since methanol has an energy density of 4.31 kWh/l, more fuel must be carried compared to MDO.	0
Retrofit (from DO) available / possible?	A retrofit is currently not available for methanol systems. However, solutions for the conversion to this technology are being worked on.	-
Bunkering procedure	The bunkering process of liquid fuels such as methanol has been tried and tested and is state of the art.	++
Storage / handling on board	Storage and handling of methanol are subject to special requirements. For example, the tank system requires protection against corrosion and double separation from the environment.	0
Classification rules in power	The DNV GL has published regulations for LFL. For example, tankers can receive the DNV class add-on LFL FUELLED after appropriate modification.	+
IMO Goals 2050	Only with a sustainable CO_2 circular economy and more economical drives the goals can be met!	--
Reputation / Image	Sustainably produced, methanol has a very good reputation and is considered as one of the fuels of the future. However, carbon dioxide is needed for production and will be emitted.	+

** Fossil Methanol was considered*

6. Ethanol

Specific Characteristics

Table 14: Specific characteristics of Ethanol *Sources: [57] [58] [59]*

Chemical Formula	C_2H_5OH
Flashpoint	12°C at 1,013 hPa
Toxicity	Is not to be classified as acutely toxic
Explosion limits	3.1-27.7 [Vol.-%]
Aggregate condition	liquid
Storage	regular tanks
Temperature	20 °C
Density at storage conditions	789.4 g/l
Calorific value per volume	21.13 MJ/l
Calorific value per mass	26.77 MJ/kg
Pressure	1.013 bar
Dynamic viscosity	1.2 mPa*s

General description

Ethanol, colloquially known as alcohol, is a colourless, highly flammable liquid with a pungent smell. It is produced in large scale from carbohydrate-containing material via fermentation or technical synthesis processes. It is already used as a biofuel (bioethanol) e. g. E85 and higher. Ethanol has a longer molecular structure than methanol containing of two carbon atoms, six hydrogen atoms and one oxygen atom.

Important specific physical characteristics

The molar mass of ethanol is 46.07 g/mol. Its vapour pressure is 59 hPa at 20 °C. [58] Its specific calorific value is 26.78 MJ/kg and its energy density is 5.87 kWh/l. [59] Ethanol is miscible with water in any ratio and forms azeotropic mixtures with many other substances. When completely oxidized, ethanol burns to carbon dioxide and water when exposed to a blue flame. Its flash point is 12 °C. The ignition temperature is 455 °C at 1,013 hPa. [59].

Resulting specific handling/requirements for crew

Handling on board required additional crew training and certified courses. For handling and storage, the following instructions are given:

- Ensuring adequate ventilation
- Keep away from ignition sources, do not smoke, protection against ESD
- Prevent the penetration of vapours in cellars, sewers and pitz
- Protect container from sunlight and keep tightly closed
- Keep away from food and feed

Care must be taken to wear appropriate protective clothing such as glasses, gloves and respiratory protection. A maximum concentration at the workplace (MAK) of 200 ml/m³ applies. [59] In accordance with dangerous goods regulations Ethanol is classified as not hazardous to the environment. According to IMO instruments, ethanol is not transported in bulk by sea.

Matrix	Description	Valuation
CII	Ethanol has two carbon atoms. Thus, significantly lower amounts of CO_2 are emitted during efficient combustion compared to other oil fuels.	++
EEDI / EEXI	With 26,77MJ/kg and a C-factor of 1.913, the combustion of Ethanol emits less CO_2 than compared to HFO.	++
ETS	In power since 2024	++
FuelEU until 2034	In power from 2025	+
Availability of combustion engines	There are currently only a few prototypes with correspondingly modified combustion engines. One example is the MAN LGIM engine, which is optimized for operation with methanol. [60]	+
Space required for tanks/ machinery & components/ pay load	The storage of ethanol does not have high requirements and can be done in standard tank systems.	0
Bunker availability	Ethanol is available for bunkering in some ports in the world. However, the refuelling infrastructure still needs to be expanded.	-/0
Ships endurance (range)	Since ethanol has an energy density of 5,87 kWh/l, more fuel must be carried compared to MDO.	0/+
Retrofit (from DO) available / possible?	A retrofit is currently not available for ethanol systems. However, solutions for the conversion to this technology are being worked on.	-
Bunkering procedure	The bunkering process of liquid fuels such as ethanol has been tried and tested and is state of the art.	++
Storage / handling on board	Ethanol is very easy to store in standard tank systems. The handling of this fuel differs insignificantly from MDO.	0
Classification rules in power	The DNV has published regulations for LFL. For example, tankers can receive the DNV class add-on LFL FUELLED after appropriate modification.	+
IMO Goals 2050	Can only to be accomplished if the fuel is produced from biogenic residues.	0/+
Reputation / Image	Produced out of biowaste, ethanol has a good reputation and is considered as one of the fuels of the future. However, carbon dioxide is needed for production and will be emitted	+

** Bio-based Ethanol was considered*

7. Hydrogenated (used) Vegetable Oil

Specific Characteristics for HVO [fuel]

Table 15: Specific characteristics of HVO *Sources: [61]*

Chemical Formula	Alkanes, linear and/or branched, C_nH_{n+2} with n = 10...20
Flashpoint	>61°C
Toxicity	Harmfull to health
Explosion limits	Not explosive
Aggregate condition	Liquid in norm condition
Storage	In regular tanks
Temperature [°C]	15
Density at storage conditions [g/l]	775-785
Calorific value [MJ/l]	34,2
Calorific value [MJ/kg]	44
Pressure [bar]	1,013
Dynamic viscosity *Kinematic Viscosity*	>= 5 mPas @ 20°C 4,0 mm²/s @ 20°C (OECD 114)

General description

Regeneratively produced hydrogen at temperatures of about 350 to 450 °C and a partial pressure of 48 to 152 bar catalytically converts (used) vegetable oils/fats and/or residual animal fats through a combination of hydrogenation, decarboxylation and isomerization to a mixture of branched and unbranched alkanes in the area of the boiling line of the diesel fuel (and some short-chain by-products).

Due to the lack of mineral oil components, the HVO fuel has a lower overall density of 775 to 785 kg/m3 than is prescribed for diesel fuel. It is free of oxygen, nitrogen, sulphur and aromatic components. There are blends and pure fuels on the market and it exists already a lot of practical experience, especially from countries that already cover a high proportion of their diesel market with it. HVO fuel is available in any blend. It can be used in its pure form (100% HVO), but also in any ratio be mixed with e.g. fossil diesel. For example, HVO20 consists of 20% HVO and 80% fossil diesel. Trademark Neste MY Renewable Diesel is a HVO100 product, i.e. HVO in its purest form. In addition, this diesel meets the requirements of DIN EN 15940 for paraffinic diesel fuels. [62]. HVO and its blends are distributed throughout the world and are widely used in passenger car, truck/transportation, off-road and construction, and locomotive applications. See-trails in shipping have started using HVO100 [63]. The storage stability of pure HVO is substantially higher than that of pure Fatty Acid Methyl Ester (FAME) biodiesel, or HVO / FAME mixtures, and even fossil diesel fuel B7. That makes HVO particularly attractive to operators of standby power systems. Tests have confirmed that there are no differences in engines performance in terms of their maximum power, load acceptance and fuel consumption – regardless of whether they are fuelled with HVO or conventional diesel. [64].

Important specific physical characteristic

Pure HVO has a slightly lower viscosity than diesel fuel and therefore has similar flow properties. Density, ignitability and low-temperature properties of both fuels are nearly the same. Furthermore, it is cold weatherproof and remains viscous at temperatures as low as -32°C, which allows plenty of wriggle room even in the coldest winters. At the other end of the temperature scale, HVO fuel has a flashpoint of 61°C, so it is also very safe in warmer conditions [65]. If it ends up in the environment, it pollutes soil and water less than fossil diesel.

The amount of fossil greenhouse gas emissions when using HVO depends heavily on the blend used. For pure HVO (HVO100) roughly 90% of fossil CO_2 emissions can be avoided [66]. According to international calculation logic, the combustion of biogenic fuels produces no CO_2 emissions *(strange, of course it produces CO_2)*. It is assumed that the biomass which the fuels are made from removes as much CO_2 from the atmosphere during growth as it later releases during combustion [67]. It is so called "neutral" (net-zero CO_2) to the climate.

HVO is fully compatible with conventional diesel engines, it is already available in large quantities and the price is only slightly higher than conventional diesel of fossil origin [68].

Matrix	Description	Valuation
CII	CII can only be improved by saving of fuel oil	++
EEDI / EEXI	The high fraction of carbon results in high CO_2 emission, EEDI or EEXI having a negative influence on both indicators	++
ETS	In power since 2024	++
FuelEU until 2034	In power from 2025	+
Availability of combustion engines	HVO is a standard fuel and for almost all thermal Diesel engines and gas turbines usable	+
Space required for tanks/ machinery & components / pay load	The efficient storage of HVO and it´s Diesel mixtures can be done by standard tank arrangements.	++
Bunker availability	HVO and it´s Diesel mixtures are available globally	-
Ships endurance (range)	HVO as drop-in fuel does not reduce the range remarkable. Typical mixtures contain of 10% HVO in 90% Diesel up to 100% HVO. Due to the slightly lower density, the range is reduced by a maximum of 20 % when using pure HVO at same tank capacity.	++
Retrofit (from DO) available / possible?	All modern Diesel Engines can run on 100% HVO and it´s mixtures with conventional Diesel. No retrofit necessary. HVO provides good lubrication properties for the injection system.	0
Bunkering procedure	The bunker process is a standard procedure, with STCW basic training. The technology is available and mature.	++
Storage / handling on board	Storage of HVO and HVO/Diesel mixture on board is no technical matter	+
Classification rules in power	Mature technology, standards and procedures are globally available and recognized.	+
IMO Goals 2050	Not comparable with the future climate goal of IMO.	0/+
Reputation / Image	HVO and it´s mixtures with conventional Diesel enjoy a very good reputation in point of energy density, application, cost and handling. The CO_2 emission reduction potential is low. Some sources tell, the content of "green" CO_2 emissions is up to 90%.	++

Resulting specific handling/requirements for crew

There are no specific requirements for the handling or crew training. Bunkering, storage and handling be subject to mature technologies and safe procedures. Tank arrangement is the easiest principle and HVO and it´s mixtures with conventional Diesel have nearly the highest volumetric energy density of all liquid Diesel fuels. All handling procedures are parts of the STCW basic training.

8. Bio Fuel Oil

Specific Characteristics for FAME (rapeseed based)

Table 16: Specific characteristics of Bio Fuel Oil (FAME) *Source: [69]*

Chemical Formula	Fatty acid methyl ester with c= 16…18
Flashpoint	120°C
Toxicity	toxic, carcinogenic
Explosion limits	n.a.
Aggregate condition	Liquid in norm condition
Storage	In regular tanks
Temperature	15 °C
Density at storage conditions	880 g/l
Calorific value	32.7 MJ/l
Calorific value	37.1 MJ/kg
Pressure	1.013 bar
Dynamic viscosity @ 40°C	7.5 μPa*s

General description

FAME = Fatty Acid Methyl Ester

is the generic chemical term for biodiesel derived from renewable sources of vegetable or animal oil/fat and e. g. methanol. It is used to extend or replace mineral diesel and gas oil used to fuel on and off-road vehicles and static engines. Current pump diesel can contain up to 7% FAME, but higher contents of FAME, even up to 100% FAME (B100), are not uncommon.

Biodiesel is commercially produced globally but has almost been utilized exclusively for the road transportation sector and power generation as **drop-in fuel.** [70]

FAME does not have any lubricating properties, so it can´t be used as pure fuel.

FAME is produced by transesterification of vegetable oils and animal fats with alcohol. These high molecular weight oils and fats react with short chain alcohol in the presence of a catalyst, usually potassium hydroxide, to produce lower molecular weight esters (FAME), by-product: clycerol. In some cases, the non-saturated fatty acid gets hydrogenated before esterification [71].

Nowadays they also can be made from various organic raw materials in several different processes. These fuels belong to the group of synthetic fuels (XtL fuels). BtL (Biomass to Liquid) fuels can be tailored to the respective requirements of modern engines and, for example, replace diesel fuel completely. BtL fuels are still in the development stage and not yet available on the market [72].

Important specific physical characteristic

Biodiesel has a slightly higher viscosity than diesel fuel and therefore has similar flow properties. Density, ignitability and low-temperature properties of both fuels are roughly the same. Due to the oxygen bound in FAME, the volume-related energy content is almost 10% lower than that of diesel fuel (~40 MJ/kg). Biodiesel has a high flash point and is therefore not classified as dangerous goods, unlike diesel. If biodiesel ends up in the environment, it pollutes soil and water less than fossil diesel [72].

The amount of greenhouse gas emissions when using FAME depends heavily on the type and origin of the raw materials. The biodiesel marketed in Germany has an average greenhouse gas saving of over 80% compared to fossil fuels. According to EU-RED II, the prescribed minimum value for greenhouse gas savings for biofuels is between 50 and 65%, depending on the year the production plant was commissioned, which guarantees a significant contribution to climate protection [72].

A successful sea trial of first marine biofuel oil with shipping company Stena Bulk could be finished. The marine biofuel oil is a 0.50% sulphur residual-based fuel (VLSFO) processed with a second-generation waste-based FAME component (ISCC certified).

The sea trial also demonstrated that the marine biofuel oil, which can provide a CO_2 emission reduction of up to approximately 40% compared with conventional marine fuel can be used in a relevant marine application without modification and can help operators take a significant step towards meeting their carbon emissions reduction targets. This also supports the International Maritime Organization's ambition to reduce total annual GHG emissions from international shipping by 2050 [69].

Resulting specific handling/requirements for crew

There are no specific requirements for the handling or crew training. Bunkering, storage and handling be subject to mature technologies and safe procedures. Tank arrangement is the easiest principle and Bio-Diesel has nearly the highest volumetric energy density. All handling procedures are parts of the STCW basic training.

With a large-scale use of pure rapeseed oil methyl ester or diesel fuels mixed with rapeseed oil methyl ester, there is a significantly higher risk of microbial growth, which leads to major problems in the long-term storage of these fuels. The activities of the microorganisms break down fuel components, promote corrosion on the tank and form biomass. The fuel is heavily contaminated and loses its usefulness [73].

Matrix	Description	Valuation
CII	CII can only be improved by saving of fuel oil	++
EEDI / EEXI	The high fraction of carbon results in high CO_2 emission, EEDI or EEXI having a negative influence on both indicators	++
ETS	In power since 2024	++
FuelEU until 2034	In power from 2025	+
Availability of combustion engines	FAME is a standard drop-in fuel and for almost all thermal engines usable	++
Space required for tanks/ machinery & components / pay load	The efficient storage of FAME/Bio-Diesel can be done by standard tank arrangements.	++
Bunker availability	FAME/Diesel mixture is globally available	-
Ships endurance (range)	FAME as drop-in fuel does not reduce the range remarkable. A typical mixture of 40% Fame in 60% Diesel reduces the range by less than 5%.	++
Retrofit (from DO) available / possible?	All modern Diesel Engines can run on FAME/Diesel mixture	0
Bunkering procedure	The bunker process is a standard procedure, with STCW basic training. The technology is available and mature.	++
Storage / handling on board	Storage of FAME/Diesel mixture on board is no technical matter	+
Classification rules in power	Mature technology, standards and procedures are globally available and recognized.	+
IMO Goals 2050	Not comparable with the future climate goal of IMO.	0/+
Reputation / Image	FAME/Diesel mixture enjoys a good reputation in point of energy density, application and handling. The CO_2 emission reduction potential is low.	--

9. Ammonia

Specific Characteristics

Table 17: Specific characteristics of Ammonia *Sources: [74] [75] [76] [77] [78] [79]*

Chemical Formula	NH_3		
Flashpoint	not determined		
Toxicity	toxic to inhalation, very toxic to aquatic organisms, long-term effect on aquatic organisms		
Explosion limits	15.4 – 33.6 [Vol.-%]		
	Norm conditions	**cooled**	**pressurized**
Aggregate condition	gaseous	liquid	liquid
Storage	-	IGC-Code: Type A Tanks	IGC-Code: Type C Tanks
Temperature	20 °C	-33.4 °C	20 °C
Density at storage conditions	0.7198 g/l	681.9 g/l	610.3 g/l
Calorific value per volume	0.012 MJ/l	11.713 MJ/l	10.483 MJ/l
Calorific value per mass	17.17 MJ/kg		
Pressure	1.013 bar	1 bar	8.58 bar

General description

Ammonia is a chemical compound of nitrogen and hydrogen and is a colorless gas under standard conditions. It has a pungent odor effect and has strong corrosive properties. In addition, it is toxic when inhaled and very toxic to aquatic organisms. Ammonia is a combustible gas and burns with oxygen to form nitrogen and water. Ammonia has a low flammability and its ignition temperature is 630°C. [76] The production can be carried out via the so-called Haber-Bosch process or the path of electrochemical ammonia synthesis.

Important specific physical characteristics

Below -33.41°C, ammonia passes from the gaseous to the liquid state and has a density of 681.9 $kg*m^{-3}$. Ammonia can also be transferred to the liquid phase via an increase in pressure. This happens at 20°C already at a pressure of 9 bar. It has a molar mass of 17.031 g/mol. Its calorific value according to DIN 51850 amounts to 17.177 MJ/kg. Ammonia is also known under the name R717. In addition to water and nitrogen, nitrogen oxides (NOx) and nitrous oxide (N_2O) can also be released during combustion. [80]

Resulting specific handling/requirements for crew

Handling on board required additional crew training and certified courses. Due to its toxicity, special rules of conduct apply when handling ammonia.

- Do not inhale gas, steam
- Avoid release into the environment
- Protective gloves, protective clothing, eye protection, face protection
- Keep away from heat, hot surfaces, sparks, open flames and other types of ignition sources

Ammonia can form an explosive mixture with air and react violently with oxidizing substances. Furthermore, ammonia forms corrosive alkalis with water and can react violently with acids. Further information on material compatibility can be found in ISO11114. Ammonia should be stored in a well-ventilated place under lock and key. The maximum workplace concentration (MAK) should be limited to $14mg/m^3$. Appropriate protective equipment as well as training on the hazards and rules of conduct are basic prerequisites for handling this substance. [77]

Matrix	Description	Cooled	Pressu-rized
CII	Because NH_3 contains no carbon, the CII is improved by 100%.	++	
EEDI / EEXI	Current combustion engines still emit significant amounts of nitrous oxide (N_2O), which has a GWP/$_{100}$ of around 300 compared to CO_2.	++	
ETS	In power since 2024	++	
FuelEU until 2034	In power from 2025	++	
Availability of combustion engines	Actual there are only few NH_3 combustion Engines in MW-scale. MAN wants to supply the first ammonia-powered 4S50ME-X9.7 marine engines by 2024. [81]	-	-
Space required for tanks/ machinery & components/ pay load	Since ammonia has a similar pressure level to liquefied petroleum gas (LPG), the corresponding technology for this fuel can be converted relatively easily. The space requirement is limited.	-	-
Bunker availability	NH_3 is available for bunkering in some ports in the world. However, the refueling infrastructure still needs to be expanded.	-	-
Ships endurance (range)	Currently, ammonia is split into N_2 and H_2 via a cracker and fed into a fuel cell system after a cleaning stage. If no market-ready technology is available for direct operation, only short distances in inland traffic will remain possible so far.	-	-
Retrofit (from DO) available / possible?	There are currently no system conversions of a diesel engine to ammonia available. However, the first multifuel engines will be available from 2024.	--	--
Bunkering procedure	Technology for the bunkering process of ammonia is available and known on the market. However, there are some limitations due to the toxicity of the substance.	-	-
Storage / handling on board	Ammonia is stored liquid under pressure (from 9bar) or cooled (< -33.4°C). Corresponding pressure tanks are known and available from the field of storage of butane and propane. Unfortunately, this energy source is very toxic and special knowledge is required to deal with it.	--	--
Classification rules in power	Currently, only regulations for the transport of ammonia are available. A classification as marine fuel is still pending.	--	--
IMO Goals 2050	Only to be complied with if no nitrous oxide or other nitrogen oxides are emitted during combustion or if technical measures will be taken against this. Nitrous oxide (N_2O) has a GWP of 310. [82]	++	++
Reputation / Image	Ammonia, unfortunately, does not have a good reputation due to its toxic and strong-smelling properties. Nonetheless, NH_3 is seen as one of the future fuels for the Maritime shipping.	-	-

10. Hydrogen

Specific Characteristics

Table 18: Specific characteristics of Hydrogen *Sources: [83] [84] [85]*

Chemical Formula	H_2			
Flashpoint	practically always			
Toxicity	non-toxic			
Explosion limits	4 - 77 [Vol.-%]			
	Norm conditions	**LH_2**	**GH_2**	**MH**
Aggregate condition	gaseous	liquid	gaseous	gaseous
Storage	-	cryogenic	pressure tank (Type I-IV)	metal hydride (Mg_2FeH_6)
Temperature	20 °C	-253 °C	15 °C	15 °C
Density at storage conditions	0.083 g/l	71 g/l	24 g/l	150 g/l
Calorific value per volume	0.0099 MJ/l	8.50 MJ/l	2.88 MJ/l	18 MJ/l
Calorific value per mass	119.72 MJ/kg			
Pressure	1.013 bar	1 bar	350 bar	12 bar

General description

Hydrogen has the lowest atomic mass of all elements. Pure molecular hydrogen occurs rare in nature. It is a colorless, odorless, non-toxic gas. The production of hydrogen is currently still carried out to a large extent by steam reforming from natural gas, but can also be regenerative and "green" via water electrolysis using renewable electricity. Hydrogen is also an important raw material for synthetic fuels (e-fuels).

Important specific physical characteristics

As an element with the lowest density, hydrogen in liquid form weighs only 70.8 grams per liter. In the gaseous state, hydrogen has a density of 0.082658 grams per liter at a temperature of 20 °C and a pressure of one bar. Its melting point is -259.14 °C and the boiling point is -52.83 °C. It has a molar mass of 2.0159 grams per mole. Its low molar mass favors a high average speed. (1,770 m/s at 25 °C). It has the highest diffusion capacity, the highest thermal conductivity and the highest effusion rate at room temperature. Compared to electric current, hydrogen is an insulator. It has a global warming potential of 6. [86]

Resulting specific handling/requirements for crew

Handling on board required additional crew training and certified courses. Hydrogen is extremely flammable and burns with oxygen, air, chlorine or fluorine with a hot flame. The flame itself is barely visible during combustion and can reach temperatures > 2,000°C. Although hydrogen has no specific toxic effect, it can have a soporific, narcotic or suffocation effect in higher concentrations as a result of oxygen displacement. As an extremely flammable substance, hydrogen must be kept away from all ignition sources, including electrostatic discharges. The ignition temperature in air is 560 °C. Contact with rapidly flowing hydrogen gas from pressure containment can lead to cold burns or injuries. The storage of hydrogen containers should be carried out far away from oxidizing gases and at moderate temperatures. In case of gas leakage, the room must be left immediately, warn people, ensure sufficient ventilation. Entering the area shall only be carried out with respiratory protective devices independent of circulating air if the safety of the atmosphere has not been ensured. A H_2-safety-course has to be absolved when using hydrogen. [84]

Matrix	Description	LH_2	GH_2
CII	Because H_2 contains no carbon, the CII is improved by 100%.	++	
EEDI / EEXI	There is no CO_2 emission per transportation work when produced sustainably.	++	
ETS	In power since 2024	++	
FuelEU until 2034	In power from 2025	++	
Availability of combustion engines	Actual there are only few H_2 combustion Engines in kW-scale. One alternative could be the use of fuel cell systems, but actual they are very expensive. The testing of auxiliary injection in diesel engines is currently being examined.	--	--
Space required for tanks/ machinery & components/ pay load	The efficient storage of hydrogen is currently still a technical problem and is associated with high costs and weight.	--	--
Bunker availability	Currently, H_2 fuel is available for bunkering in very few ports in the world.	--	-
Ships endurance (range)	The ship endurance is hard limited to short sea transportation, based on the low energy density of hydrogen in actual storage technologies.	--	--
Retrofit (from DO) available / possible?	A retrofit is currently not available for H_2 systems. However, solutions with additional H_2 injection in marine diesel engines are being researched.	--	--
Bunkering procedure	The bunker process in hydrogen vehicles is technically mature but there are currently no systems for bunkering ships.	--	--
Storage / handling on board	The efficient storage of hydrogen is currently still a technical problem. For example, only a few test vehicles are currently equipped with hydrogen storage. Direct H_2-storage forms are: - liquid by cryogenic technology - pressurized in tanks (350, 700 or 1,000bar) - metal hydride storage	--	--
Classification rules in power	Currently, no classifications and regulations for the use of hydrogen in shipping are available.	--	--
IMO Goals 2050	If sustainably produced from renewable energy sources.	++	++
Reputation / Image	Hydrogen enjoys a very good reputation and is seen in many places as a clean and sustainable energy carrier of the future.	+	+

12.2 Technology Descriptions – Operational Measures

1. Dynamic Draught and Floating Monitoring
2. Numerical Wave Tank
3. Onboard Measurements – Hull and propeller performance management
4. Onboard Measurement – Common condition-based efficiency assistance
5. Onboard Measurement – Fuel performance assessments to fulfil energy efficiency SEEMP regulations
6. Onboard Measurement – Searecs – the electronic record book
7. Weather Routing

1. Dynamic Draught and Floating Monitoring

Summary by André Marquardt, Hoppe Marine GmbH

The Hoppe Dynamic Draught and Floating Monitoring solution (DDFM) provides detailed information about the floating condition of the vessel at standstill and during sailing.

It compensates for influences of hydrostatic pressure measurements during sailing and is thus independent of hydrodynamic effects.

Torsion and deflection are always known beyond the static load case. It is a highly accurate solution that also monitors roll and pitch angles, rates and periods, and much more motion-related information. It can even calculate draught and trim at any user-defined position.

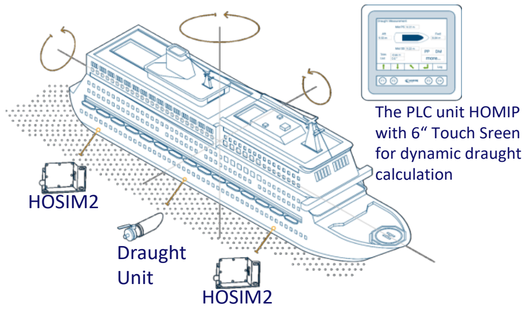

Figure 13: Necessary Locations for Dynamic Draught and Floating Monitoring

When the vessel is at transit speed the draught measurement by pressure sensors becomes inaccurate, so that the system switches automatically to calculate the draught, bending and trim from the HOSIM position sensors.

In normal daily operation an incorrect evaluation of the relationship between engine power and trim condition can cause significant increase in fuel consumption and costs, which could be avoided with the correct monitoring of the vessels operational data to optimize speed and trim.

Dynamic trim optimization in combination with the Hoppe Performance Monitoring System is the basis for the determination of the most favourable trim with the lowest speed loss. It makes it possible by precise real-time dynamic trim and draught measurement and logging of real-world data so that the self-learning system finally allows substantial power savings and thus a reduction of operational costs and emissions.

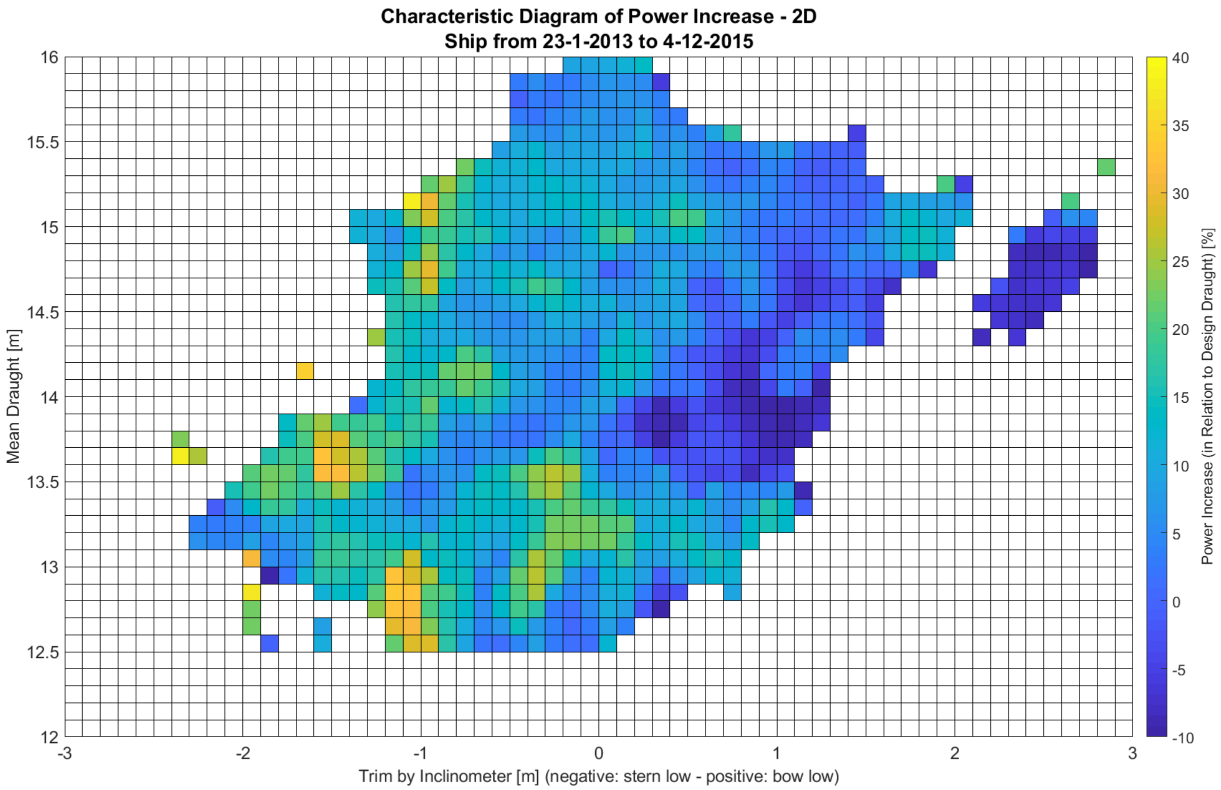

Figure 14: Influence of draught and trim on propulsion power

The potential fuel savings are in a wide range as they depend on hull form, speed and loading conditions and are different for each ship type and size. The best effects will be reached in ballast mode when the vessel is not fully loaded and the maximum flexibility for ballasting for the optimum trim is given.

2. Numerical Wave Tank

Summary by Erik Borof, Futurion Engineering GmbH

The numerical wave tank (NWT) is a very precise tool to reduce the energy costs and the emitted gases that causes the greenhouse effect. The NWT is a computer-based method calculating the hull motions on a given water surface, which is visualised in Figure 15.

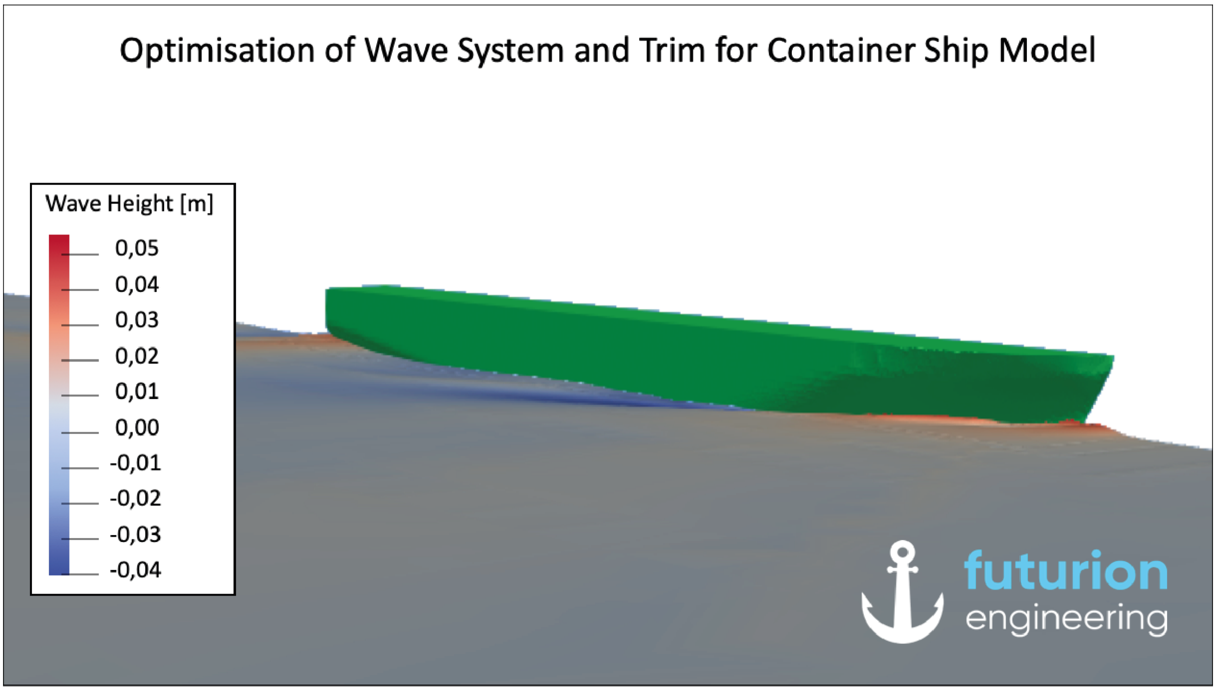

Figure 15: Showing fundamental results for the optimisation of the wave system and trim of a container ship model for a model speed of 1 knot.

The computed hull motion is the foundation to predict the most efficient trim of a ship, depending on load distribution, wave properties, hull shape, wind speed and ship speed. In addition, our methods can optimize hull shapes for given boundary data (wind speed, sea states, cargo capacity, etc).

Our Method shows many advantages compared to experiments:

First of all, the manufacturing of a ship model is no longer needed. Our method works with a 3D-CAD-Model of the given hull, which makes the NWT faster than experiments. The NWT can combine many different environment conditions (e. g. different sea states and their directions, wind speed, etc) without any significant effort. Moreover, there are no limits for the hull shape. And it doesn't matter if the ship is operating offshore or if it's a new build during our calculations using the NWT.

Compared to other commercial computer software our calculation methods contain all important and necessary physical models to predict the best trim and/or hull shape. This way we can adjust the accuracy of our results very precisely.

3. Onboard Measurements – Hull and propeller performance management

Summary by Nadine Paschen, TX Marine Messsysteme GmbH, Richard Marioth, Idealship GmbH and Christoph Bünger, NautiTronix UG (haftungsbeschränkt)

Hull and propeller performance refer to the relationship between the condition of a ship's underwater hull and propeller and the power required to move the ship through water at a given speed. Measurements of changes in ship specific hull and propeller performance over time make it possible to indicate the impact of hull and propeller maintenance, repair and retrofit activities on the overall energy efficiency of the ship in question. To obtain this saving one needs to measure a set of parameters, transfer them to the office and analyse the data. Some details to each step below:

Measure

Primary parameters that need to be measured for an evaluation are the ship speed through water, in knots, using a speed log and the delivered power. This is based on calculations of shaft power, from measurements of shaft torque and shaft revolutions mostly with permanently installed shaft power meter. Important for the measurements is the sensor accuracy and regular maintenance to eliminate incorrect measurements.

Transfer

Transfer systems enable selected operationally relevant parameters of a ship to be monitored onshore or displayed on web platforms. Installed shipinternal sensors are connected to transfer unit parallel to the display elements of the ship.The data is transmitted to servers onshore via LTE or Satellite. The data can be displayed as graphs, maps or numerical values, to set up live monitoring. There are different variants of the Server Windows / Linux: to operate via any other external data center. Also a private data center can be implemented on-site on own servers.

Analysis

There are several methodologies used, the most renown one is the ISO 19030, a standard using the average percentage of speed loss as performance indicator. In the ISO 19030 methodology one determines the performance indicator "percentage of speed loss" for each valid observation. Models correcting for the weather impacts are used. Additionally, reference models for the hull & propeller performance are required, which can be created, e. g. based on Sea Trial information. An example of how percentage speed loss develops over time and is impacted by Idle periods is shown below (dots in graph = vessel observations, every 3 hours):

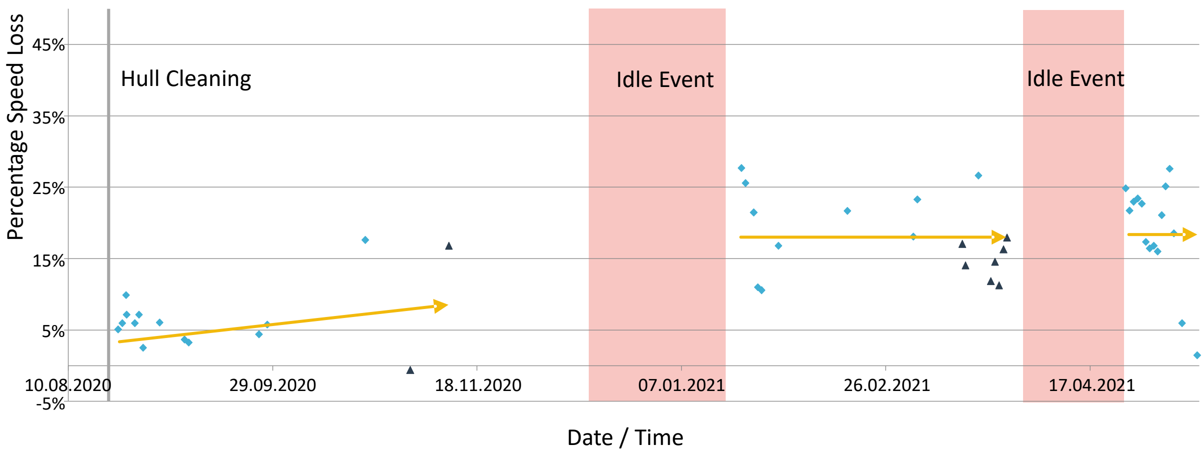

Figure 16: Speed loss with growth of fouling

At the Hull Performance and Insight Conference (HullPIC) 2019, experts in the field answered that typically 4-6% of propulsion related fuel consumption can be saved by having digital processes in place to monitor Hull & Propeller performance *(HANSA 07/2019)*.

4. Onboard Measurement – Common condition-based efficiency assistance

Summary by Christoph Bünger, NautiTronix UG (haftungsbeschränkt)

Ship technology does not have to fail before it can be repaired. Condition monitoring points out technical faults before they occur. It avoids replacement of large, expensive ship components. Through continuous access to selected operationally relevant parameters, the condition data of diesel and electric ships are permanently collected and evaluated by an early warning system. By configuring threshold values and more complex rules, problems can be detected early from the sensor data and signalised by alarms.

Thus, condition monitoring always allows to accurately assess the condition of the ship's technology. With this knowledge advantage, workflows can be optimized immediately, sources of error can be avoided, and preventive measures initialised in short time. This is how you can act instead of reacting. Condition monitoring supports maintaining ships with foresight and conserving resources.

Industrial PCs specially designed for marine applications provide interfaces to the ship's technology. Digital and analogue interfaces enable communication with engine control units, chargers, etc. Many industrial interfaces are already supported (mostly manufacturer-independent). In most cases, existing equipment can be used, and it is not necessary to supply additional measuring equipment.

Data transfer is done via encrypted LTE or satellite connections by using state-of-the-art standard protocols. In case of connection losses, data is buffered and is then transferred to the software platform when a connection is re-established. The data evaluation is done via a central software platform with different access types (internal web interface with visualization of historical and live data, passenger information system with on-board screens or website integrations). Offering data to 3rd party software via REST APIs or data exports is supported as well. Data sovereignty lies with the customer.

As part of the overall operation of ships, the chosen maintenance strategy must weigh the costs and benefits. Only a diagnostic system can achieve such an optimal ratio. Furthermore, the measured values allow the creation of driving profiles, i. e. the creation of elementary prerequisites for the modernization, hybridization or even electrification of existing ships. The same applies, of course, to the construction of new ships. Thus, condition monitoring systems can also be used to minimize the fuel consumption and CO_2 emissions of ships.

Figure 17: Hardware, software and architecture example of a condition monitoring system

5. Onboard Measurements - Fuel performance assessments to fulfil energy efficiency SEEMP regulations

Summary by Dr. Ralf Moeck, Technical Director Aquametro Oil & Marine GmbH and Tom Thorwirth, Project Engineer Aquametro Oil & Marine GmbH

The new regulations for safe, environmentally friendly and efficient ship operation are described in the Ship Energy Efficiency Management Plan (SEEMP).

The parameters to be measured and determined as KPIs for compliance with the SEEMP regulations are the fuel consumption of the energy systems in operation on board (propulsion and auxiliary engines, boilers), the ship's propulsion power, the fuel efficiency and the exhaust gas emissions.

Energy-efficient ship operation is significantly influenced by optimizing the energy systems and thus by reducing fuel consumption. If this is insufficient as a potential for optimization, regulations are issued that restrict operation for example in shaft power limitation (ShaPoLi).

The Fuel Performance System (FPS) provides the necessary information with the tamper proof features data measurement, KPI analysis, data storage and reporting according to SEEMP regulations such as:

Energy **E**fficiency **O**perational **I**ndex	**EEOI**
Carbon **I**ntensity **I**ndicator	**CII**
CO_2 reporting	**MRV / DCS / MSA**
Energy **E**fficiency E**x**isting **I**ndex	**EEXI** (Shaft Power Limitation – **ShaPoLi)**

The online fuel performance optimization

The Fuel Performance System is based on an industrial computer with a programmable logic controller (PLC). The system configuration and visualization are web-based on any PLC-connected computer.

The Fuel Performance System as well as the SEEMP KPI's allow a fast and direct influence on and optimization of the current operating status of the energy systems on board. The data transfer in onshore cloud solutions is most important for technical support by the fleet management.

The Fuel Performance System is an open-source system. It can be easily extended in hard and software components.

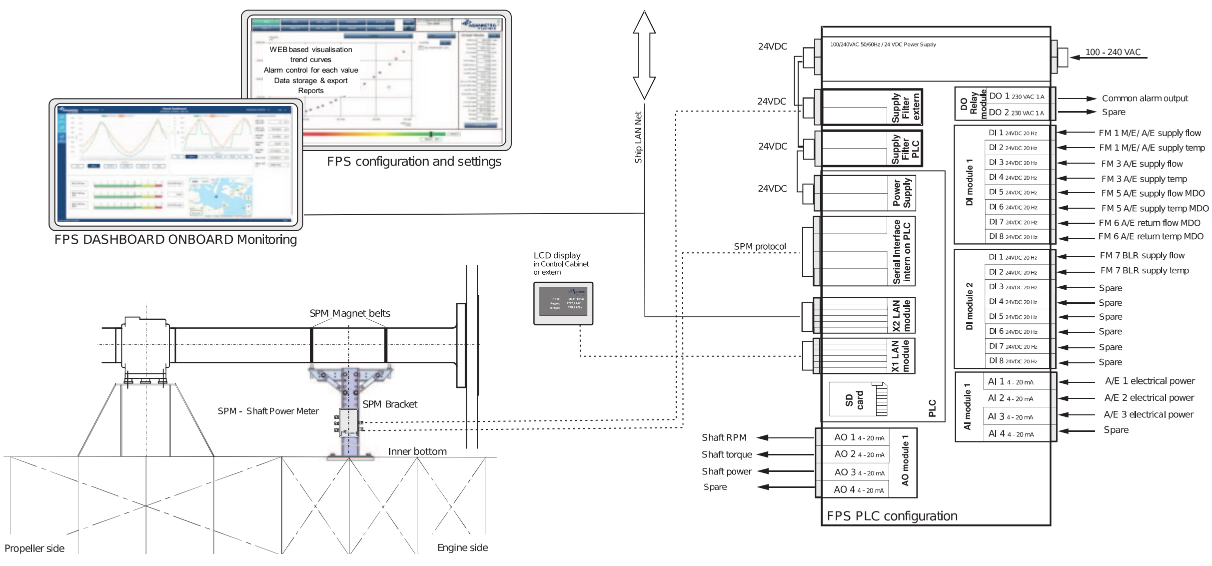

Figure18: System overview – AOM fuel performance system

6. Onboard Measurements - Searecs – the electronic record book

Summary by Nils Külper, Systems Engineer MARSIG mbH Rostock and Kathleen Kuhn, Maritime Consultant MARSIG mbH Rostock

A flag state approved electronic record book platform is superseding relevant paper record books (approved as per ISO 21745:2019 and MEPC.312 (74)).

Available data sources are for example NMEA messages for position, speed, course and weather, automation data for running hours, rpm and temperature as well as data about bunker operations, cargo operations, detailed distances and consumption together with other special events entered by crew.

What are the **general advantages** of electronic record books:

- High quality of data (readability, plausibility, completeness)
- Reduced redundancies (single data source, distributed instances of record books)
- Time saving (workplace close by, automatic and prefilled entries)
- Usability of data (fleet-wide comparability, generation of more-detailed reports)

The solution searecs™ implements and combines existing Record Books on board in one platform, for example Navigation (Bridge) Record Book (incl. radio and compass correction), Engine Record Book (incl. soundings and ODS), Oil Record Book I and Oil Record Book II (Cargo), Garbage Record Book I & II, Ballast Water Record Book and more.

Collected data increases information about ship status, events and processes to identify reasons for operational and fuel costs. Environmental and emission reporting, such as EU monitoring, reporting and verification (EU MRV) and IMO Data Collection System (IMO DCS) is optimized by **improved monitoring, plausibility checks and in time counter measures** addressing CII rating, consumption KPIs, sustainability ambitions and enhanced shore side evaluation aspects.

Approved electronic record book searecs™ supersedes handwritten record books, allows simultaneous work at different stations or tablets and increases databased optimization.

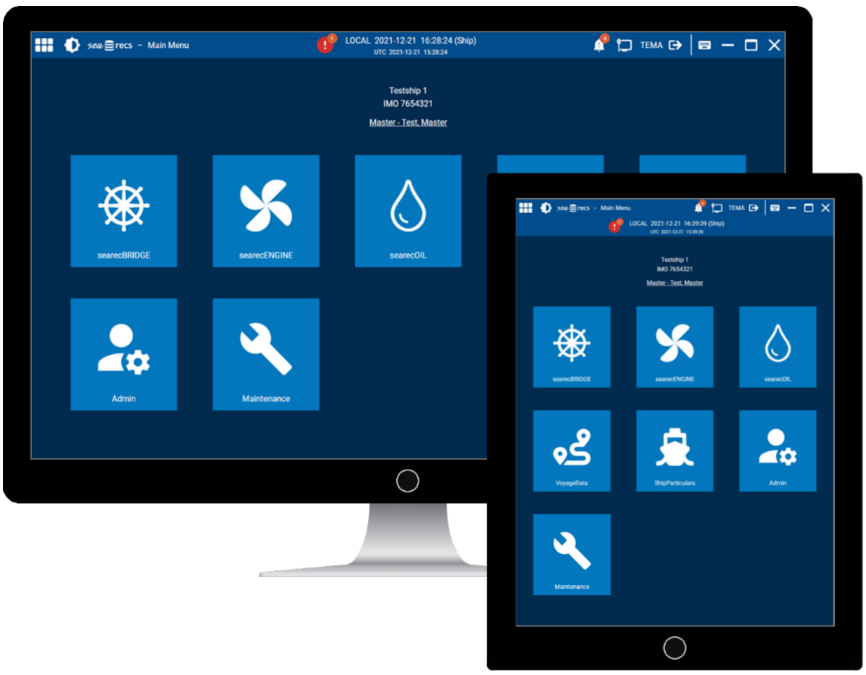

Figure 19: Approved electronic record book searecs™

7. Weather Routing

Summary by Adam Bakke, Director Met Operations, Fleetweather

The goal of weather routing is to minimize the transit time that avoids significant risk to the vessel, crew, and cargo reflecting a combination of safe weather routing, ship safety, and maximum efficiency. Weather Routing requires a deep understanding of environmental factors in order to perform voyage optimization and is also essential for analysing hull and machinery performance.

Advanced mathematical equations are used in order to calculate the forces on a vessel from the outside environment which can include variables such as wind, seas, and currents. These forces will impact vessels differently depending on individual vessel characteristics such as vessel type, size, and hull design.

These calculations provide the basis for debits or credits to the vessel speed. They can be assessed along an entire route in hindsight, real time and the future. When predictive calculations are compared decisions can be made optimizing voyage parameters for multiple routes. This capability would, for example, permit route selection which would have the least emissions or meet some other voyage priority such as a required time of arrival.

Accounting for environmental factors is an important part of assessing hull and propeller performance and the more sophisticated voyage informatics platforms are capable to accommodating the necessary data points.

fleetweather

VOYAGE FORECAST

Initial ETA: 20200722T19:57 Expe

The forecast table shows weather forecast and oceanographic parameters for estimated ship positions at 00UTC and 12UTC for the next six day.

	Date	10/07	11/07	11/07	12/07	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Time [UTC]	12:00	0:00	12:00	0:00	12:00	0:00	12:00	0:00	12:00	0:00	12:00	0:00	12:00
est. Position	Latitude	31.8S	33.1S	34.2S	34.8S	35.0S	34.0S	32.8S	31.3S	29.3S	27.4S	25.4S	23.3S	21.2S
	Longitude	31.7E	28.8E	26.2E	23.2E	20.3E	17.8E	16.6E	15.5E	14.7E	13.9E	13.0E	12.2E	11.3E
	Heading [degrees]	WSW	WSW	WSW	W	W	NW	NW	NNW	NNW	NNW	NNW	NNW	NNW
	avg. Speed [knots]	14.4	12.3	12.8	12.0	12.8	8.1	10.0	9.3	10.2	10.7	11.1	11.4	11.3
Wind	Direction	NE	WSW	SW	WNW	NNE	WNW	WSW	S	ESE	SE	SE	SE	SSE
	Speed [knots]	15	334	29	18	9	38	24	12	18	26	13	12	11
Visibility	Good/Mod./Poor/Fog	Good	Good	Mod.	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
Wind Waves	Height	2.3	2.9	4.0	1.7	0.7	6.3	3.0	1.0	1.7	3.7	1.5	1.0	0.7
	Wind Wave Direction	SW	SW	SSW	WSW	SW	WSW	WSW	SW	SW	SSW	SSW	SSW	S
Swell Waves	Height [m]	3.1	1.7	0.4	3.1	3.1	Neg	8.5	6.2	3.9	2.5	3.0	2.3	1.9
	Direction	SW	NE	E	WSW	SW	Neg	WSW	SW	WSW	WSW	S	S	S
Sig. Wave Height	Height [m]	3.9	3.4	4.0	3.7	3.1	6.3	8.5	6.5	5.2	4.5	3.4	2.6	2.1
Current	Impact [knots]	1.2	0.1	0.3	-1.0	0.1	0.2	0.3	0.0	0.3	0.0	0.0	0.3	0.2
Weather	Impact [knots]	-0.9	-1.8	-1.5	-1.0									
Temperature	Air [deg. C]	21.4	20.9	15.2	15.4									
	Sea [deg. C]	20.6	21.6	19.2	19.4									

Table also shows spot values except for average speed, current factor and weather factor which represents the average values expected for the next 12 hr period

Warnings														
Wind	>BF6 / >BF8													
Sog. Wave Height	>4m / >6m													
Visibility	Poor / Fog													
Potential Ship Icing	Light / Mod / Heavy													
Seakeeping*							RIS	RIS	RIS	RIS				

* Seakeeping: Reduced Intact Stability RIS / or possible parametric Rolling PR /Synchronous Rolling SR. Neg=Negligible, Conf= Confused.

Figure 20: Fleetweather services are offered as part of the Podium5 voyage informatics platform. www.stratumfive.com/podium"

12.3 Technology Descriptions – Periodical Measures

1. Full blasting of the hull before paint application
2. High Performance Antifouling Solutions
3. Proactive hull cleaning without capture
4. Robotic hull cleaning with capture

1. Full blasting of the hull before paint application

Summary by Tom H Evensen, Regional Category Manager - Hull Performance - Jotun AS

The effects of "performance gains of pre-treatment in dry-dock" refer to the effects of various types of pre-treatments in drydock as well as the effects from any repairs, retrofits, smoothness of coating application etc. Most commonly vessels undergo either a spot repair or a full blast. For spot repairs, the damaged parts of the coating system are blasted down to bare steel and the coating system is subsequently repaired according to coating manufacturer's instruction. The alternative is to conduct a full blast of the vessel's hull. Blasting is most commonly either conducted using "steel grit blasting" or "hydro-jetting". The Swedish Standard Institution describes the grades of surface preparations in different levels, where Sa 2 and Sa 2½ are commonly referred to as "a full blast".

Differences found between spot and full blast operation

The effects of various types of pre-treatments were analysed through the ISO 19030 – "Measurement of changes in hull and propellor performance". The "maintenance effect" part of the standard was used. The accumulative effects of drydocking a vessel come as a result of all the measures taken in dry-dock. In the data sample analysed, no vessel had undergone any major repairs nor retrofits. The vessels that had undergone a "touch-up", had spot repairs in the range of 20-40%. The out of dock performance of the coating system, so the smoothness of the coating applied, will have a certain effect on the overall performance, but in the greater scheme the effects will be marginal as the major effect will come from the improvement of the underlying physical roughness. The overall effects associated with any pre-treatment in dry dock will rely on the performance level prior to the docking, so the worse the "pre-dock performance level", the larger the performance gain potential will be.

Having analysed several reference cases, the following conclusions were drawn:

- For touch-ups (spot repairs) a speed gain in the range of 3-7% was disclosed. Assuming a cubical speed-power relation this this would equate to a 9-21% fuel saving or subsequent reduction in green-house gas emissions.
- For full blasts (Sa 2 and Sa 2½) a speed gain in the range of 5-17% was disclosed. Assuming a cubical speed-power relation this would equate to a 15-41% fuel saving or subsequent reduction in green-house gas emissions.

One can expect a clear performance difference of hull & propeller performance due to the way how the vessel was pre-treated during Dry Docking. A full blast surface preparation will in general lead to more efficient vessel operation.

Figure 21: Example of spot repair (touch up)

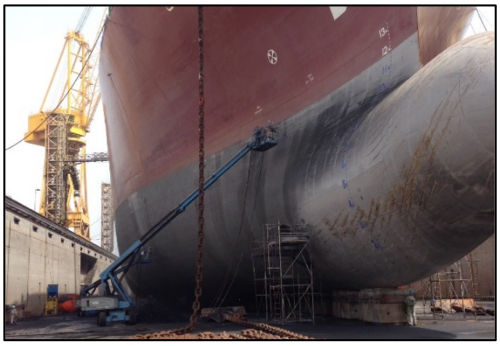

Figure 22: Example of full blast

2. High Performance Antifouling Solutions

Summary by Stein Kjølberg, Global Category Director - Hull Performance -Jotun AS &
Tom H Evensen, Regional Category Manager - Hull Performance - Jotun AS

Antifouling performance effects the energy efficiency of a ship and the performance can be measured as the relationship between the condition of a ship's underwater hull and propeller and the power required to move the ship through water at a given speed. The right antifouling system can keep an exterior hull almost free of biofouling, and the cleaner the hull, the less speed loss a vessel will experience.

Biofouling has always been of great concern in shipping and can impact a vessel's efficiency often expressed through speed loss. Comparing the documented performance of market leading solutions (Figure 14) to an assumed market average performance, discloses an energy efficiency gain of as much as 20%. The fuel savings are higher, if the market average solution is tracked and maintained at a certain level. An increase in frictional resistance due to biofouling can cause a vessel not to be able to meet their required speed.

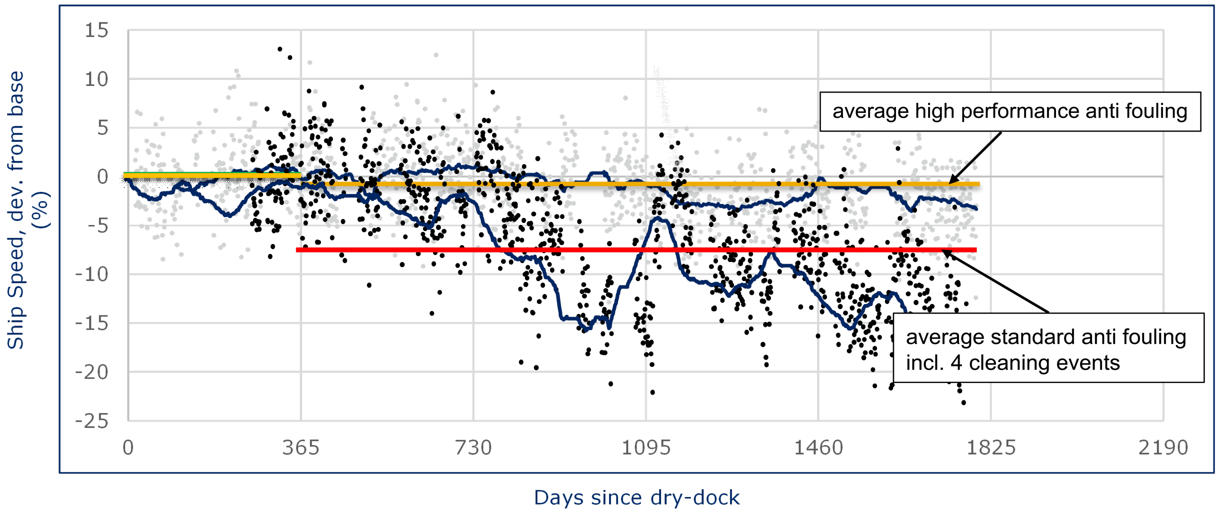

Figure 23: Comparison high performance / market average performance antifouling solution

Speed loss can either be fully or partly compensated for or accepted in full. It will in any case lead to an excess fuel consumption, and subsequent increased in CO_2 and other greenhouse gas emissions of each voyage. Speed loss will also have negative impact on the Carbon Intensity Indicator (CII) rating.

Considerations:

There is a wide range of antifouling solutions available, all associated with various advantages and disadvantages. An owner should carefully consider the expected trade of the vessel in question including details such as sailing time, stops, lay-ups, fouling intensity, water temperature, vessel speed profile etc. At the end of the day, the specific technology may not be the deciding factor, but the proven and documented performance impact it has had. Any vessel hull will have a certain excess consumption caused by fouling. This can be measured through Hull & Propeller Performance management strategies, e.g. by using the ISO 19030 methodology – "Measurement of changes in hull and propeller performance".

Business impact:

Speed loss can be transferred into fuel savings and hence the investment of applying a specific antifouling system can easily be calculated into a business case. The more fouling intense the trade is, the better the business case would in most cases be in terms of the added value from investing in a documented high performance antifouling system. The value comes from savings in fuel, the lower greenhouse gas emissions as well as a better CII rating.

3. Proactive hull cleaning without capture

Summary by Stein Kjølberg, Global Category Director - Hull Performance -Jotun AS & Tom H. Evensen, Regional Category Manager - Hull Performance - Jotun AS

Hull cleanings will be conducted, when the vessels hull surface has passed a certain level of fouling. It is a necessity to keep the hull clean and the fouling below a certain level, to avoid excess fuel consumption which can be as high as 50% more. The industries` practice is to do reactive cleanings. This approach means that the hull-condition and subsequently hull performance deteriorated before fouling will be removed. One challenge is that the higher the level of abrasiveness required to remove ingrained fouling, the greater the likelihood of hull coating damage and erosion. It has been thoroughly documented that hull performance is seldom fully restored, and that new biofouling growth tends to accelerate following each reactive cleaning. Over a full dry-docking interval, the average over period performance loss associated with reactive cleaning can therefore often be substantially.

Pro-active cleaning is a new tool in the biofouling management toolbox. Instead of relying on antifouling properties in coatings alone, coatings are combined with cleaning at a sufficiently high frequency to ensure that any biofouling is removed before it becomes a problem. Consider it as brushing your teeth proactively daily rather than waiting and going to the dentist for a "good scrubbing", later. With a pro-active cleaning approach, biofouling will be removed before it causes a measurable reduction in hull performance, resulting in exceptionally low performance loss and corresponding to this there is a reduction in both carbon intensity (grams of CO_2 emitted per ton-mile) and fuel cost. Biofouling is also removed before it reaches the macrofouling stage and as such before it comes to represent a risk of transfer of invasive species. Finally, the biofouling will be removed before it has rigidly attached to the hull surface and therefore before removing it results in a risk of damaging or eroding the hull coating and thereby also a risk of contaminating the water column. In principle cleaning can be done proactively using any technology platform; divers, brush carts, swimming or crawling ROVs. To get under the definition of pro-active cleaning, however, the cleaning must be done at a sufficiently high frequency (e. g. monthly in a fouling intensive vessel operation) so as to remove any fouling before it becomes a problem and must be done with a sufficiently gentle force so as not to damage or erode the hull coating. A real-life example of changes in hull performance on a reactively cleaned vessel is shown in Figure 25 below. Note the accelerated drop in performance following the reactive cleaning events and that starting point for hull performance is lower following each cleaning event. Average over period speed loss, as per ISO 19030-2, was 6.2%. As compared to keeping the hull always clean by a high frequency of pro-active hull cleanings, the excess fuel consumption and increase in carbon intensity would be around 18.6%. This can be addressed by pro-active hull cleaning.

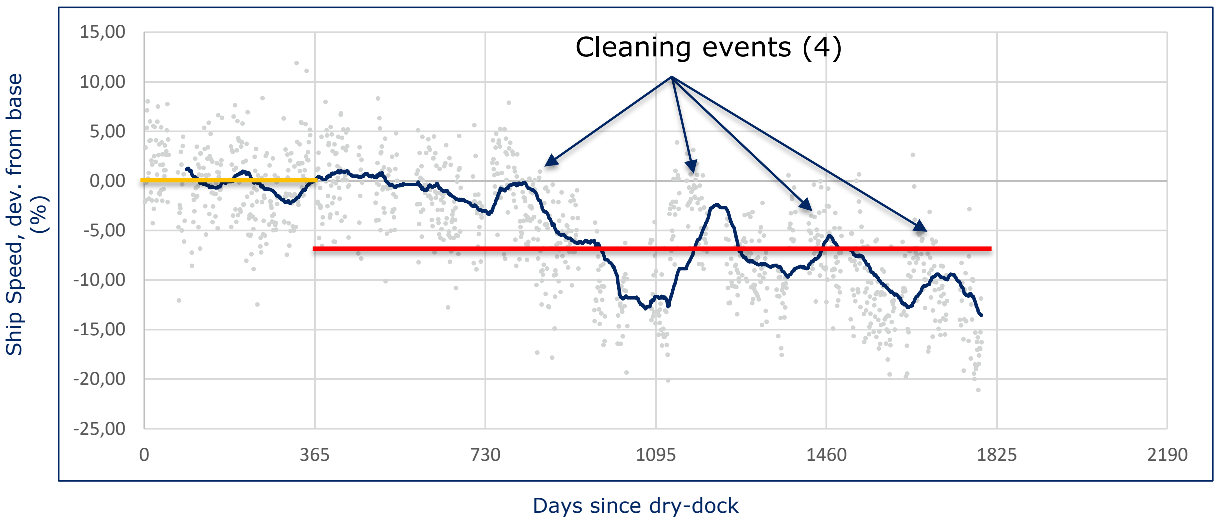

Figure 24 Real-life example of changes in hull performance as per ISO 19030-2 on reactively cleaned vessel

4. Robotic hull cleaning with capture

Summary by Cornelis de Vet, COO – Fleet Cleaner B.V.

Within minutes after submerging an object under water, a conditioning film forms onto the surface. After hours, a complex, multispecies microbial biofilm starts to grow, followed by secondary and then tertiary colonizers: this is the growth process of biofouling. The growth depends on factors such as the operational profile of the ship and the applied type and state of the antifouling. Depending on the stage of biofouling growth, the impact of biofouling on greenhouse gas emissions and fuel consumption can range from 5-60% (IMO GHG Study).

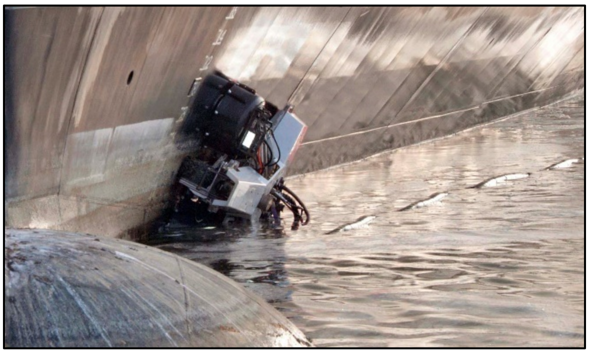

Figure 25: Robotic hull cleaning with capture

Hull cleaning is a widely employed way to reduce fuel consumption for ship operators and owners. Traditionally divers clean the underwater hull with brushkarts without capture. This causes off hire time of the vessel and harm to environment. Over the last decade more and more shipping companies value the advantages of robotic hull cleaning with capture due to the advantages on the environmental impact and the total cost side.

Advantages on the total cost side

Robotic hull cleaning with capture comes with several advantages on the total cost side:

- <u>No operational downtime</u>. Unlike diver operated systems or non-capture systems, robotic cleaning with capture can be allowed even by strict port authorities to be conducted during loading / unloading in ports, resulting in no unwanted vessel downtime for cleaning.
- <u>Safe and high workability operations.</u> The robotic hull cleaning systems have improved workability by operating 24/7 in situations with high current or waves compared to traditional methods, while increasing safe working conditions for service providers.
- <u>Controlled and minimized coating impact</u>. Robotic cleaning solutions are typically equipped with high pressure water systems, which can be adjusted to match the coating and fouling type, thus minimizing the impact of the cleaning operation on the coating.
- <u>Cleaning quality with high coverage</u>. Subsea sensor and navigation technology is an ever-developing field, resulting in reliable coverage of the hull during cleaning and limiting human error, even in limited visibility environments such as ports.

High quality and extensive coverage of the robotic hull cleaning operation ensures maximum reduced fuel consumption in the future and reduces regrowth likelihood of biofouling. This is also to the benefit of the environment. The lower indirect costs outweigh overall the slightly higher direct cost of robotic hull cleaning with capture as compared to traditional cleaning methods.

Further advantages of cleaning with capture concerning the environmental impact:

While fuel saving and thus emissions is often the main driver to start hull cleaning operations, the true total environmental impact of cleaning operations is affected by the following:

- Capture and filter of invasive species. The impact of invasive species is widely documented. Research shows that several potential invasive species which can be released during in-water cleaning can reproduce even when they are below 50 micron in size.
- Capture and filter of biocides and other polluting coating particles. As antifouling coatings with biocides are designed to release these biocides during operation, any hull cleaning operation without capture can locally increase release of these biocides in the aquatic environment, affecting the local biology and food chain.

Robotic cleaning with capture and filtration minimizes the environmental impact of hull cleaning and is the way forward to zero-emission cleaning operations. When combined with proactive robotic hull inspections to monitor hull fouling status, the environmental impact and total cost of fouling are minimized.

12.4 Technology Descriptions – Technical Retrofits

1. Air Lubrication System
2. Biofilm protection based on ultrasound technology
3. Bow Windshield – the "steamlined" Vessel
4. Bulbous bow retrofit
5. Change from HFO to green Methanol
6. Electric Propulsion Concept with Cycloidal Propeller
7. Energy Saving Device – Becker Mewis
8. Flume® roll damping solution
9. Frequency Inverter Retrofit
10. GATE RUDDER™
11. Hybrid Power System
12. Integrated Propulsion and Maneuvering System
13. Marine ORC waste heat recovery
14. Modification of Trailing Edge
15. Propeller Fin Cap
16. Propeller Retrofit
17. Reduction of parasitic losses on 4-Stroke-Medium-Speed Diesel Engine
18. Schneekluth Wake Equalising Duct (W.E.D)
19. Shaft Generator
20. Variable Speed DC Drive and Distribution System
21. Wind Assisted Propulsion: Asymmetrical Air Foils
22. Wind Assisted Propulsion: Flettner-Rotor
23. Wind Assisted Propulsion: Parafoil Wing
24. Wind Assisted Propulsion: Suction Wing VentiFoils

1. Air Lubrication System

Marcel Somers MSc., Alfa Laval Mid Europe GmbH

Introduction

Air lubrication changes the interaction between water and a vessel's hull, reducing the frictional resistance. This reduces vessel drag and therefore fuel consumption and associated emissions. Three types of (hull) air lubrication are identified: Bubble Drag Reduction (BDR), Air Layer Drag Reduction (ALDR) and Partial Cavity Drag Reduction. With bubble-, and air layer drag reduction air is distributed below the vessel. Partial cavity drag reduction is realized by one or more air filled recesses in the vessel bottom section. Air layer drag reduction theoretically leads to the maximum reduction level.

Description

Alta Laval's OceanGlide™ air lubrication system is a solution which reduces the vessel's frictional resistance based on Air Layer Drag Reduction. It is a complementary, independent system retrofitted to an existing ship or integrated into the newbuilt design. The system has been under development since 2014 and addresses several challenges of existing air lubrication systems:

- how the air bubbles are generated
- how the air layer is created, and
- how the air layer is controlled.

In principle the OceanGlide™ System consists of a pool of compressors that feed air through a wing-shaped "Air Distribution Band" (ADB) attached to the bottom of the ship, ensuring optimal coverage of the flat bottom surface. Each ADB generates thousands of air bubbles per second by injecting air through fluidic oscillators mounted into the ADB itself. The amount of air injected by each ADB is independently controlled by the control system, optimizing the performance for loading and sailing condition, respectively.

Micro air bubbles are generated efficiently, using less compressors, to form a homogenous air layer resulting in maximum drag reduction (Air layer Drag Reduction, ALDR, see figure 1). Precise and continuous control of the air layer enables remote optimisation, for best possible performance in each operating condition.

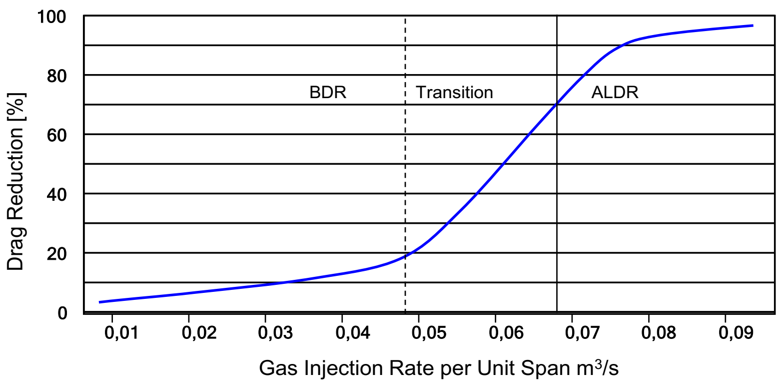

Figure 26: Drag reduction is depending on air flow rate

Application Range

Highest benefits under following conditions: Draft 10 - 12 meter Speeds up to 18 knots	And for following vessel types: Tankers (GP; MR; LR1 & LR2) General cargo/bulk Ro-Ro/Ro – PAX Container vessels	The simplicity of air lubrication means that it can be retrofitted during a planned dry dock.

2. Biofilm protection based on ultrasound technology

Summary by Jan Kelling, HASYTEC Electronics AG

System Description

Ultrasound based marine growth prevention system which keeps surfaces free from marine growth and fouling.

Application areas include: propellers, thruster tunnels, hulls, heat exchangers, sea chests, pipes, filters and freshwater generators.

Advantages

The DBPi system provides and environmentally friendly solution as it replaces coatings and therefore the release of toxins such as heavy metals or other chemical substances into the oceans. The DBPi system is maintenance free and mitigates the need for time consuming maintenance and cleaning of the systems and components it is used for, therfore reducing OPEX costs. It overall improves the lifetime, the utilizability as well as the operationl safety.

In particular when used on propulsion units and hulls, the DBPi system helps to reduce fuel consumtion and therefore CO_2 as well as air pollutants. Through this application the release of toxins into the oceans is reduced. Carrying invasive species to foreign eco systems is also reduced as marine growth on a vessel is mitigated.

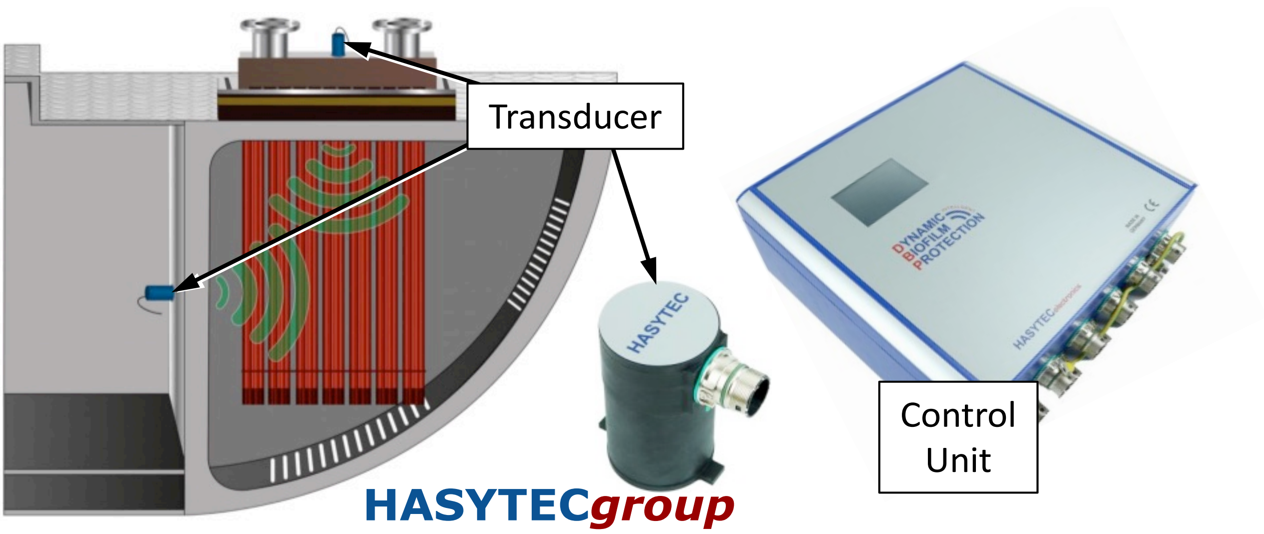

Figure 27: Working principle HASYTEC DBPintelligent, on heat exchanger

3. Bow Windshield – the "streamlined" Vessel

Summary by Dr Tobias Wesnigk, MCN e. V. / WTSH

Wind resistance caused by poor aerodynamics has always played a major role in achieving high speeds and/or reducing fuel consumption. However, mainly land vehicles and aircraft have been considered. Can it help to reduce fuel consumption and thus CO_2 emissions if a ship also receives an "aerodynamic upgrade"? This idea is not a very new: in the beginning of the 1930s the idea of a steam powered "Streamlined Ocean Liner" came up and was published in Geddes´ 1932 book "Horizons" and several design studies followed the years after [87], before flying across the ocean became affordable and popular.

Now, a few years ago, an attempt to equip a container vessel with an aerodynamically favourable extension at the bow in order to reduce wind resistance was made in Japan (Mitsui O.S.K. Lines, MOL). After commissioning and continuous trial operation, it was confirmed that a fuel saving of about 2% was achieved, compared to an identical vessel without this extension, but otherwise under the same general conditions. The results of these tests were already presented back in May 2017 during the Japan Society of Naval Architects and Ocean engineers' spring meeting. In the meantime, this enhancement has also found imitators.

Figure 28: Container Vessel "ONE Trust" equipped with Bow Windshield in 2022 [88]

Application

Favourable ships for this add-on: Container Vessels. It makes sense to equip the vessel with such a kind of Windshield while it´s periodically required dry-docking at a shipyard. As it becomes more and more common to do this conversion/add-on, every shipyard in the world should be able to perform these conversions. The conversion of "ONE Trust" was executed at Qingdao Beihai shipyard in China during the vessel's drydock.

Better aerodynamics, not even suitable for container vessels:

Hurtigruten´s upcoming vessels will have a completely streamlined shape to provide less wind resistance for their zero emission ships [89, 90].

Figure 29: Visualisation of Hurtigruten´s next generation post ship (Hurtigruten / Vard Design) [91]

4. Bulbous bow retrofit

Michael Wächter, SDC Ship Design & Consult

The effect of the bulbous bow is to accelerate the flow by its displacement counteracting the deceleration at the stem. This helps to reduce the bow wave significantly and will result to less resistance, thus fuel consumption, consequently.

Generally, when the operational speed differs from the design speed, a modification/ replacement of a limited area in the forward part of the ship, i.e. the bulbous bow, may be worthwhile.

To save fuel, it has become generally accepted worldwide to reduce the sailing speed of the vessel. But the further the new speed is below the design speed, the more counterproductive a bulb, designed for high speeds, can become. A bulbous bow designed and adapted for the new operational speed therefore can save energy significantly at the new, lower speed in addition to the savings from the speed reduction.

Additionally, it became common practice to optimise the hull form including the bulbous bow, not only for one speed at one certain (design) draught. Nowadays the hull form, thus the new bulbous bow is generally optimized in such a way that it achieves the largest fuel savings across all combinations of draught and speed, weighted by time. For this purpose, the operating profile is simplified to a matrix of 2-3 draughts and 2-3 speeds with an indication of the probability of occurrence.

The optimization of the shape of the new bulbous bow is performed in a limited area only, to keep the construction effort and costs at the shipyard in a reasonable magnitude. The exact boundaries of the hull shape modification are to be agreed between the hydrodynamic experts and the structural designers beforehand carefully. Many aspects are to be observed and a compromise considering manufacturing costs and potential savings is to be discussed intensively.

Application Range

The weight of the steel to be replaced is depending on the size of the vessel and ranges from 100t to 300t and more. As a rule of thumb, the weight of the scrapped bulbous bow is abt. 0.2t/m3 of its volume. The new bulb is about 80% of the volume of the original one caused by the more slender shape thus it is slightly lower in weight.

The benefit highly depends on the operational profile and the differences in the initial design speed and the actual operational speed. Thus, slender containerships, designed for higher speeds are the most obvious and predominant applications for a bulbous bow retrofit.

Figure 30: Courtesy of Hapag Lloyd

5. Change from HFO to green Methanol

Summary by Hinrich Mohr, GasKraft Engineering

The exhaust emissions of engines depend mainly on the utilized fuel and the combustion concept, not on the engine itself. Carbon-containing fuels generates a respective amount of CO_2, but for the impact to the atmosphere the fuel source is of relevance. In case of fossil sources additional CO_2 is generated by the combustion, in case of so-called green fuels from renewable sources no additional CO_2 is produced because it is taken from the atmosphere beforehand within the fuel production process.

Medium-Speed Engine Re-Design:

Although an existing medium-speed Diesel engine is designed for a specific fuel usage, e. g. HFO, it can be modified for the combustion of green Methanol. For such conversion it must be considered that Methanol requires an ignition source. Therefore, for retrofitting a small amount of Diesel fuel amount – Biodiesel can be used as well – is injected by the existing Diesel fuel injection system. By this measure the Diesel engine is converted to a dual-fuel engine, which can operate in Diesel-ignited Methanol mode (Otto cycle) and in pure Diesel mode. The advantage of Methanol is the high knocking resistance, so it can be expected to keep the existing compression ratio of the original Diesel engine. In principle, also a spark-ignited (SI) concept is applicable to Methanol usage, but this requires a complete change to an Otto-cycle engine with quite severe modifications. The Methanol supply into a medium-speed engine can happen by two different concepts: as low-pressure port fuel injection (PFI) before the inlet valves and as high-pressure direct injection (DI) into the cylinder. The PFI solution requires less conversion effort but does not allow the performance and efficiency of the DI concept, which should be close to the original Diesel engine setup. The DI concept requires a modification of the cylinder heads to integrate the Methanol injector.

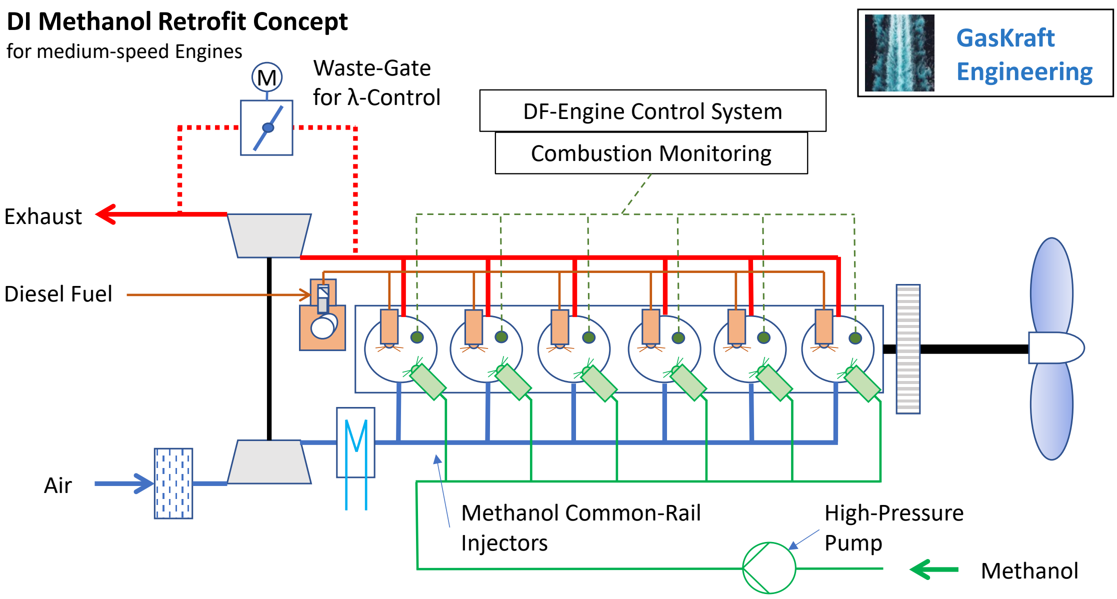

Figure 31: Exemplary engine scheme for medium-speed engine equipped with additional Methanol direct injection system

An important aspect for such conversion is the avoidance of Formaldehyde emissions. This needs to be proven and optimized during commissioning.

Application Range:

A respective engine re-design can be applied to all kind of vessels. The effort and performance differ by the engine type and applied conversion concept. The engineering needs to include specific tank coating and a separate Methanol fuel supply system. Further, the lower heating value of Methanol leads to approximately double the fuel consumption figures than for HFO.

6. Electric Propulsion Concept with Cycloidal Propeller

Summary by M. Stapelfeldt, ABB and Dr. Tobias Wesnigk, MCN e. V./WTSH

Introduction

The new, fully electric ABB Dynafin™ concept has been developed to achieve very high propulsive efficiency, which is directly reflected in lower fuel consumption and lower emissions. In addition, the concept will allow the ship to have excellent maneuverability. These two advantages can significantly reduce operating costs and increase safety at sea. The concept also makes it possible to reduce fuel consumption regardless of the type of fuel used.

In-depth studies, conducted in collaboration with the ABB Corporate Research Center in Västerås, Sweden, have clearly shown that achieving extremely high open water efficiencies of up to 80-85% is both realistic and achievable, and an increase in efficiency of up to 25%, compared to existing propulsion systems in the same performance range, seems possible.

Characteristics

The ABB Dynafin™ solution comprises a cycloidal propeller with individually controlled, vertical blades. Its main elements consists of:

- a main electric motor that
- powers a large wheel rotating at a moderate 30-80 rounds per minute which is
- fitted with multiple vertical blades, each regulated by an individual motor and control system that oscillate in a manner imitating the high efficiency
- movement of a fish tail, delivering up to 25 % efficiency improvement in propulsion

Further advantage: the ABB Dynafin™ generates propulsion and steering forces simul-taneously, offering immediate and stepless/gearless variation of thrust and its direction.

Figure 32: 5-Blade Dynafin™ [92]

7. Energy Saving Device

BECKER MEWIS DUCT® (MD) + BECKER TWISTED FIN (BTF)

Summary by Sören Hildebrandt, Becker Marine Systems GmbH

Power-saving devices are designed to reduce flow losses around the working propeller and therefore improve propulsion efficiency.

The Becker Mewis Duct® (MD) is a novel hydrodynamic Energy-Saving Device (ESD) for full form and slow speed vessels like Tankers, Bulk Carriers, Heavy-Lift- and MPP vessels.

The Becker Twisted Fin (BTF) is a novel hydrodynamic Energy-Saving Device (ESD) for high-speed vessels like Container vessels and others with speeds higher than approx. 17kn.

The design goal of the Becker Mewis Duct® and Becker Twisted Fin in comparison with other ESDs is to improve two fully independent loss sources, namely:

- **Losses in the ship's wake via the duct**

  The duct is equalizing the propeller inflow by positioning a duct ahead of the propeller. The duct axis is positioned vertically above the propeller shaft axis, with the duct diameter smaller than the propeller diameter. The duct is stabilising the fin effect.

- **Rotational losses in the slipstream via the fins**

  Reducing rotational losses in the slipstream by integrating a pre-swirl FIN system within the duct. The chord length of the fin profiles is smaller than the duct chord length, with the fins positioned towards the aft end of the duct

In addition, the installation of the MD or BTF leads to positive effects with propeller cavitation, yaw stability and rpm-stability.

The realistic possible power reduction lies between 3 and 8 % for the MD and between 2.5 and 4% for the BTF.

The average power reduction amounts to 6.0 % for Mewis Duct after more than 270 model test series in 13 different towing tanks. The average power reduction amounts to 3.2% for BTF after more than 65 model test series. This means a significant reduction of CO_2 and SOX to the same extent than the power reduction.

Application range:

Energy Saving devices can be installed on all type of vessels, newbuildings as well as for retrofits. The efficiency strongly depends on vessel type, hull lines (Block coefficient) and propeller efficiency.

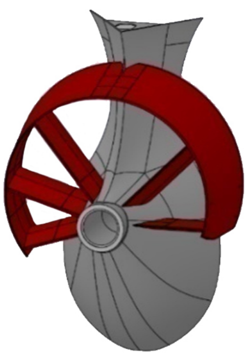

Figure 33: BECKER MEWIS DUCT®

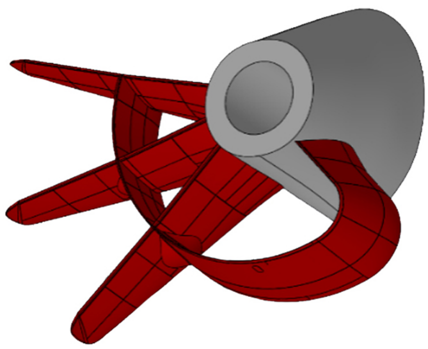

Figure 34: BECKER TWISTED FIN (BTF)

8. Flume® roll damping solution

Summary by Mona Wilhelm and André Marquardt, Hoppe Marine GmbH

The Hoppe FLUME® Roll Damping System is a type of roll damping system individually sized for each specific application. Number of tanks, proper dimensions, shape, location, internal structure and volume are varied to match each individual vessel and its operating condition.

When correctly designed, the liquid flow within the tank will naturally lag the resonant roll motion of the ship by 90°.

This means the tank will create a stabilizing moment directly opposing the moments created by the passing wave.

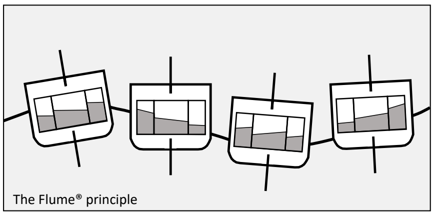

Figure 35: The Flume® principle

The FLUME® stabilization system is a passive roll stabilizer. "Passive" due to the fact, that there are no moving parts necessary for its operation. By a change in the liquid level, the natural response period of the tank is adjusted to correspond to the roll period of the ship.

The achieved roll reduction depends on the actual loading condition, vessel speed and sea state. The system provides its full advantages already at zero speed.

The basic FLUME system is equipped with an operation panel for guiding the crew to adjust the liquid level according to the measured roll period. As an upgrade the system is also available with an Automatic Level Adjustment (ALC) function. This ensures that the tank will be operated at the highest efficiency under all conditions. It requires additional software and hardware and a loading computer interface in the case of application to container vessels.

Advantages of FLUME® for container vessels: The Reduction of roll motions and accelerations increases the cargo and crew safety and significantly reduces the risk to lose containers in heavy seas. Even parametric rolling will be prevented by applying a Flume system.

This reduction is also considered in the lashing rules of major classification societies (BV, DNV-GL, ABS) and therefore allows additional payload. For example, up to 1.5% more full containers (10t) can be loaded on 9,000 TEU.

With a FLUME® on board more than 50% of lashing force conditioned restows can be omitted, e. g. heavy containers on upper positions, which provides more flexibility for the stowing plan. This way the restowing efforts in ports will decrease which reduces port times and costs.

The reduced roll motion has a positive effect on the hull resistance and thus reduces the fuel consumption and finally the exhaust gases/emissions.

Calculated fuel saving, depending on roll angle distribution, taken from real time measurements spanned over 1.5 years from a 5k TEU CV.

RMS Roll Angle	*Overall Distribution*	*Resistance Savings*
0,0°- 0,5°	43%	0,0%
0,5°- 1,5°	46%	1,4%
1,5°- 3,0°	10%	4,0%
> 3,0°	1%	5,1%
Average Savings		**1,4%**

Figure 36: Savings by FLUME ®

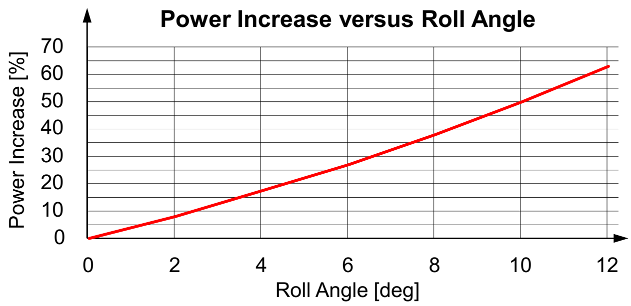

Figure 37: Increasing power demand when rolling

9. Frequency Inverter Retrofit

Olaf Kuss, DIMAR-TEC Pte. Ltd., Singapore

Frequency Inverter proven their reliability in shore industry installations for 40+ years to operate electric motors on variable speeds; on marine vessels they can easily be retrofitted during normal operation. Cooling Water Pump Applications and Engine Room Ventilation Fans operate on the propeller curve. They are designed for 100% Main Engine Load at 32°C Sea Water temperature; however, typical vessel operation is very different.

When operating load dependent, impressive 40-85% savings are achieved, leading to ROI's of 6-15 months (depending on vessel size and operation profile). Electric motors can operate on propeller curve loads with half rpm – typically 30 Hz – without problems. On 50% speed the pumps and fans still provide about half of the volume flow – i.e. cooling capability – but saves up to 87.5% electricity; considering typical Frequency Inverter losses of 2%, maximum savings of 85% are achievable.

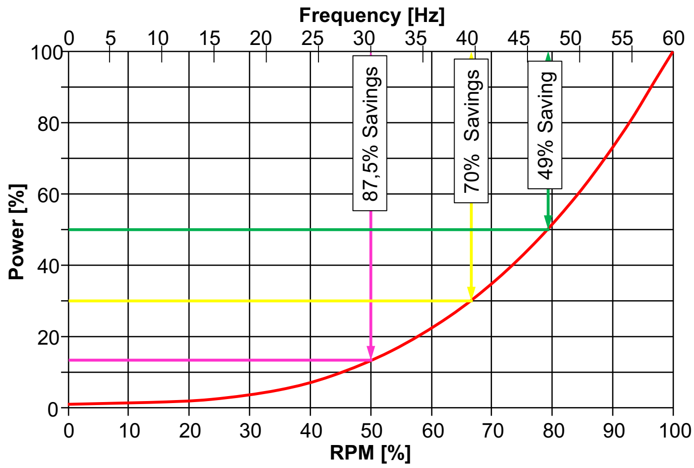

Figure 38: Power Savings

A retrofit shall focus on professional installation to avoid Electro-Magnetic Compatibility (EMC) problems, as inverter causing noise in the motor power cables. Proper system integration in the existing Alarm-and-Monitoring system and operational procedures are essential to maintain existing class-required safety features. To enable highest savings the retrofit system shall export the operational data for remote optimisation support, as vessel-specific fine-tuning is only possible with the main engine on high load in tropic waters; a condition seldom available during commissioning on board.

The graph (*Figure 2*) demonstrates how the new Sea Water pump control matches perfectly with the existing LT-Bypass Valve control on board. Even under tropic conditions and a Main Engine Charge Air Pressure around 2 bar the 90 kW rated SW pump operates around 40 kW.

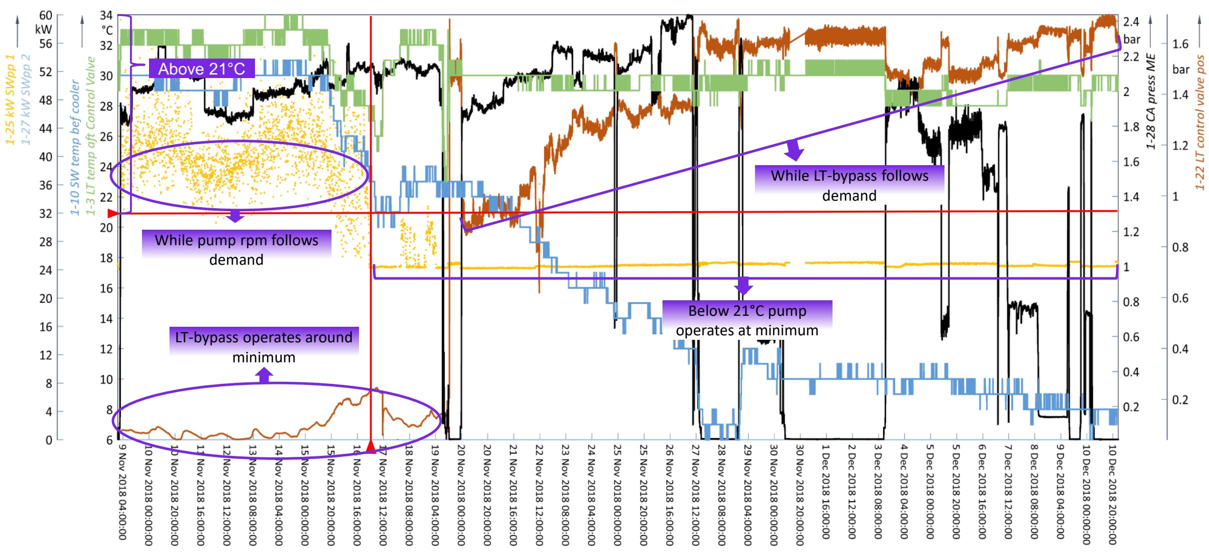

Figure 39: Load Profile Sea Water Pump 90 kW

10. GATE RUDDER™

Lucca Arnim Ratz, WÄRTSILÄ Germany GmbH

Short Summary

GATE RUDDER™ BY WÄRTSILÄ, reduces a vessel's fuel consumption by replacing the drag of a traditional rudder system with a thrust-generating arrangement. The arrangement also provides enhanced manoeuvring capabilities and improves the noise and vibration signature. Placing the high-lift rudder foils on either side of the propeller enables turning at higher speeds, faster course changes and quicker crash stops.

Description

GATE RUDDER™ BY WÄRTSILÄ is an innovative energy-saving and manoeuvring device with a unique design formed of two foils on either side of the propeller. During transits, the resulting thrust performance is increased due to the beneficial hydrodynamic effects of the propeller and steering system. Unlike a traditional rudder arrangement, during transits the gate rudder foils can rotate their angular position, changing the hydrodynamic load on both the propeller and the foils. This is proven to have a positive effect on efficiency, particularly during changeable sea conditions, weather or currents. For manoeuvring purposes, the function of the foils changes the gate rudder from a thrust-generating to a thrust-directing device.

The resulting reduction in fuel consumption depends on the vessel type, its operational profile and on the reference propeller and rudder. Vessels with highly loaded propeller systems, such as container or multipurpose vessels, can achieve the highest power savings. Power savings for any vessel can be estimated by Wärtsilä once the input parameters are known but are typically significantly higher than 5%. The main application for gate rudder technology is single-screw vessels.

The ESD also improves manoeuvring performance by making it possible to decrease turning circles with higher turning speeds. Using the crabbing mode, thrust can be generated at angles of up to 80 degrees, which could eliminate the need to use tunnel thrusters in specific cases.

By placing the rudders sideways of the propeller, the propulsion system of new vessels can also be shifted aft wards which adds additional cargo space and further enhances efficiency of the vessels operational profile.

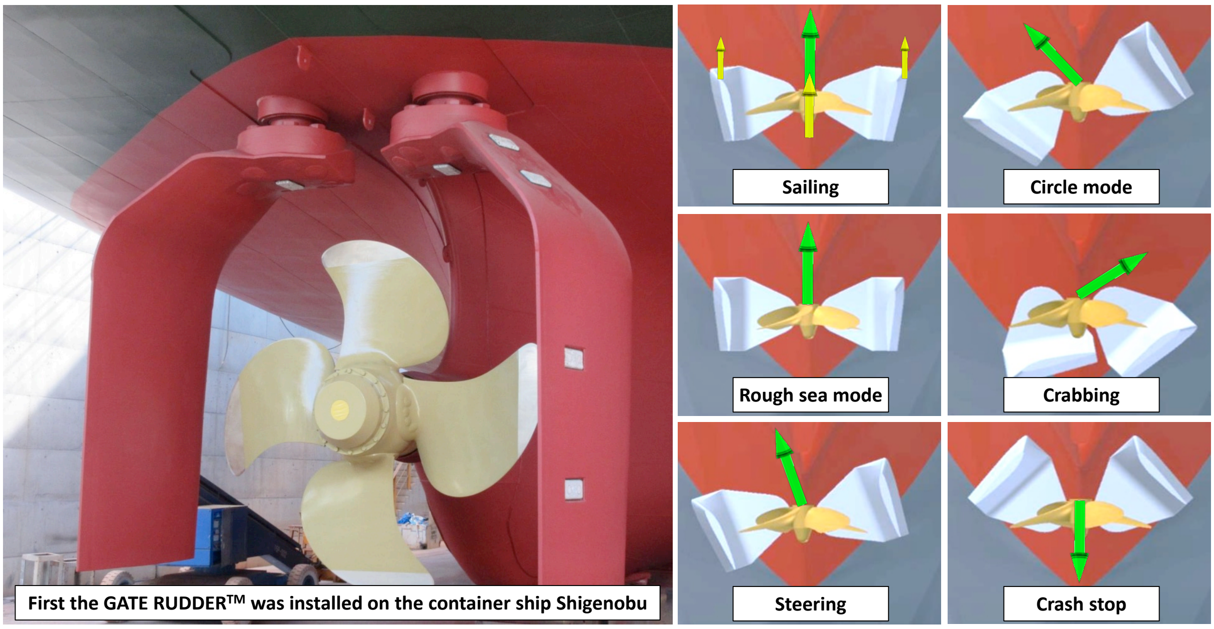

Figure 40: Different operation modes as well as the first installation onboard of the test vessel MV Shigenobu in Japan.

11. Hybrid Power System

Summary by Uwe Heine, Wärtsilä Deutschland GmbH

Hybrid propulsion is the most flexible known today. All vessels will be hybrid at some point in the future. Advantages are already today positive return of invest and reduce installed power.

Vessel operations will be optimized by hybrid functionality such as peak shaving, load optimization and spinning reserve. In this content thruster mode and crane operations can be optimized, too. Further, zero-emission operations e. g. close to port are possible.

Fuel consumption reduction can achieve values from 7 % up to 25 %.

A hybrid vessel is not done by adding a battery to the propulsion power train. The hybrid control system gives the optimization functionality to the vessel and safeguards battery lifetime.

These hybrid control systems are not yet available on the market, only the experienced hybrid integrators come with a solution. A standard power management system only turns the battery on and off on a hybrid vessel and will not deliver its functions. The conventional PMS cannot safeguard charging / discharging speed that is so important to keep battery lifetime as engineered.

The main applications of the hybrid technology are the peak shaving and the optimized power reserve.

Peak Shaving: transients increase fuel consumption and emissions. The energy storage will reduce transient loads in engines. It will further reduce engines wear and tear, the fuel consumption and maintenance costs.

Optimized power reserve: redundancy requirements require min. two engines to run. An energy storage can be accepted as a redundant power source. Means fewer engines are required to run and the running engines can be operated more efficient on higher load. The dynamic response will be improved. This results in reduced fuel oil consumption and maintenance costs.

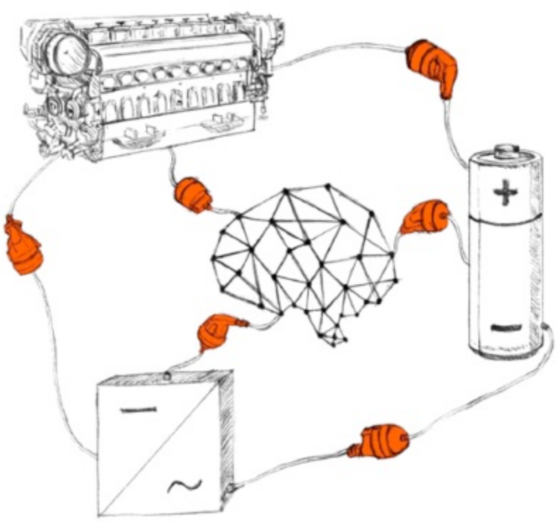

Figure 41: Hybrid power system

12. Integrated Propulsion and Maneuvering System

Summary by Kai Lindenberg (Kongsberg Maritime Germany) with support of Ph. D. Joakim Hirvonen Grytzelius, Kongsberg Hydrodynamic Research Centre.

The integrated propulsive system is designed as one unit to improve the propulsive efficiency, increase maneuvering performance while reducing noise and vibration. It is equipped with an optimized bulb which gives additional positive effects. The bulb optimizes the hydrodynamic properties by nearly eliminating the buildup of hub-vortices, reduces hub drag and improves the flow that allows for a more efficient propeller design with a very homogeneous thrust distribution.

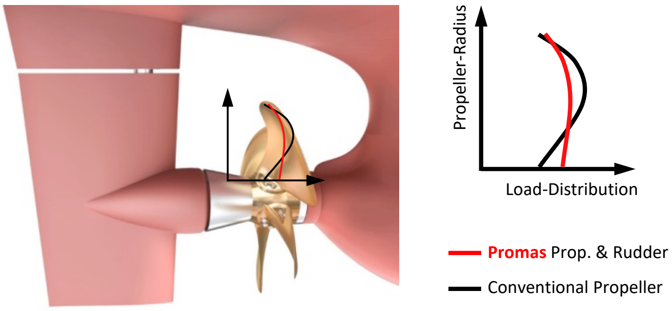

Figure 42: Promas for a single screw vessel including graph illustrating the change in propeller blade loading for improved system efficiency.

For most retrofits, the efficiency gain of this concept is further enhanced by also adapting the propeller design to any change in operation profile compared to original design criteria. Such adaptions result in quite significant fuel savings, often more than 10%.

The **Pr**opulsion and **Ma**neuvering **S**ystem (Promas) was introduced to the maritime business in 2008 as a response to shipowner´s and operator´s demand for fuel reduction whilst avoiding complex and unproven design features on the propulsor. The integrated propulsive unit consists of a propeller, a propeller Hub-Cap, a hydrodynamically corresponding rudder bulb, and a twisted rudder (twisted rudder only for Newbuilds), designed as one propulsive unit to achieve the best compromise between efficiency, cavitation and propeller induced pressure pulses. For upgrading/retrofit projects in which the existing rudder won´t be replaced, this system can be installed to optimize the propulsive unit. It consists of a re-bladed propeller, hubcap, and the bulb mounted on the existing rudder.

Application Range

Promas (for Newbuild) and Promas Lite (refit version of Promas) can be applied to most kinds of vessels with Controllable or Fixed Pitch Propellers. Depending on vessel type and number of propulsors the efficiency gain will differ. However, the improvements are individually calculated and estimated from case to case.

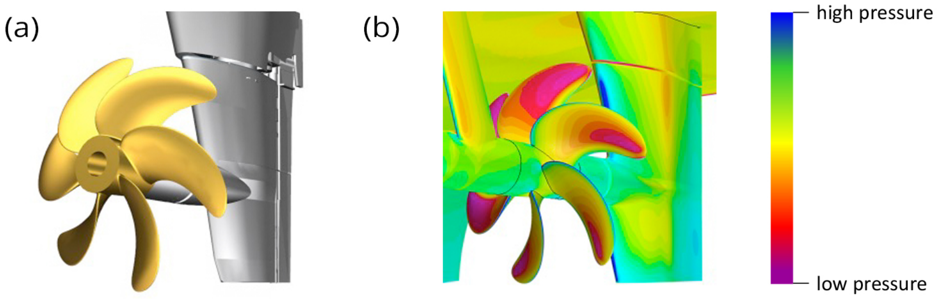

Figure 43: (a) Illustration of Promas with a fixed pitch propeller adapted for a twin screw vessel. (b) show a CFD pressure distribution plot from the optimization process from the same system as in (a), (red/blue colours represent low/high pressure regions, respectively.

13. Marine ORC waste heat recovery – transferring waste heat into sustainable electricity Orcan efficiency PACK / Alfa Laval E-PowerPack (licensed product)

Summary by Marcel Flipse, Head of Marine Applications, Orcan Energy AG

The Orcan efficiency PACK is a modular system for generating power from waste heat based on ORC technology principle. An ORC is a physical principle in which an organic working fluid instead of water is used. The high-temperature waste heat is extracted from its heat source (exhaust gas, thermal oil or steam) via a heat exchanger and transferred to the efficiency PACK by means of an intermediate hot water loop.

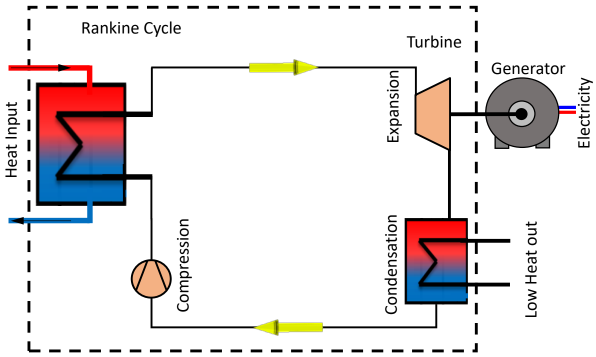

Figure 44: Rankine cycle, principle

Jacket cooling or HT water is fed into the efficiency PACK directly. The waste heat enters the cycle via the evaporator and drives the ORC in the efficiency PACK. In the evaporator the refrigerant is vaporized and routed to the expansion machine as superheated vapour. Here the highly pressurised refrigerant is expanded, thus releasing mechanical work and driving the rotary screws in the expansion machine. This rotational energy is in turn used to drive a generator (included in the module) that produces electricity. After the expansion machine the still gaseous refrigerant is liquefied again in the condenser and then re-pressurised by the feed pump. The electricity output can be fed into the on-board grid, nearly maintenance-free.

Advantages:

- Significant fuel savings & carbon dioxide and other hazardous emissions reduction
- Attractive NPV (Net Present Value) and IRR (Internal Rate of Return) on investment made
- Accumulated free cashflow positive from day 1 of start deployment
- Improvement of the Energy Efficiency Design Index (EEDI) and EEXI/CII for existing ships
- Operates independently of type of fuel used
- Reduced carbon tax (when introduced by EU & IMO) payments
- Compensation for extra air compressor electrical power when Air Hull Lubrication technology is applied on vessels
- More propulsion power available due to less shaft generator power demand (only in case of a shaft generator present)
- Well selected and class approved rugged marine components that requires minor scheduled maintenance, 0.32 Euro /running hour & first TBO at 120,000 running hours.

Figure 45: Orcan efficiency PACK HP ePM 50.100 HP

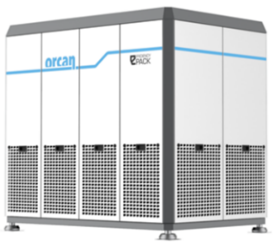

Figure 46: Orcan effciency PACK eP M 150.200 EPP100

14. Modification of trailing edge

Ronja Topp, Mecklenburger Metallguss GmbH

Short Summary

Running a propeller in a permanent heavy load condition can be problematic. There can be various reasons for the situation, such as a poor propeller design, an aged and slightly deformed hull or a retrofit that puts additional load on the propeller shaft, such as a shaft generator. In ship operation, it can then happen that the propeller runs too heavily, which is particularly problematic in unfavourable sea and weather conditions. Under such circumstances, it is often not possible to achieve the desired RPM even with increased fuel supply and the propeller curve comes dangerously close to the torque limit of the engine, a propeller-specific trailing edge modification is a potential solution, applicable to existing propellers of vessels with heavy running issues.

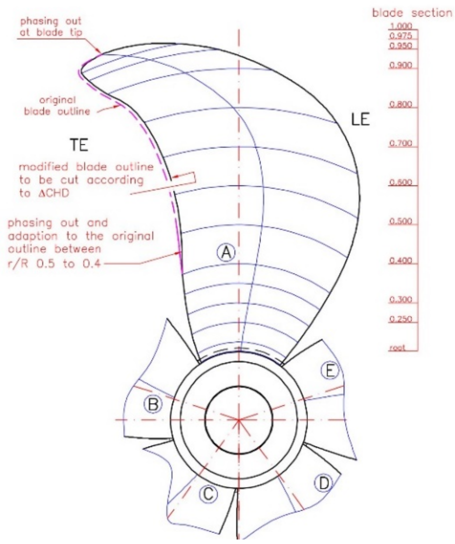

Figure 47: Overview on the edge modification

Description

The modification of the blade trailing edge represents a technical measure aimed at aligning the propeller to its operational profile. This approach avoids reducing the propeller diameter to reduce torque of heavy running propellers, as this would potentially be accompanied by a loss of propulsion efficiency. The trailing edge is reshaped to shorten the chord length and reduce the local pitch resulting in a smoother propeller operation. It is done by a parabolic rounding of the pressure side contour towards the suction side. Depending on the pitch profile design, the modification extends from the blade radius above 0.30R to the blade tip. If necessary, additionally the blade outline may be cut based on the original design of the profile trailing edge, to be able to round the trailing edge completely from the face to the back.

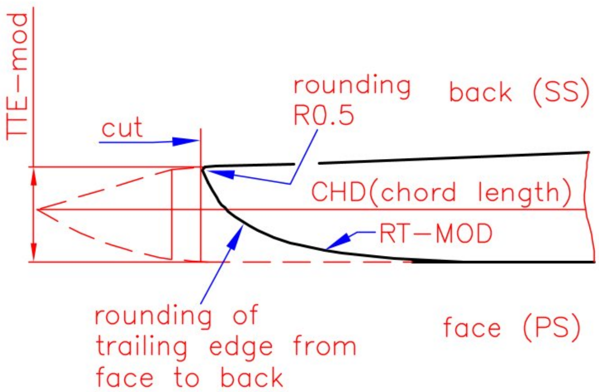

Figure 48: detailed view on the edge modification

Overall, modifying the trailing edge of the propeller can significantly enhance performance characteristics without compromising the fundamental geometric dimensions. These adaptations require precise analysis and implementation to ensure an optimal tailoring to the specific operating conditions of the propeller. This approach not only enhances the efficiency of the propulsion system but also sustains the longevity and reliability of the propeller over time.

As the position of the propeller curve is optimized in the engine diagram, a region of lower specific fuel consumption can be targeted, thereby a trailing edge modification contributes to reduced emissions and operating costs.

Application Range

For all types of vessels already in service with heavy running issues, the trailing edge modification is a simple solution to adapt the propeller design to the changed operating conditions. This reduces fuel consumption and operating costs.

15. Propeller Fin Cap / MMG ESCAP®

Summary by Dr. Lars Greitsch, Mecklenburger Metallguss GmbH

Short Summary

The basic principle of a propeller follows the wing theory whereas the lift of the wing is based on a system of bound vortices. Changes in the vortex system over the sections of the wing or blade cause free vortices. The propeller hydrodynamic shows this flow phenomena as a tip vortex and a hub near vortex. As the tip vortex can be influenced by special tip geometries the hub near vortex of each blade of the propeller forms a joint hub vortex. This hub vortex generates losses for the propulsion system.

Description

A propeller fin cap is able to regain a part of these losses by straighten the vortex due to small fins standing behind each propeller blade as a fixed part of the propeller cap. The change of the hub near flow downstream of the propeller lead to two positive effects. First of all the flow around the fins generates a positive torque to the system of propeller an cap which increases the efficiency of the propeller. As a second effect the pressure distribution at the end plate of the propeller cap is pushed towards higher pressure as the undisturbed hub vortex leads two to low pressure due to its strong vortex core. An increase of this pressure region downstream reduces the drag to be effective.

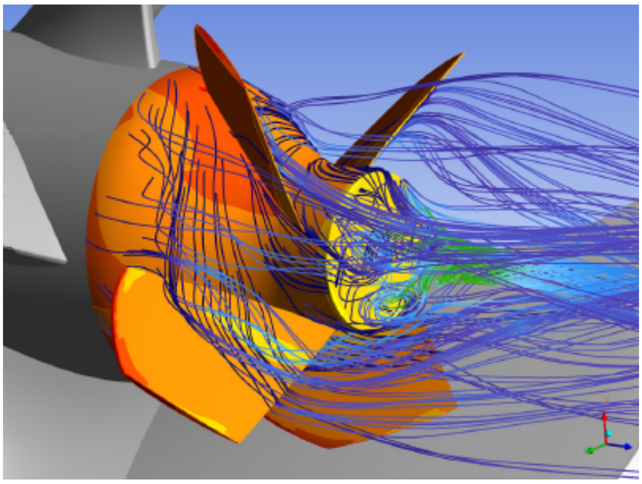

Figure 49: Hub vortex system with application a propeller fin cap

Application Range

Propeller fin caps can be applied to all kind of vessels. But depending on the configuration the possible efficiency gain can differ. A significant influence on the achievable efficiency is the blade characteristic of the propeller and therefore the strength of the unhindered hub vortex system. For propeller application whereas the hub vortex does not show a strong vortex core the possibility of regaining losses is limited.

Figure 50: mounted fin cap in the workshop

Propeller fin caps can be applied already for newbuildings and easily as a retrofit measure as only the cap has to be changed. Constructional requirements of course have to be checked regarding the junction between propeller and cap. For newbuidlings a competitive measure to the fin cap is the rudder bulb with positive effect on the pressure distribution behind the propeller cap but with no ability to regain positive torque.

16. Propeller Retrofit

Summary by Dr.-Ing. Lars Greitsch, Mecklenburger Metallguss GmbH

Short Summary

Propeller performance is highly depending on the hydrodynamic design considering all influences and restrictions as hull form, engine type and the operational scenario of the vessel. In case of changes of the operational matrix e.g., the maximum speed, other restriction as cavitation safety and strength requirements must be revised while focusing the maximum possible propulsion efficiency.

Description

The process of optimising a high efficiency propeller starts with finding the optimum main dimensions for the specific application. Depending on the speed range of the vessel and the main engine parameters, the design can vary the number of blades, blade area and the radial distributions of pitch, chord, skew and rake. In the case of a redesign, the change in the ship's operating range will result in new optimum geometric (main) dimensions, even if the same design routines are used as in the earlier newbuilding phase for the original propeller.

Furthermore, the design routines benefit from a dynamic development of the hydrodynamic toolbox usable for propeller related simulations and calculations. This ends up in additional efficiency gain for redesigns, even if all design requirements remain the same as in the original specification. But in case the new design specification includes lower vessel speeds and a lower maximum power level, the propeller design restriction can be loosened for two decisive items. First, the consideration of the cavitation behaviour of the propeller regarding possible erosive cavitation phenomena allows more design freedom if set on a lower speed and power basis. Secondly the strength layout of the new propeller can lead to a slenderer profile for the propeller sections if related to a lower speed and power basis. This leads to a decrease in propeller weight and performance-wise to a higher propeller efficiency.

Figure 51: retrofit propeller and original propeller in the dock

Application Range

Propeller retrofits can be applied to all kind of vessels. But depending on the configuration the possible efficiency gain can differ. Significant influences on the achievable efficiency are the design quality of the original propeller and a possible change in vessel operation, at best

17. Reduction of parasitic losses on 4-Stroke-Medium-Speed Diesel Engine

Summary by Dr Tobias Wesnigk, Maritime Cluster Northern Germany e. V.

Introduction

In the past the overall efficiency of two- and four-stroke large-bore diesel engines was unreached by any other combustion engine application. Besides fuel consumption, durability and robustness were the major development targets. Efforts to improve the combustion process it-self increased exponentially with new technologies like high-pressure common-rail injection and increased charge-air pressures. For further improvement large-bore engine community must unlock new potentials from other efficiency-influencing engine parameters. One of them is the improvement of the mechanical efficiency. Bearing dimensions, lube oil and cooling water temperatures, lube oil flow rates and friction between partners like piston/piston rings and liner are just a few points were a large-bore marine engine is a victim of its own conservative design.

Approach

Example: One of many other measures is a controlled and demand-depending oil flow and temperature, as it is state of the art for smaller engines, and it will help to lower primary energy consumption. Therefore lube-oil-pump should be electrically driven and regulated, and lube-oil-temperature should be increased load dependently, if possible, to lower the viscosity of the oil.

A comprehensive research project showed a lot of potential:

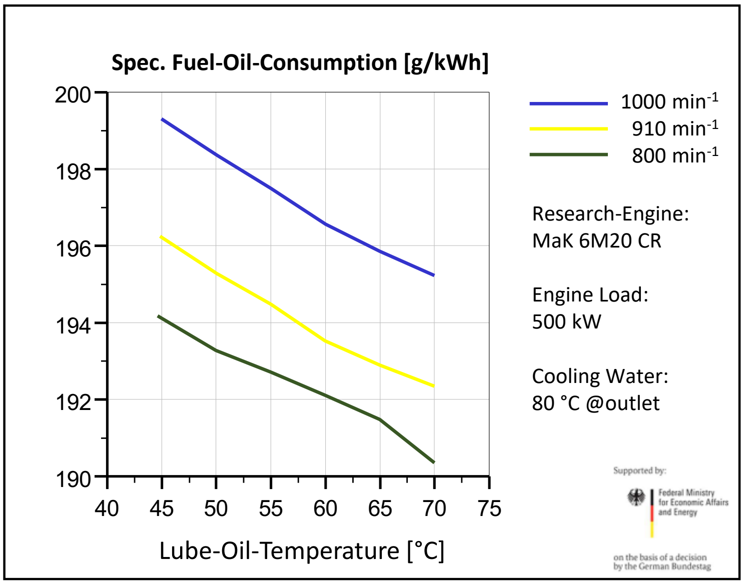

Figure 52: Reduced Fuel-Oil-Consumption at higher Lube-Oil-Temperature

The Research-Project was funded by the Ministry for Economic Affairs and Energy: "eta-up – Steigerung des Gesamtnutzungsgrads und Reduzierung der Reibverluste am mittelschnell-laufenden Schiffsmotor" (project number: 03SX419A).

Special thanks to Caterpillar Motoren GmbH & Co. KG, IST GmbH, Technical University Braunschweig, ADDINOL Lube Oil GmbH, FEDERAL-MOGUL Burscheid GmbH, M. JÜRGENSEN GmbH & Co KG, KS KOLBENSCHMIDT GmbH, RICKMEIER GmbH and ZOLLERN BHW Gleitlager GmbH & Co. KG for supporting this project.

18. Schneekluth Wake Equalising Duct (W.E.D.)

Summary by Peter & Eckhard Ostra, Schneekluth Hydrodynamik Entwicklungs- und Vertriebsgesellschaft mbH

Compared to the ship's speed the intake velocity of the water in the upper region of the propeller disc is slowed down considerably. For ships with a high block coefficient (CB) this can amount to approx. 75% of speed. In the neighbourhood of the lower blade tip of the propeller the velocity is close to the ship's speed. Compared to a uniform situation this means loss of efficiency.

The W.E.D. counteracts this loss leading to a more uniform wake field by being positioned in front of the upper part of the propeller. The opening through which the water enters is larger than the one through which it leaves the duct, leading to increased velocity in an area where it is most desired. Moreover the W.E.D. not only increases the flow in the area behind its opening, it also slows down the flow around it. The result of the W.E.D. averaging effect is an improvement of the propeller efficiency and therefore saving in power.

Figure 53: W.E.D. on hull

Suppression of flow separation

Water flowing to the aft body of the conventional type merchant vessel tends to lose too much speed which leads to flow separation and loss of energy. The duct counteracts this phenomenon by causing a circulating flow which is directed towards the hull. The effect is that the water flow is pressed against the hull, leading to a lower drag. To achieve the best effect, the length of the duct is selected between 0.5 – 0.8 times inside diameter.

Further positive side effects:

Reduction of vibration levels due to a more even loading at the propeller tips.

Reduces danger of cavitation erosion due to improved inflow into the propeller.

Improved course stability and rudder action: the W.E.D. causes the point of application of the resulting flow forces to move further aft and accelerates water flow to the upper part of the rudder.

Drag compensation: like any nozzle, the W.E.D. develops thrust. This thrust is larger than its own drag.

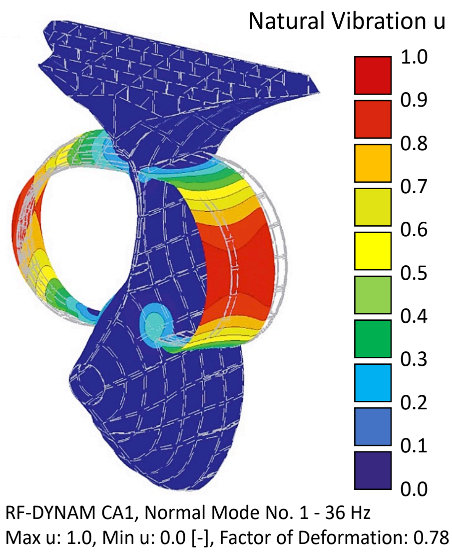

Figure 54: Natural Vibration

Some more facts:

Around the world thousands of ships can benefit from the wake improvement duct leading to reduced fuel consumption.

No structural modifications to the ship, propeller or rudder are required, which, together with the low investment, leads to remarkably short pay-back times.

The wake improvement duct is extensively patented by Professor Schneekluth.

19. Shaft Generator

Summary by Uwe Heine, Wärtsilä Deutschland GmbH, Sven Schemmink, RENK GmbH, Prof. Dr.-Ing. Axel Rafoth, University of Applied Sciences Wismar

Sea ships have different options to generate electrical power for both the ship's operational equipment as well as crew accommodations or cargo in terms of fridge containers. One option to do is a gen-set that burns a large volume of marine diesel fuel, which increases the operational cost, requires more frequent maintenance of the generator engines and contributes to air pollution. As merchant vessels sail long distances in the deep sea during most of the time they operate, fuel economy is the most important factor after safety and reliability.

Shaft generators today experience a significant rise in demand. This is mainly due to tightening emission regulations. A shaft generator (SG) driven by the ship's main engines will lead to less diesel generator fuel consumption. But saving money on fuel is only part of the equation. Because of tightening emissions limits for ships, the most important argument to apply a shaft generator is to increase efficiency – the less fuel burned, the lower the emissions.

The shaft generator concerning rpm (rotational speed) may be applied in two variants:

a) Constant speed shaft, direct grid connection what requires a controllable pitch propeller at the main shaft. Traditionally, the cons of this arrangement are that the propulsion engine could be run only at constant speed. Because the ship network frequency by the synchronous generator is tied to propeller rotational speed. Any change in speed has a direct impact on network frequency. Therefore, thrust and ship speed only can be controlled by changing the propeller pitch which can lead to decreased efficiency and increased CO_2 emissions.
b) Variable main shaft speed may be applied with fixed pitch propeller but requires a frequency converter between generator and on-board electrical power system to enable efficient and reliable power generation.

For mounting shaft generators we can have two options:

a) In line mounting: These systems are available in slow speed technology, where the generator is directly mounted on the main propulsion shaft, approx. 95 % of all shaft generator installations.

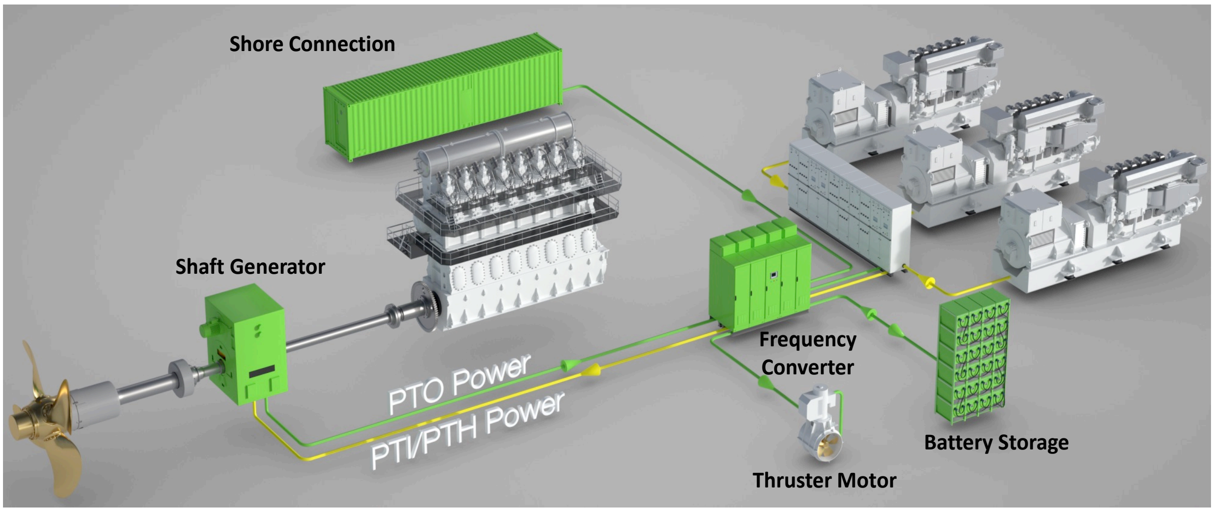

Figure 55: Shaft generator in a hybrid set-up (Wärtsilä); Inline systems proposed Wärtsilä Deutschland GmbH

b) Gearbox operation: In medium speed technology the shaft generator is driven via a gearbox or a tunnel gearbox aside from the main shaft.

c) Front-end shaft generator systems: These systems consist also of generator system, maybe a frequency converter– similar to conventional shaft generator systems. The separation of the generator and the crank shaft resp. propeller shaft by a flexible coupling allows minimal air gaps between stator and rotor, reducing the losses inside the generator.

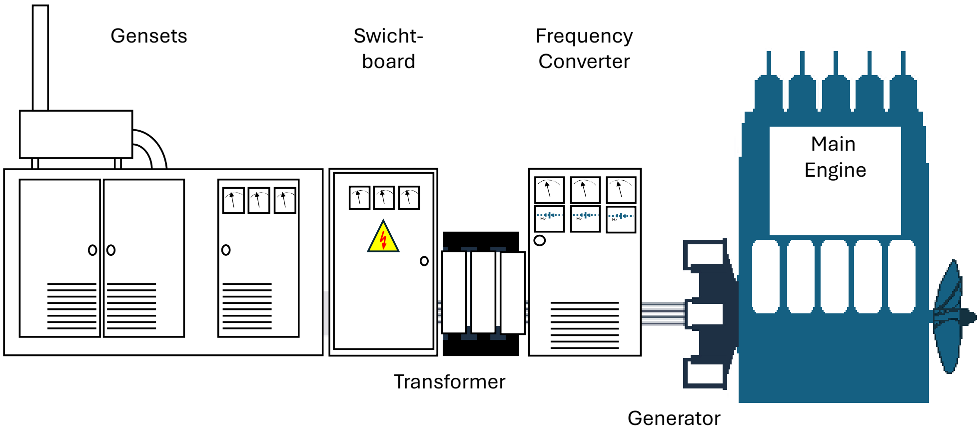

Figure 56: Front end shaft generator in a hybrid set-up (Systems proposed by RENK)

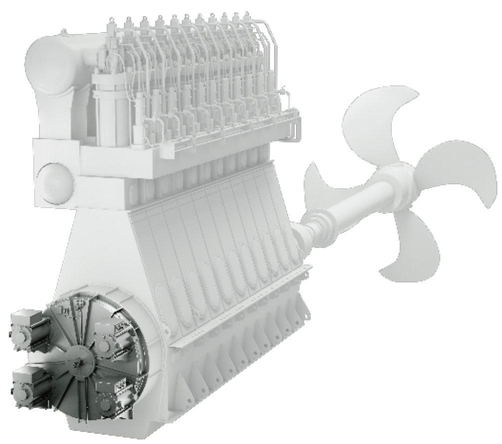

Figure 57: Front end shaft generator in a hybrid set-up (RENK)

The system with compact parts allows the front-end shaft generator to be applied comfortably as a retrofit solution. Other than an inline shaft generator retrofit, the retrofit of a front-end shaft generator is conducted without new propeller shaft alignment. The installation gets by without a separate foundation, as the system is directly flanged to the main engine. Comparably small and light parts allow easy installation in the constrictive surrounding of the main engine room. Hence a front-end shaft generator retrofit can be conducted without long drydocking periods.

All the generator systems are available in the same voltage range and about the same power range. As generators can be applied high efficiency permanent-magnet generator or an electrically excited synchronous generator.

Main function of shaft generator is generating power while sailing at sea, called PTO power take out.

Other options are available (only together with full converter system, operating 4 energy quadrants):

1) PTI (power take in booster motor), here the auxiliary diesel engines supply additional drive energy, also at big cargo ships a steam turbo generator can be used to recover steam energy and supply it to the main shaft to increase overall efficiency (but difficult under slow steaming).
2) PTH (power take home), shaft generator becomes motor supplied form auxiliary diesel generators to come home safely if main engine is broken and propeller shaft can be separated.
3) Harbour supply system: The converter system is used to adapt voltage and frequency to a shore supply system. It easily can be synchronized, via the converter. So, in harbour the auxiliary diesel engines are not running (but be aware of shore power energy mix).

20. Variable Speed DC Drive and Distribution System

Summary by Sven Ropers, Siemens AG and Robert Banek, RENK GmbH

In DC-Bus Energy distribution systems all sources of electrical energy (e. g generators, batteries, fuel cells, shore connections, solar panels etc.) are connected to a common DC bus via inverters irrespective whether they supply AC or DC. The same applies for all larger consumers. For redundancy the DC bus typically consists of at least two units that can be operated independently and can be placed in separate rooms. This holistic approach to diesel-electric vessels increases safety, cuts operational costs, improves lifecycle economics and decreases the environmental footprint.

Advantages

- Due to the fact that generators do not feed a common AC network with a fixed frequency they can be operated with variable speed which offers significant fuel saving potential. Combustion engines usually have poor efficiency when operated at low torque / power at nominal rpm. In a DC-Bus system generator rpm can be reduced according to required power. Whenever the total power demand is lower than nominal power the generator is operated at optimal rpm with optimal efficiency.
- DC-Bus allows generator operation without the need for synchronization which results in a very short generator startup time. Thus, generators can be switched off earlier and more frequent leading to less generator uptime and less fuel consumption.
- Option to use battery power to reduce engine running time and provide further savings in fuel and greenhouse gas emissions
- Easier integration of energy sources such as fuel cells (DC), Photovoltaic systems (DC), wind turbines (variable frequency)

-

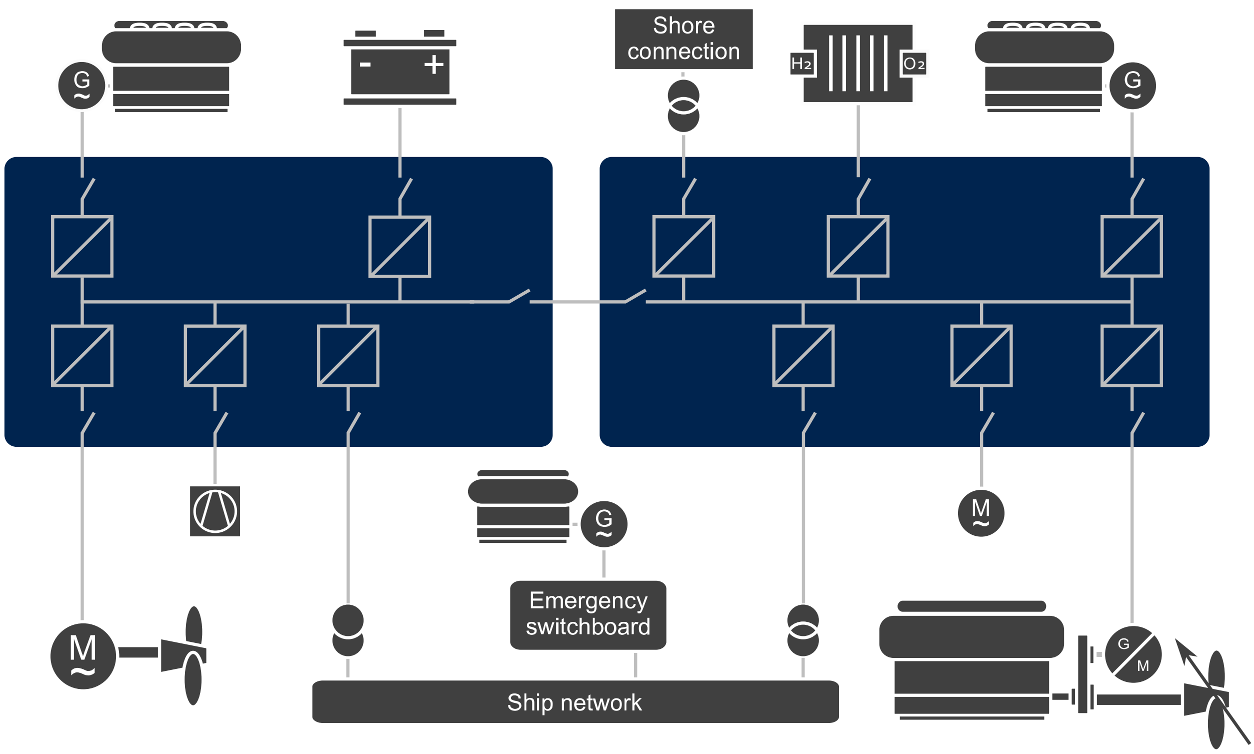

Figure 58: General topology of DC-Bus system

21. Wind assisted Propulsion: Asymmetrical Air Foils Technology

Summary by Saar Carmeli, NayamWings Ltd., Hanno Wiese, InfraStrat GmbH

Overview

The asymmetrical Air Foils Wind-Assisted Propulsion Technology draws inspiration from the aerospace industry, utilizing wing-like structures akin to airplane wings. The technology was successfully tested in two proof-of-concept models: an 8-meter wing tested in open sea conditions and a 3-meter autonomous craft used to refine the control algorithms.

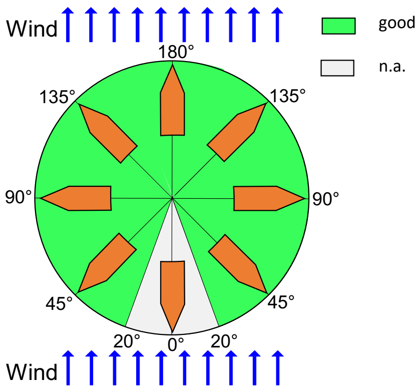

Figure 59: Courses where system still creates a thrust

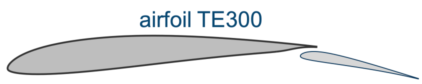

Figure 60: NYW TE 300 Cross-Section

Working Principle

Existing systems from NayamWings Ltd. use multi-element asymmetrical air foils with patented technology allowing rotation along both vertical and horizontal axes. Wind flowing over and between these air foils triggers the Bernoulli effect, generating lift. The wing bends the wind at precise angles to enhance propulsion. The streamlined design minimizes drag and turbulence, ensuring efficiency. With a lift-to-drag ratio of 6.25:1, it maximises thrust. The wings autonomously adjust to the optimal angle of attack. The aerodynamic design remains effective at narrow angles (±20°) and adjusting wing roll angles improves stability.

Energy Savings

In terms of propulsion effect, modelling has shown that under normal operating conditions (vessel speed 13 kts, true wind speed 16 kts) each 36m sail will contribute on average over the full operating course angle range 156 kW/h.

For a retro-fit Panamax-size vessel this can realistically achieve fuel savings of 1.75 tons per day per wing. With the installation of the usual four wings system, this potentially translates to approximately 7 tons per day in fuel savings.

Based on above modelling this creates fuel advantages for retrofits between 15-25% and for new-builds of up to 35% in conjunction with engine load adaptations and hull and propeller optimisations.

Figure 61: Ship with an autonomous 4-wing system

22. Wind assisted Propulsion: Flettner-Rotor

Summary by Dr. Tobias Wesnigk, MCN e. V. / WTSH

The Flettner-Rotor is a wind propulsion system consisting of a tall vertically aligned cylinder with two end discs/end plates which is rotated along its vertical axis. When air passes across the rotating cylinder, the **Magnus-Effect** causes an aerodynamic force in the direction perpendicular to the air flow (Force F_2, see Fig. 63) and in the direction of the airflow (F_1). The Flettner-Rotor sail is named after the German aviation engineer and inventor **Anton Flettner**, who started developing the rotor sail in the early twenties of the 20. Century.

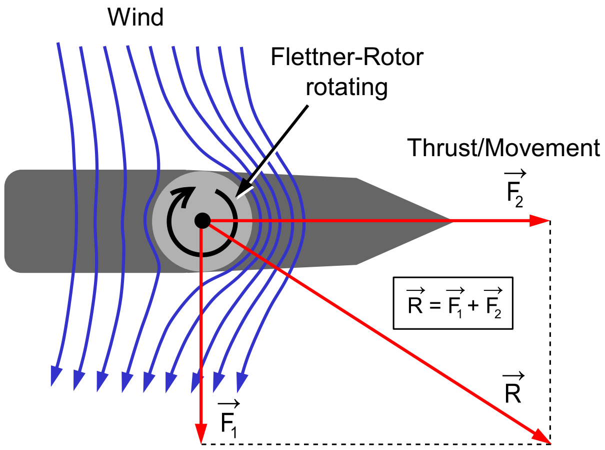

Figure 62: Forces on the Flettner-Rotor [91]

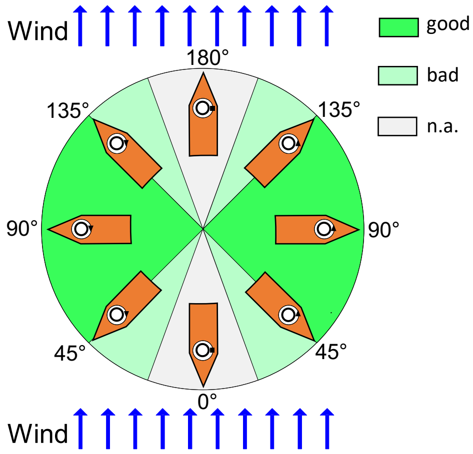

Figure 63: Effective Sailing Courses [93]

This principle is working most effective if wind direction is perpendicular to the direction of travel. Rotor's direction of rotation (cw, ccw) must be controllable, also rotational speed to adapt to wind direction and force. But it is not possible to gain wind propulsion for all possible situations (see Fig. 63) and it's working best in the range of 70° to 110° [94].

Application Range:
The Flettner-Rotor can deliver a high amount of additional thrust to all kind of ships, with a small investment of power to rotate the cylinder. Expectation: performance expectations > 3 kW main engine equivalent propulsion power per 1 m^2 of rotor surface in very good wind areas and best wind direction [95].

Figure 64: Flettner´s Yacht 1920s

Figure 65: E-Ship 1, launched in 2008

The Flettner rotors not only provide thrust, but also stabilize the ship in adverse weather conditions by damping the roll of the hull and making it easier to steer. So even if they don't generate propulsion, it makes sense to keep them spinning. Roll damping also has a positive effect on fuel saving and the crew by reducing their risk of seasickness and other injuries.

23. Wind Assisted Propulsion: Parafoil Wing (Kite) 200+ m above Sea Level

Summary by Dr. Tobias Wesnigk, MCN e. V. / WTSH

Decarbonising shipping by using wind energy as an additional propulsion – a technology existing and proven for thousands of years. New is the use of more stable and higher windspeeds at an elevation of around 200 m or more above sea level. Harnessing the wind power and towing a ship with the large foil can reduce fuel consumption by up to 20%. Several kinds of nearly fully autonomous parafoil sails are existing, including release and recovering of the sail. Controls of the sail system are integrated into bridge control equipment, including route optimizing with weather routing [96].

Figure 66: Testing of Airseas Seawing System [97]

Necessary equipment

On deck at the bow it is necessary to provide a system for automated releasing and recovering of the wing/kite with a large mast, where the sail can be hoisted and inflated, additional some installations for towing and storing of ropes, flight-control-unit and the sail itself.

Flight control equipment – while flying, the wing is automatically controlled by a steering system (flight-control-unit) to provide maximum power and safety and the system also controls the release and recovery of the wing.

On the bridge you will have to install a control panel (bridge equipment) to control the wing itself and give control information (route planning, steering information) to the flight-control-unit.

Airseas' calculations estimates that wind can be used in 70% of the time, and as long as there is wind and it is in an angle of more than +/- 40 degrees to direction of travel [97, 98].

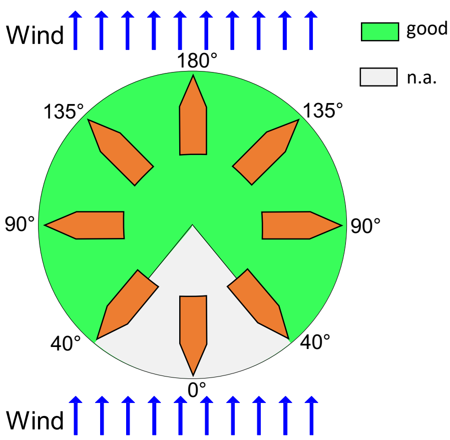

Figure 67: Possible courses with kite

24. Wind Assisted Propulsion: VentiFoils

Summary by Frank Nieuwenhuis, EconoWind, NL

EconoWind offers wind propulsion units for sea-going ships. The goal of the units is to reduce costs and CO_2 emissions by reduction of used motor power.

The basic technology is an airplane wing placed vertically. We optimize the airflow by suction, which allows the wing to be really thick to create about 4x more force than a normal sail. We offer the systems inside a container for easy installation, on a flat rack to be handled by the hatch crane of the ship or as a retrofit on fixed position. On captain's demand, the Ventifoils deploy. Further sailing is done automatically finding the optimal angles relative to the apparent wind. The generated force will be transferred right into the deck and thus helping with propulsion. To maintain the ships speed, the motor power can be reduced. Depending on the size, the units reduce motor power up to 200, 450 or 750 kW.

Figure 68: MS Frisian Sea with VentiFoils in movable Flatracks

Figure 69: MS Ankie with foldable VentiFoils after refit

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14. Glossary of Abbreviations

ADB	Air Distribution Band
AER	Annual Efficency Ratio
AFIR	Alternative Fuels Infrastructure Regulation
AI	Artificial Intelligence
AIS	Automatic Identification System
ALDR	Air Layer Drag Reduction
a.s.o.	and so on
BDR	Bubble Drag Reduction
BtG	Biomass to Gas
CAD	Computer Aided Design
CAPEX	Capital Expenditure
CCS	Carbon dioxide capture and storage
CF	Conversion Factor [g_{CO2}/g_{fuel}]
CFD	Computational Fluid Dynamics
CII	Carbon Intensity Indicator
CI	Compression Ignition Engine
CLC	Carbonate Looping Process
CO_2	Carbon Dioxide
COP 26	26th United Nations Climate Change conference
DAC	Direct Air Capture
DC	Direct Current
DCS	Data Collection System
DDFM	Dynamic Draught and Floating Monitoring
DE-propulsion	Diesel electric propulsion
DI	Direct Injection
DMA	Marine Gasoil (MGO)
DMB	Marine Diesel Oil (MDO)
DMX	Marine Diesel Oil X (light)
DMZ	Marine Diesel Oil Z (heavy)
DNV	Det Norske Veritas
DOC	Document of Compliance
ECA	Emission Control Area
EEA	European Economic Area
EEDI	Energy Efficiency Design Index
EEOI	Energy Efficiency Operational Indicator
EEXI	Energy Efficiency Existing Ship Index
EMI	Electromagnetic Interferences
EPL	Engine Power Limitation
ESD	Electrostatic Discharge
ETS	Emissions Trading Scheme
FAME	Fatty Acid Methyl Ester
FPS	Fuel Performance System
FuelEU Maritime	FuelEU Maritime Regulation (Regulation (EU) 2023/1805
GHG	Greenhouse Gas
GWP	Global Warming Potential
GT	Gross Ton
HFO	Heavy Fuel Oil
HullPIC	Hull Performance and Insight Conference

HVO	Hydrogenated Vegetable Oil
IFO	Intermediate Fuel Oil
IGF-Code	International code of safety for ships using gases or low flashpoint fuels
IMO	International Maritime Organisation
IMO DCS	IMO Data Collection System
ISO	International Organization for Standardization
IRR	Internal Rate of Return
KPI	Key Performance Indicator
kW	kilo Watt
LED	Light-emitting diode
LNG	Liquified Natural Gas
LPG	Liquified Petroleum Gas
LTE	Long Term Evolution (mobile standard third generation)
LFL	LOW FLASHPOINT LIQUID
LRIT	Long-Range Identification and Tracking
LSHFO	Low Sulfur Fuel Oil
MAK	Maximale Arbeitsplatz Konzentration
MARPOL	Marine Pollution: International Convention for the Prevention of Marine Pollution from Ships
MCN	Maritimes Cluster Norddeutschland e. V.
MDO	Marine Diesel Oil
MGO	Marine Gas Oil
MPEC76	Marine Environment Protection Committee
MPEC80	Marine Environment Protection Committee
MRV	Monitoring, Reporting, Verification
MSA	Measurement System Analysis
NCV	Net Calorific Value
NGO	Non-Governmental Organisation
NMEA	National Marine Electronics Association
NO_X	Nitrogen oxides
NPV	Net Present Value
NWT	Numerical Wave Tank
OCCS	Onboard Carbon dioxide Capture and Storage
ODS	Ocean Data System
OPEX	Operational Expenditures
OPS	Onshore Power Supply
PFI	Port Fuel Injection
PLC	Programmable logic controller
Promas	Propulsion an Maneuvering System
PtG	Power to Gas
PTH	Power Take Home
PTI	Power Take In
PtL	Power-to-Liquid
RED	Renewable Energy Directive
REST API	Representational State Transfer - Application Programming Interface
RFNBO	Renewable Fuels of Non-Biological Origin
RoI	Return on Investment
RoPax vessel	Mixture of Ro/Ro and passenger vessel
RO/RO vessel	Roll-on/Roll-off vessel
rpm	Revolutions per minute
SCR	Selective Catalytic Reactors

SECAs	Sulfur Emission Control Areas
SEEMP	Ship Energy Efficiency Management Plan
SG	Shaft Generator
ShaPoLi	Shaft Power Limitation
SOLAS	International Convention for the Safety of Life at Sea
SNG	Synthetic Natural Gas (Synthetic Methan)
STCW	International Convention on Standards of Training, Certification and Watchkeeping for Seafarers
TEU	Twenty-foot Equivalent Unit
TtW	Tank-to-Wheel
ULSD	Ultra-low sulphur diesel fuel
VLSFO	Very Low Sulphur Fuel Oil
WAPS	Wind Assistance Propulsion Systems
W.E.D.	Wake Equalising Duct
WtT	Well to Tank

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