REPORT

# Energy transition in shipping – facts and timeline

## Maritime Oslofjord Alliance

June 2022

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# **Editor's** NOTES

Decarbonisation is one of the biggest challenges in shipping and will affect everybody involved in the industry for decades. Ocean Consulting has helped the Maritime Oslofjord Alliance with investigating, compiling, reviewing, and analysing the most recent and relevant documentation available.

Interviews and clarifications have been pursued with engine manufacturers, classification societies, equipment manufacturers, service companies, bunker brokers, NGOs, and energy trading houses to confirm and verify the available information and its context. Our approach to this topic has been to be neutral about both fuel and technology and to focus on realistic options and possibilities.

The aim of this study has been to identify the most relevant information and insight to provide facts and a timeline for the "Energy Transition in Shipping". We hope that the information we've put together will make you want to learn more and help you make better decisions about your fuel strategies in the future.

This report should be read in the following order: An executive summary and an introduction are included first. Following that, pertinent information is offered, with each topic summarised on a single page. A summary of major findings can be found at the end of the report.

*Svein Helge Guldteig is the Owner and CEO of Ocean Consulting AS. Svein has decades of maritime experience spanning engineering, technology, operations, business consulting, and senior management experience from several blue-chip shipping and offshore service companies. Svein holds a M.Sc. degree in Marine Engineering and an MBA in International business. He is also a licensed marine engineer.*

This has been a very interesting project to work on! I am both honoured and grateful for this assignment. It has been a pleasure to have been able to tap into the vast combined knowledge and experience of the Maritime Oslofjord Alliance. Such a thriving team, fuelled with engagement, offering support and knowledge, providing information and always taking the project to the next level.

Questions or feedback about the information and findings in the report can be directed to the editor.

We hope you enjoy the reading!

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OCEAN CONSULTING

## Energy transition in shipping
- facts and timeline

MEMBER OF THE ALLIANCE

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THIS REPORT WAS CREATED
WITH FINANCIAL SUPPORT FROM OSLO MARITIME FOUNDATION
AND OSLO SHIPOWNERS' ASSOCIATION

BY

**THE MARITIME OSLOFJORD ALLIANCE**

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## Project TEAM

Members of the project team (from left): Svein Helge Guldteig, CEO and Owner (Ocean Consulting AS), Per Olaf Brett, (Chairman of Shipping & Offshore Network), Aage Thoen (Chairman of Oslo Shipowners' Association), Agnese Zvirbule (apprentice Maritime Oslofjord Alliance), Jon Rysst (Chairman of Ocean Industry Forum Oslofjord), Tom O. Kleppestø (General Manager, Maritime Oslofjord Alliance)

*Note: Quote from this report is allowed and encouraged with the credit to Maritime Oslofjord Alliance.*

# Energy transition in shipping
## - facts and timeline

This project has been initiated by the Maritime Oslofjord Alliance. The objective of the study has been to investigate how the existing fleet of ships (see below) can contribute to lower global GHG emissions. As part of this activity, the available options and the technical and financial implications of converting existing ships in deep sea trade to use low or zero-emission fuels in the future have been studied.

The following scope was made for the project:

- The ship segments considered are existing dry bulk, tanker, and container vessels above 25,000 GRT
- The time window considered is the next 3-5 years (2025-2027)
- A well-to-wake perspective is applied in emission considerations

Partners of the **Maritime Oslofjord Alliance** are

● Oslo Shipowners' Association ● Shipping & Offshore Network ● Ocean Industry Forum Oslofjord ●

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# Executive Summary (1)

Shipping, which transports 90% of the world's trade, contributes nearly 3% of global GHG emissions. If gone unchecked, this share could increase by 2050 as the world's GDP and seaborne trade are expected to continue growing. To reach net-zero carbon emissions, we need to decarbonise existing ships and coming newbuildings. However, shipping is a hard sector to abate and difficult to decarbonise. Thus, the shipping industry is in for a game-changing transformation and begs many questions, which this report will address and evaluate based on the prevailing information at hand and the expected development in technology.

The study is commissioned by the Maritime Oslofjord Alliance, comprising the Ocean Industry Forum Oslofjord, Shipping & Offshore Network, and Oslo Shipowners' Association.

The aim of the report is to provide support to decision makers in the marine industry when considering emission abatement of existing ships within the next 3-5 years. The shipping industry comprises some 94,000 vessels worldwide. The three shipping sectors tank, bulk and container in size (segment) above 5,000 GRT (Gross Register Tonnes) are responsible for 80% of the total shipping industry emissions. In the world fleet segment above 25,000 GRT the 19,000 ships (21%) consume 65% of all the fuel used in shipping. Most of them are in world-wide trade (p17).

To be successful in decarbonising shipping, it is important to include the larger segments of the three sectors (tank, bulk, and container). It is more challenging to reduce GHG emissions for this group of vessels compared to smaller ships in short sea trade. This report focuses on existing vessels above 25,000 GRT. In addition, it also gives an overview of current trends in alternative fuels and technologies to support the 2050 aim of the IMO.

Industry stakeholders have different opinions on how to calculate the GHG emissions from ships. Some, like the IMO, currently have a "Tank-to-Wake" perspective (downstream), meaning that only the emissions from the use of fuel on board the ship are considered. Others include a "Well-to-Tank" perspective (upstream), meaning that the emissions from production and transportation of fuel to the tank (ship) are included in the total estimation of emissions. The 'Well to Wake' (WTW) approach is increasingly gaining momentum, including the full fuel life cycle perspective. This report uses the WTW emission approach.

On the regulatory scene, operational guidelines and performance yield markers known as EEXI and CII will affect the industry to limit emissions on the existing fleet with increasingly stricter goals over time. These regulations will put expectations on the existing tonnage and may influence and limit the commercial value of an asset (ship) if not complied with (p15).

The annual fuel consumption in shipping is about 300 – 330M tonnes fuel/ year

# Executive Summary (2)

This report is based on a library of more than 170 recent reference papers, studies, and reports, as well as a large number of articles and news feeds (see the list of sources on page 49).

Enabling the use of alternative fuels in existing shipping to meet the IMO goals very much depends on a rapid and safe increase in the availability of alternative and decarbonised fuels, both in terms of production facilities, distribution and bunkering infrastructure. Proposals to establish "Green corridors", which means enabling the availability of alternative fuels along certain trade lanes, might be a good start, but even green corridors cannot be fully developed within the target period of the next 3-5 years (p27).

The findings and conclusions from this study are:

Out of the sample of vessels above 25,000 GRT, only 15% (2,700 ships) are outfitted with electronically controlled main engines suitable for being converted to the use of alternative fuels. This represents a potential to reduce emissions by some 100M tonnes $CO_2$/year (p20).

The remaining fleet (85%) needs to search for and find other emission reduction means and measures, of which few exist, and whose utilisation is uncertain based on their limited availability, small capacity, and low technological maturity.

The engine manufacturers have, however, quickly addressed the challenges and will be in a position to offer main engines that can operate on alternative fuels from 2023-24. Primarily, this will cater to the new building market of about 1000 vessels per year.

The scarce availability of alternative fuels will limit the readiness to adapt quickly for the large vessel shipping segment within the time frame portrayed in this report.

The current fuel ecosystem today comprise the three categories fossil fuels, biofuels, and synthetic fuels - being liquid or in gaseous form. The biofuels and synthetic fuels are available, but as of yet, in limited quantities (p22).

The existing fuels available, besides HFO/MGO, are the alternative fuels such as LNG, LPG, and methanol. The large scale of volumes is based on fossil fuel (oil and coal). The feedstock of the limited volumes of methanol in the market is also predominantly fossil-based.

The energy density of the various fuels is critical as it affects the design, size and construction criteria of fuel tanks and, consequently, the whole ship. All alternatives to conventional fossil fuels will require significantly larger tanks, less payload for any given vessel size, or increased bunkering frequency (p23).

# Executive Summary (3)

Propulsion of ships based on nuclear power has not been pursued in this report. Yet, it is not realistic to convert existing ships from combustion engines to nuclear power with steam propulsion plants, and other alternatives must be chosen.

The value chain consequences and considerations for distributing the significant extra costs of decarbonising the shipping fleet are considerable. Thus, the new transformation structure of costs should enable fair pricing among the value chain stakeholders and cover the owners' front-loaded costs. The criteria for carbon pricing are yet to be established and are uncertain. Until then, this uncertainty will limit the investment funds' and banks' interests and eagerness to enable such value chain transformation of costs.

Additionally, the shipbuilding capacity to renew our target fleet is limited and it will take a long time to deliver vessels that will outcompete and overtake the great number of existing and conventionally fuelled vessels currently in operation. Therefore, reaching the regulatory long-term objectives may prove to be a daunting exercise. The age distribution of the existing world fleet reflects the peak of construction around 2006.

An often overlooked and important determinant to operate new vessels of any type is the seafarer and the operation of next generation vessels adapted to the new fuels and ship features.

Therefore, the industry needs to facilitate and invest in safe operations of ships using alternative fuels in which the onboard crew plays a critical role. Education and training are vital and require investments, time and preparations.

Emission abatement technology is currently in its early stages, and it is to hope that for many existing ships, such technology will become available and economically feasible. If so, the existing vessels can contribute more to the future reduction of GHG emissions than what is currently possible. Onboard Carbon Capture and Storage (CCS) is a technology that is being investigated and piloted. Currently, the regulatory bodies are sceptical about accepting it as a $CO_2$ reducing feature.

Most existing ships will have to find applicable ways and means to reduce emissions, based on tangible technical and operational measures. It boils down to the reduction of energy and fuel consumption. This can be achieved by reduced speed (p33), technical modifications, and by imposing other operational measures, including use of drop-in biofuel/eFuel when becoming available. If used correctly, digitalisation in vessel operations can provide significant benefits in terms of fuel optimisation. We, therefore, assume there will be an increased focus on speed reduction in the coming years and that this will apply to both new and existing ships.

# Introduction –
# from where are we coming?

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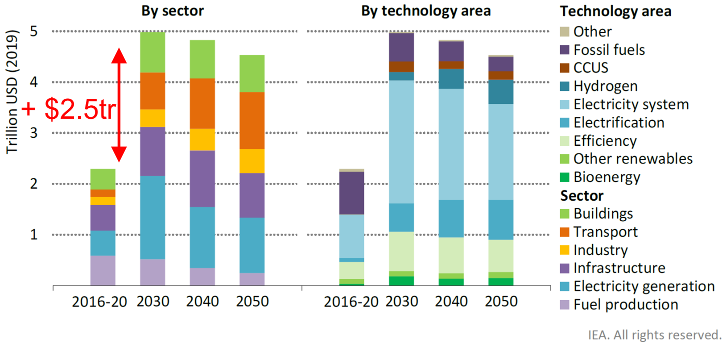
# **Global Investment** in Net Zero Emission

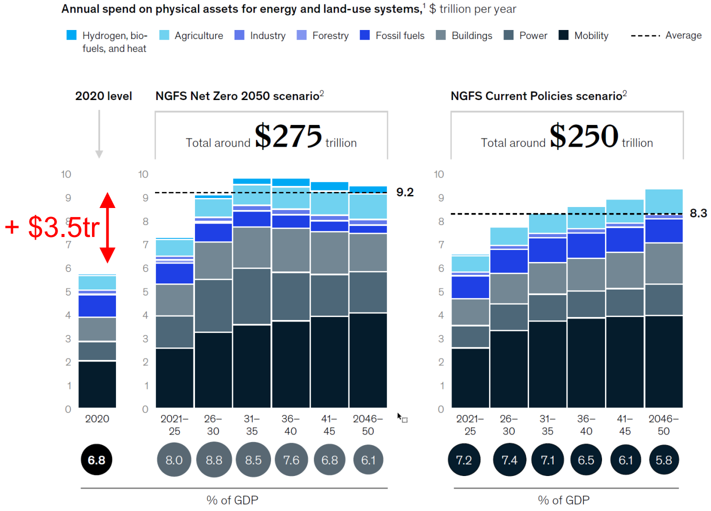
The front-loaded investments in net-zero emission (NZE) 2050 target are huge. Increasing the annual investments with $2.5-3.5T is needed and a shift on what capital is spent on.

**IEA**: Annual average Capital investment in the NZE 2050




*Capital investment in energy rises from 2.5% of GDP in recent years to 4.5% by 2030; the majority is spent on electricity generation, networks and electric end-user equipment*

**McKinsey**: Net Zero Emission $275T cumulative investment over 30 year




Larger portion of GDP will be reallocated for investment in NZE transition. A cumulative investment of $275T will impact business and societies. Annual investments of $9.2T (McKinsey) is 7 x the aggregated value of the Norwegian 'Government Pension Fund Global', comparably.

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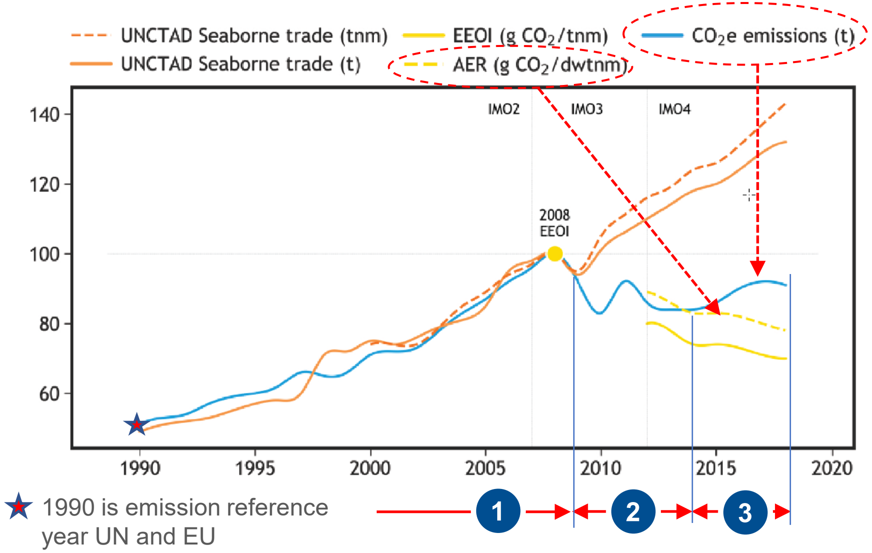
Sources: *IEA – Net Zero by 2050. A roadmap for the Global Energy Sector, Oct 2021, rev 4.*
*McKinsey – The net-zero transition. What it would cost and what it would bring. January 2022.*

# **GHG emissions** in Shipping (IMO)

GHG emissions in shipping reached a peak point in 2008. Reduction in shipping related $CO_2$ emissions has slowed, down and new and stricter regulations will be phased in.

### International shipping emissions and trade 1990-2018




### Three discrete periods:

1. 1990-2008 – Emission tightly coupled with growth in seaborn trade.
2. 2008-2014 – Decoupling of emissions and growth in seaborn trade. Rapid carbon intensity reduction (EEOI and AER).
3. 2014-2018 – Only moderate improvement in carbon intensity (EEOI and AER), but at rate slower than growth in demand. Therefore a return to a trend of growth in emissions ($CO_2$e).

- Annual fuel consumption in shipping is about 300 – 330M t fuel/ year [1)]
- The annual emissions are about 1B $tCO_{2eq}$/year (TTW) and about 1.3-1.5B $tCO_{2eq}$/year (WTW) [2)]
- Relative to the world, shipping accounts for 3% of the 50B tGHG emission/year [2)]

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*Sources: 1) IMO, Fourth IMO GHG study 2020. Executive summary and 2) E. Lindstad, Sintef Ocean, Reduction of maritime GHG emissions and the potential role of E-fuels*

# Emission regulations

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# IMO GHG and $CO_2$ emission regulations

**AMBITIONS**

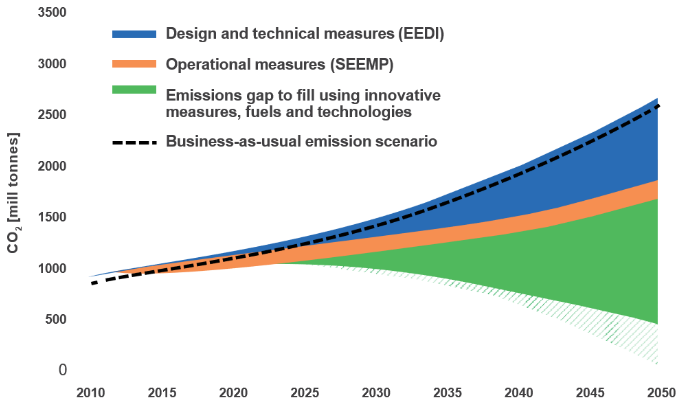
- Reduce the average carbon intensity by 40% in 2030 and 70% in 2050 compared to 2008 ($CO_2$ emission per transport work).
- Reduce total Greenhouse Gas (GHG) emissions from shipping by at least 50% in 2050 compared to 2008 (mt $CO_2$e).
- Review the Energy Efficiency Design Index (EEDI) with the aim of strengthening requirements.
- Strategy review 2023. Higher ambitions to be expected.

**DEVELOPMENTS IN THE PIPELINE**

- Reduction of GHG emissions (mt $CO_2$e ) well beyond 50% by 2050.
- New regulations
  - Carbon pricing as marked based measure (MBM)
  - Fuel GHG standard
- EEXI / Cii / SEEMP guidelines for adoption MEPC 78, June 2022
  - Effective January 1, 2023
- Discussions
  - Highly political
  - GHG intensity standard easier to agree (per transport work)
  - Carbon pricing / MBM is challenging

*Source: DNV*

**IMO: 2018 GHG reduction strategy**




*Source: IMO 2018 GHG reduction strategy*

IMO is under pressure to strengthen its emission regulations. The overall energy consumption must be reduced to meet the GHG emission targets by 2050.

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# **EU Green Deal** climate neutral by 2050

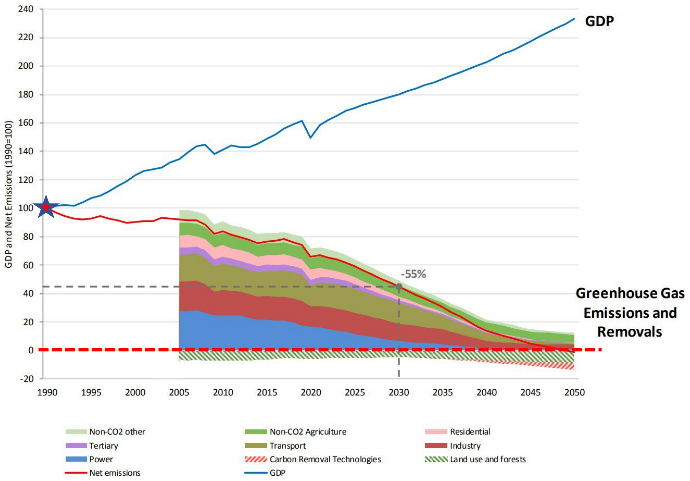
- Estimated **90% reduction in maritime transport emissions** relative to 1990 needed by 2050.
- **Fit for 55** package proposed by Commission on 14 July 2021.

### KEY ELEMENTS FOR SHIPPING

- Inclusion of shipping in the **European Trading System**, ETS.
  - Tank to Wake $CO_2$ emissions
  - Calculated based on fuel consumed related to EU / EEA ports
  - Phase in from 2023 onwards
- **Fuel EU Maritime**: requirements on lifecycle **GHG intensity** of energy
  - **Well-to-wake** GHG intensity of energy used on board
- Revision of **Alternative Fuels Infrastructure Regulation**:
  - LNG in core network ports by 2025
  - Shore side electricity in core network ports by 2030
- Revision of **Energy Taxation Directive**:
  - Ending tax exemptions for marine fuels within EU

*Source: DNV*

**EU: climate neutral by 2050**




*Source: DNV/ EU Commission, COM(2020) 562 final*

Other: COP26 and IPCC increases focus on decarbonisation by 2050. Global methane pledge gaining momentum to reduce methane emission by 30% within 2030.

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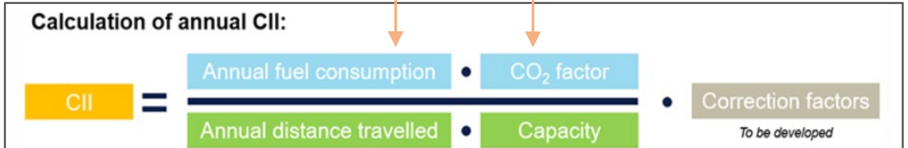
# **AER and Cii** – what can be done?

The Carbon Intensity Indicator, Cii, is an **operational index** based on another measure, the Annual Efficiency Ratio, AER. For an existing vessel there are several powerful ways to reduce the Cii and stay compliant within rating A-B-C.

- Reduce speed
- Voyage optimisation
- Technical measures

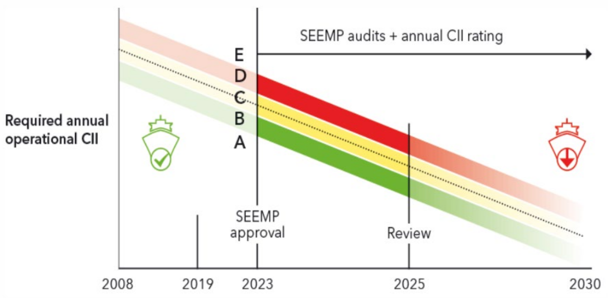
Alternative fuel will reduce $CO_2$ factor




Source: DNV

Reduced idle time improves Cii

Jumboising vessel to increase $DWT_{CAP}$ will improve Cii




Source: DNV

| Year | Reduction from 2019 ref. (mid-point of C-rating) |
|---|---|
| 2023 | 5 % |
| 2024 | 7 % |
| 2025 | 9 % |
| 2026 | 11 % |
| 2027-2030 | To be decided |

Source: DNV

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# EEDI/ EEXI – for existing ships

The Energy Efficiency Existing Ship Index (EEXI) has commonalities with the Cii but is focusing on **technical measures** to reduce energy consumption and thereby emissions.

- Limit engine power
- Technical measures to improve efficiency

Derating of engine to optimise SFOC

Alternative fuel will reduce $CO_2$ factor

$$\text{EEDI/EEXI} = \frac{\text{Engine Load kW} \bullet \text{Specific fuel consumption} \bullet CO_2 \text{ factor}}{\text{Design speed} \bullet \text{Gross Tonnage}}$$

*Source; DNV*

Optimisation compared to engine load

Jumboising vessel to increase GRT

*Source: DNV*

| Ship type | Required EEXI* |
|---|---|
| Bulk carrier | Δ15-20% by size |
| Tanker | Δ15-20% by size |
| Container | Δ20-50% by size |
| General cargo | Δ30% |
| Gas carrier | Δ20-30% by size |
| LNG carrier | Δ30% |
| Reefer | Δ15% |
| Combo | Δ20% |
| Ro-ro/ro-pax | Δ5% |
| Ro-ro (vehicle) | Δ15% |
| Cruise ship | Δ30% |

** Reduction from EEDI reference line*  *Source: DNV*

# Shipping sector

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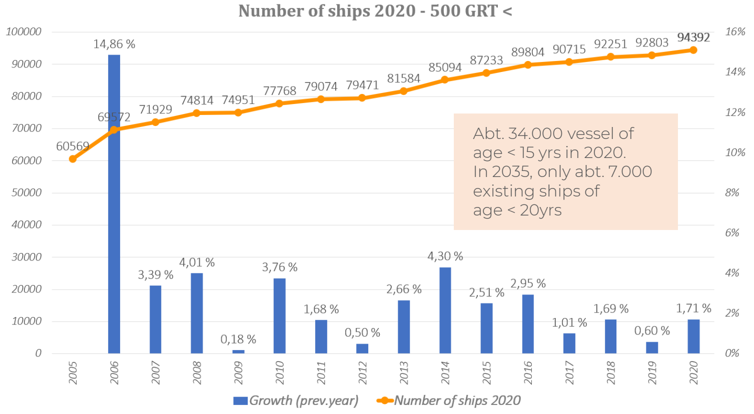
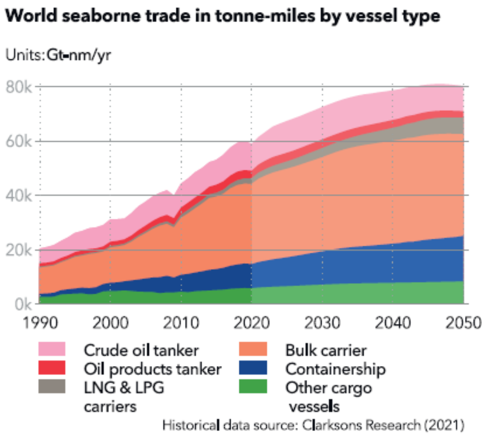
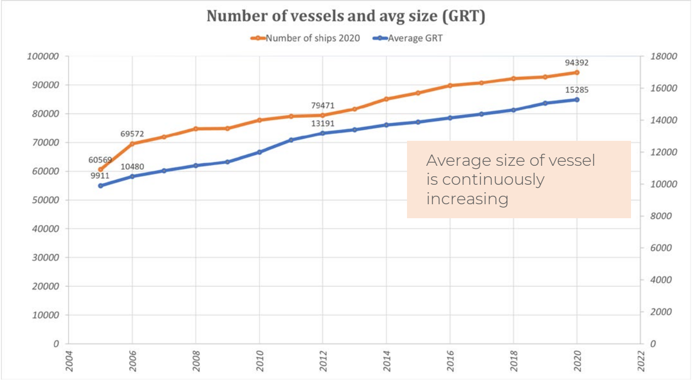
# **World fleet** in numbers (1)

- The world fleet is growing in number of ships.
- Each ship is getting bigger (avg GRT).
- The world seaborne trade in tonne-miles is expected to continue to grow.
- GHG emission reduction targets are getting increasingly difficult to reach.
- The age distribution of the world fleet reflects the peak of construction around 2006.




*Source: DNV Energy Transformation Outlook 2021/ Clarkson*

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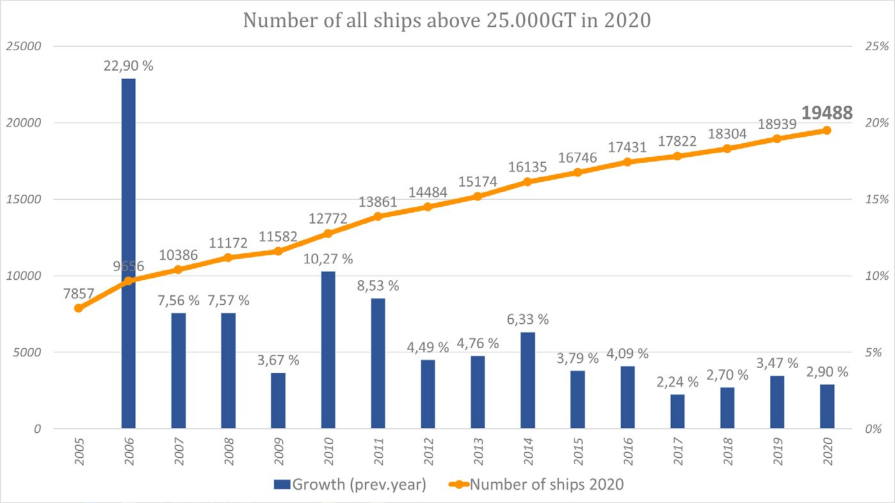
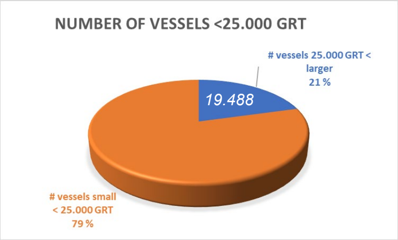
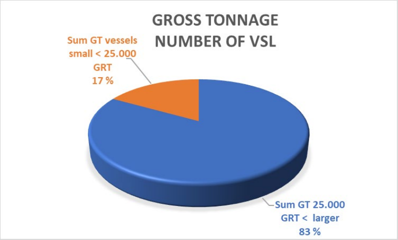
*Source: http://infomaritime.eu/index.php/2022/01/05/equasis-world-merchant-fleet-data-2005-2020/*

# **World fleet** in numbers (2)

Of the world fleet of approx. 94,000 ships of 500 GRT <, only 19,000 ships are 25,000 GRT <




There is a correlation between the size of the ship in GRT and the amount of fuel it uses. With 21% of the number of ships in the world fleet representing 83% of the tonnage, these ships also represent the largest consumers of fuel. The GHG emissions are about 800M $tCO_2$/year (WTW).

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Source: http://infomaritime.eu/index.php/2022/01/05/equasis-world-merchant-fleet-data-2005-2020/

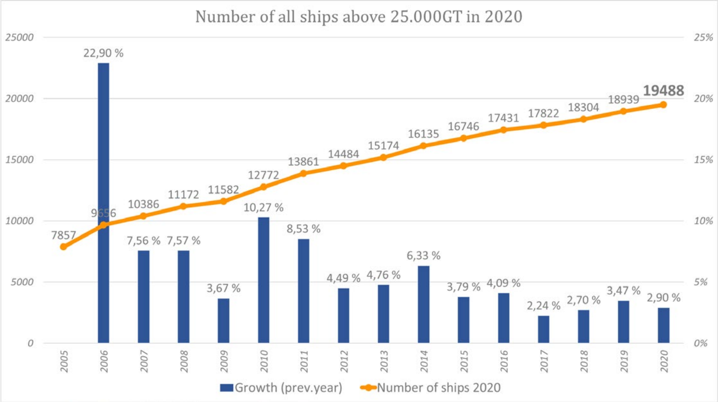
# **Candidates** for Retrofit

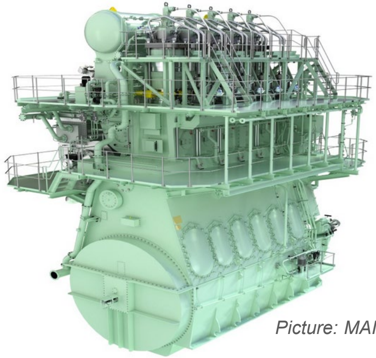
Retrofitting existing ships has the potential to reduce emissions by 100M t $CO_2$/year.

Only fully electronically controlled engines can be converted to dual fuel operation and use alternative fuel.

Market leader MAN ES has installed approx. 3,500 fully electr. control. engines (ME-C) type, and about 2,300 are candidates for conversion (retrofit).

WinGD has installed about 600 fully electr. control. engines (RTFlex, X and X-DF), and about 400 are candidates for conversion.



*Picture: MAN ES*

2,700 engines can be retrofitted to use alternative fuel

- Less than 15% of the fleet of vessels above 25,000 GRT are outfitted with main engines suitable for conversion to run on alternative fuels in the future.
- More than 85% of the existing vessels must find other ways and means to comply with stricter environmental regulations

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# Alternative fuel type emissions and availability

# **Alternative** and conventional fuel

### THREE CATEGORIES OF FUEL

There are three categories of fuel:

- Fossil (fossil fuel has high energy content and low cost)
- BioFuel (from biomass)
- eFuel / Synthetic Fuel (eFuel is made be renewable energies)

The fuels can be in liquid or gaseous form.

### CONVENTIONAL FUELS

Fuels with flash point above > 60deg C. (Solas) (MGO/ HFO / LSHFO, some BioFuel and SynFuel )

### ALTERNATIVE FUELS – EXISTING

Fuels with flash point below < 60deg C. (IGF)

- LNG / methane/ ethane
- LPG /propane/ butane
- methanol / ethanol

The only alternative fuel with some existing infrastructure and scale developed for shipping is LNG. Others are marginal.

### FUTURE ALTERNATIVE FUELS

Future realistic alternative low or zero-carbon fuels for ships are hydrogen based (zero carbon)

- Ammonia ($NH_3$)
- Hydrogen ($H_2$)

### GREEN FUEL

Use of low or zero-carbon (green) fuels offers low or zero GHG emissions. There are no Green Fuel available in the market for ships. All conventional and alternative fuels are grey

### BioFUEL

- BioFuel can be carbon positive, neutral or negative. BioFuels are slow to produce from biomass.
- Several BioFuels have characteristics that are very close to conventional fuels in use.

### eFUEL

- eFuel / synthetic requires huge amounts of energy to be produced. eFuels are green fuels.

### DROP IN FUEL

- Small amounts of low or zero-carbon fuels as **drop in** fuel together with conventional fuels reduces GHG emissions and can be used in engines without modifications.
- Drop in fuel can be liquid or gaseous type and bio or synthetic. E.g. biodiesel, eDiesel, bioNG, syngas (SNG), eLNG. Many different types, no current standardization.

### DEVELOPMENT

- Use of e.g. ammonia or LOHC as energy carrier of hydrogen.
- Combining e.g. green hydrogen with net negative $CO_2$ can be used to produce green methanol.
- Development of fuel production processes and Carbon Capture (CCUS) will be essential for uptake of new green fuels.

### COST REFERENCE

// Used in this report//

- Using conventional MGO / HFO / LSHFO as reference
- BioFuel 2 x cost of conventional fuel
- eFuel /synthetic 3 x cost of conventional fuel

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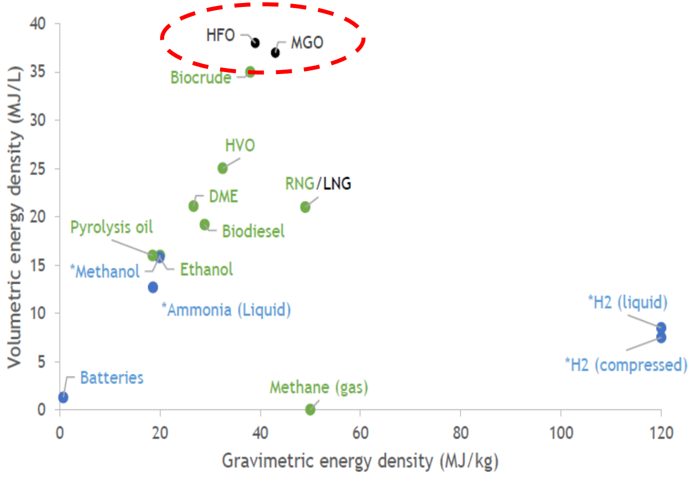
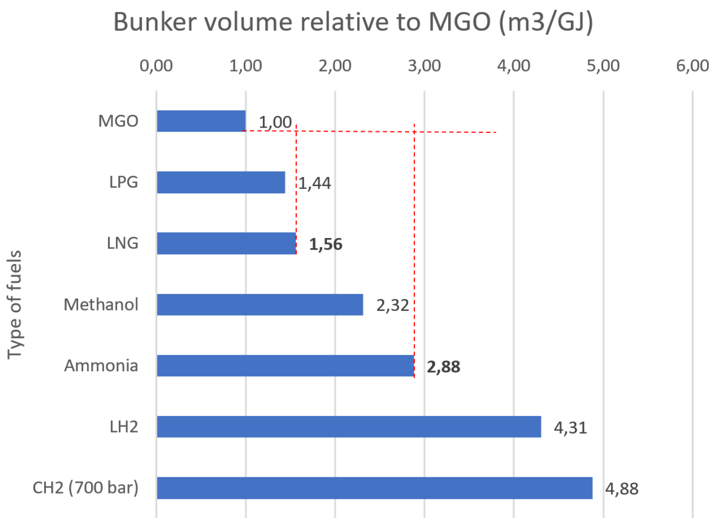
# Alternative fuel properties

The conventional fossil fuels (HFO and MGO) have the highest energy density. This means that all other alternatives, like biofuel, eFuels (synthetic) and hydrogen-based fuels, require more space. They are also more costly and give vessels shorter endurance. Ships must have larger bunker volumes or bunker more often compared to conventional fuels.




*Gravimetric and volumetric energy density of fossil and renewable fuels. Color indicate primary energy source. Black: Fossil. Blue: Electricity. Green: Biomass.*Ammonia, Methanol and hydrogen are currently primarily produced from fossil energy sources.*

*Source: IEA Bioenergy, Progress towards biofuels for marine shipping*

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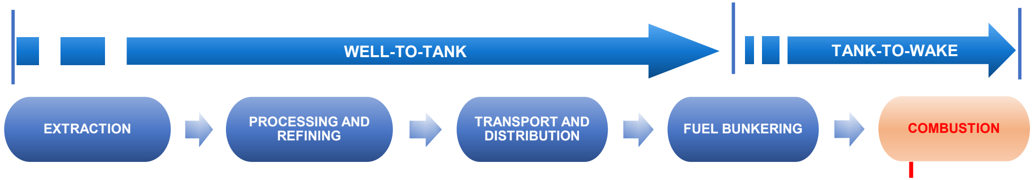
# **Well-to-Wake** emissions

GHG emissions from shipping is about 1B $tCO_{2eqv}$/ year (TTW)




### WELL-TO-WAKE

The Well-to-Wake (WTW) perspective includes emissions from energy consumed in fuel extraction, production and transportation to ship (WTT) and the emissions from combustion and use on board (TTW).

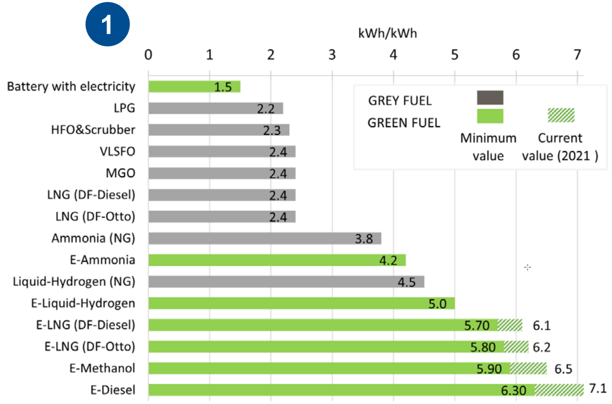



*Fig.1 : Well to Wake energy required as a function of fuel per kW delivered at propeller*

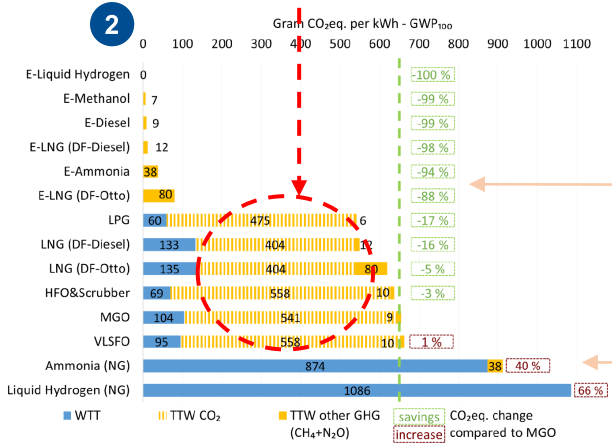



*Fig. 2: Well to Wake emission in gram $CO_2$eq per kW (GWP100)*

**1** Use of eDiesel based on current technology will triple shipping energy consumption - WTW.

**2** LNG and LPG have lower $CO_2$ emissions than other fossil fuels (MGO/HFO).

BioFuels can have low or high WTT emissions (not shown).

eFuels have zero WTT emissions if produced by use of renewable energy.

Energy consumption to produce hydrogen-based fuels (incl. ammonia) is so high that emission (WTW) exceeds use of fossil fuels.

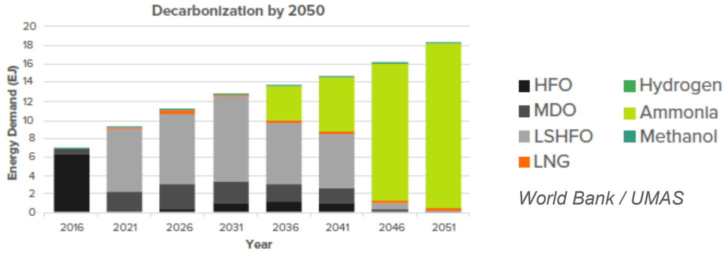
*Source: E. Lindstad, Sintef Ocean, Reduction of maritime GHG emissions and the potential role of E-fuels*

# Green alternative fuel uptake

Uptake of green alternative fuels in shipping is anticipated to gain scale and momentum as new energy carriers become available around 2035–2040.

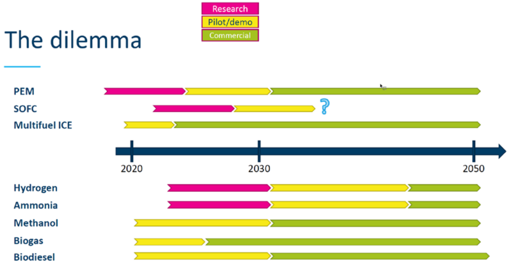
Each alternative fuel type will require its own tailored production, logistics and infrastructure to be scaled up with sufficient feedstock.

1



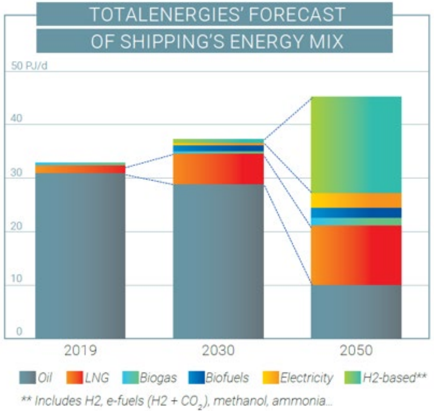

*World Bank / UMAS*

3

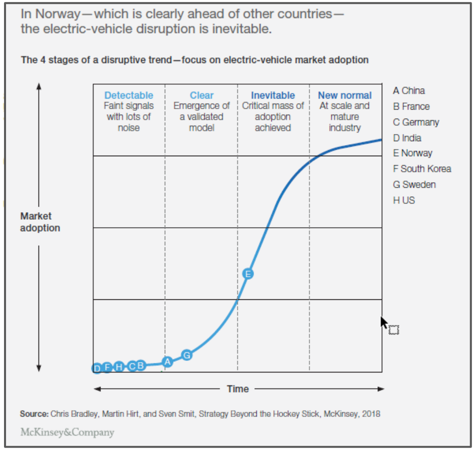



*Sintef Ocean*

2

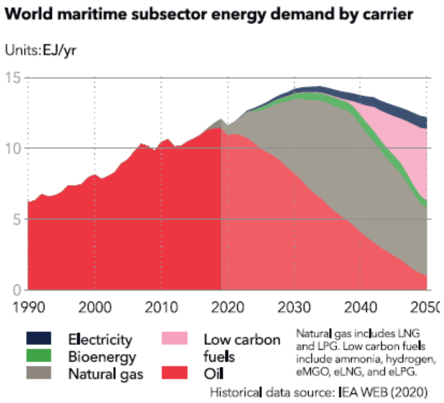



*TotalEnergies*




*McKinsey*

4




*DNV ETO 2021/IEA*

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# Ship trading areas and infrastructure

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# **Ship trade lanes** and infrastructure

1 **ALTERNATIVE FUEL INFRASTRUCTURE**

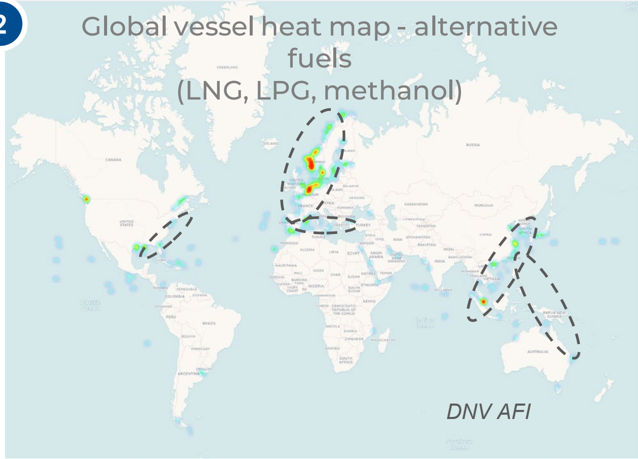
- The world fleet annual consumption of conventional fuel (HFO/MGO) is about 330B mt/yr.
- Supply of fuel for many of the large shipping lanes are based on bunkering in large hubs (Rotterdam, Singapore, Houston, AG).
- For shipping to use low or zero-carbon fuels in the future the current fuel ecosystem will have to be rebuilt from use of monofuel to availability of multifuel.

2 **GREEN CORRIDORS**

- The current availability of alternative fuels like LNG, LPG, and methanol is mostly present in local clusters like
  - Singapore
  - Northwest Europe and the Mediterranean
  - US East and West coast
- Ships operating between ports where alternative fuel is available can trade in a 'green corridor'.
- Use of alternative fuel as the primary source of energy is best suited for ships trading regionally where the fuel is available in sufficient scale.
- It is only limited use of alternative fuels in shipping in general. There are currently no vessels operating on ammonia as fuel.

1


2

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# **Fuel infrastructure** and scale

Experience from building up the logistics for LNG as an alternative fuel shows that it takes a long time

## INFRASTRUCTURE AND SCALE

- As of January 2022, there are 59 LNG bunker vessels in operation or under construction. The early vessels are smaller in size, and the newer bunker vessels are larger in size (DNV AFI).
- Experience from the Norwegian market: the first vessels started using LNG as fuel in 2000. After 20 years, it is still in its early adoption phase.
- Catering for different types of alternative fuels requires independent and segregated supply chains. Due to material incompatibility, it is not possible to use an LNG bunker vessel to deliver ammonia as fuel, even both are of gaseous type.
- To build up multiple infrastructure for many different fuels requires huge investment and planning. The approval and execution phase takes years to finish.
- Assumingly, we could expect use of green or blue alternative fuels to ramp up sometime between 2030-2035, and to be available in the key ports first. The current available alternative fuels are predominantly grey.

1

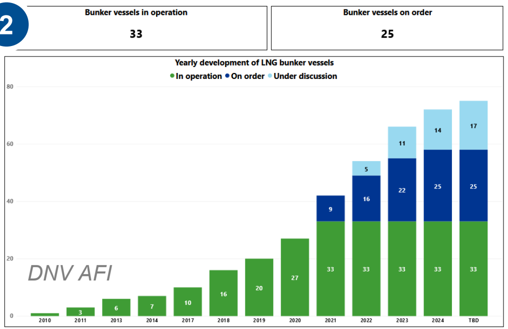
## Alternative Fuel Exist


The mark-up of all positions where alternative fuel exists can give an overly optimistic impression of availability, scale and readiness.

There will not be one fuel solution that fits all users.

2

## LNG Bunker Vessels




| | |
|---|---|
| Number of vessels | 59 |
| Total cap. | 450,000 $m^3$ |
| Avg. cap. | 7,600 $m^3$ |

Converted to oil equivalents the existing fleet of LNG bunker vessels could provide 5% of the world fleet with LNG as fuel. For ammonia the volume would be 3,5%(WF)

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# Shipping value chain

# Shipping value chain – green shipping implications

The risk of investing in ships prepared for low or zero-carbon fuel should be shared across the whole value chain

*Production Site* → Transport to port → Port handling → Sea voyage → Port handling → Transport from port → *Delivery Site*

Alternative fuel investment:

existing ship $20M

new build $10-15M

Revenue from freight market
High operational/market risk

Owner receives charter rate – less market risk – exposed to financial risk

Opt. *) Owner charter in vsl on B/B

Management fee from owner – cost competitive and compliance driven, limited liability

Charterer & operator

Owner *)opt

Ship Manager

*Integrated*

## Rationale for investing in emission reduction

**Tonnage provider** – Tonnage provider with external management and chartering / operation will only receive its revenue from charter hire on a voyage or time basis (T/C). The revenue is fixed for the period and market risk is low. Options to upgrade/retrofit the vessel have traditionally not been well paid, and the pay-back on investment often proves insufficient for the financial risk involved (ROI).

**Integrated shipping company** – Fully integrated shipping companies can more easily justify investment because the whole value chain (vertical) is kept in house, and the benefits in revenue from chartering also benefit the owner and main stakeholder (the company).

In order to facilitate investment in emission reduction technology and uptake of alternative fuels the risk should be shared and revenues and costs should be distributed across the value chain for all stakeholders. Owners have front-loaded investment cost as well as vessel out of service for about 2 months or more for conversion of the ship to become alternative fuel compliant.

*Source: Horizontal shipping value chain: Value creation in maritime chain of transportation, Cph. Business School, 2015*
*Vertical integration based on SDS model*

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# **Fuel** and market pricing

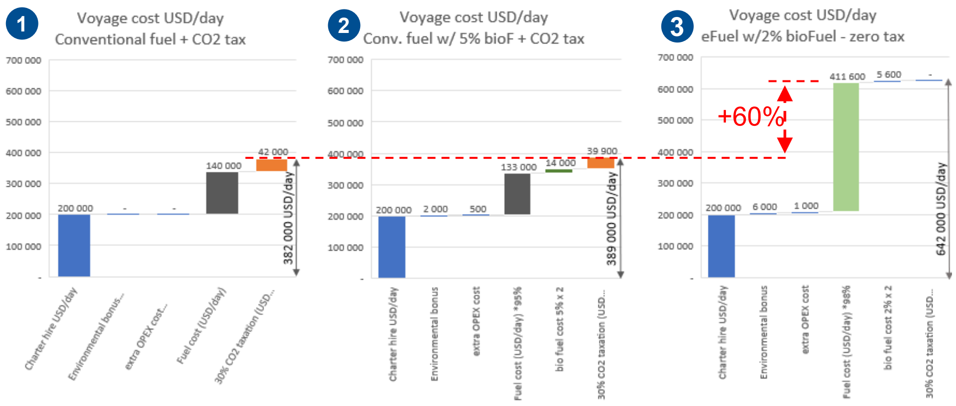
$CO_2$ taxation must reach 200% in order to benefit alternative fuel installation in ships

Investment case alternatives

For a 14,000 TEU cont. vessel with fuel consumption of 200 mt/day at 21.5 knot. Daily rate is $200K

1. Use of conventional fuel and pay 30% $CO_2$ tax
2. Use conventional fuel + 5% drop in biofuel. Pay $CO_2$ tax on use of conv. fuel. Receive premium rate $2k/day
3. Conversion to use eFuel w/price 3 x conv. fuel. Use bio pilot fuel. No $CO_2$ tax. Receive premium rate of $6K/day

**Post Panamax 14,000 TEU container vessel**




- Option 1 – the voyage cost is $382K/day with conventional fuel and pay 30% $CO_2$ tax
- Option 2 - the voyage cost is marginally higher at 389K/day with use of 5% drop in biofuel and pay 30% $CO_2$ tax on conventional fuel
- Option 3 - the voyage cost is $624K/day with use of eFuel (e.g., eLNG) + BioPilot fuel This is 60% higher voyage cost than with the use of conventional fuel.

## RATIONALE

With the option of using conventional fuels and pay $CO_2$ tax, the 3 x higher cost of eFuel will be a barrier against market driven transition to low/zero-carbon fuels.

Regulatory enforce-ment like Cii will drive the transition.

*Fuel cost 700 USD/mt.*
*BioFuel 2 x = 1.400 USD/mt*
*eFuel 3 x = 2.100 USD/mt*
*$CO_2$ taxation +30% of fuel cost*

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# Existing ships –
# operational and technical measures

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# **Operational** measures

Reducing ship speed is the most powerful way to cut emissions

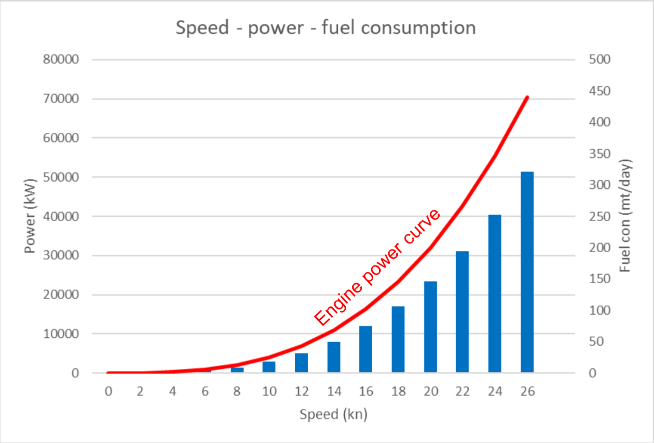
For a 14,000 teu container vessel the fuel consumption is approx. 180-200 mt/ day at 22-23 knot service speed.

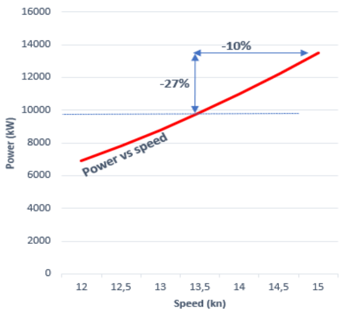
At 10 knots the fuel consumption would be approx. 18-20 mt/day.

It would reduce fuel consumption and emissions with about 90%.

Reduced speed might increase the number of vessels needed.

**Post Panamax 14.000 TEU cont vessel**




For a generic ship, a 10% reduction of speed will reduce power, fuel and $CO_2$ emissions by 27%

*Source: BRS, Annual review 2020*

- Reducing speed from 15 → 12 knots will reduce fuel consumption and emissions by about 50%.
- There is a lower limit to how much speed can be reduced before the engine, hull bow, and propeller are no longer operating at their optimum and technical measures must be applied.
- Cost of technical measures is reasonable compared to retrofitting for alternative fuels, and the effect of reduced emissions comes immediately.

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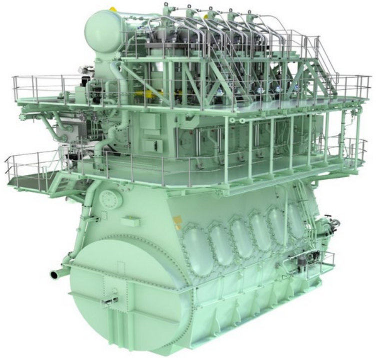
# **Technical** measures

Optimising bow, propeller and retuning the engine for lower speed can be very efficient technical measures

## Engine retuning



*Picture: MAN ES*

## Efficient propeller

*Picture: Berg Propulsion/ MarineLog*

*Picture: Stone Marine*

## Analysis & engineering

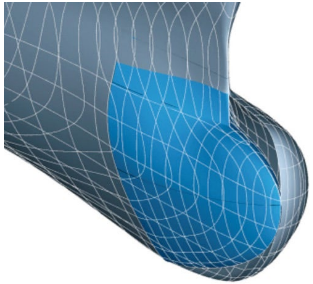


*Illustration: IMO/Green Voyage 2050/ DNV*

## Optimise bow for lower speed

*Picture: CMA CGM /MarineLog*

- Retuning of main engine is required if the load (power) is reduced beyond 40-50% MCR (ie. due to low speed).
  A retuning will typically reduce SFOC and emissions by about 3-4%, and increase the time between overhaul (TBO).
- Optimising propeller for lower speed and fit PBCF can reduce fuel consumption and emissions by 2-10% (+)
- Optimising bow area for lower speed can reduce fuel consumption and emissions by 3-12%

*Source hull & propeller savings: ITF. Navigating Towards Cleaner Maritime Shipping. Lessons From the Nordic Region,2020.*

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# Conversion to alternative fuel or new build – fuel tank issues

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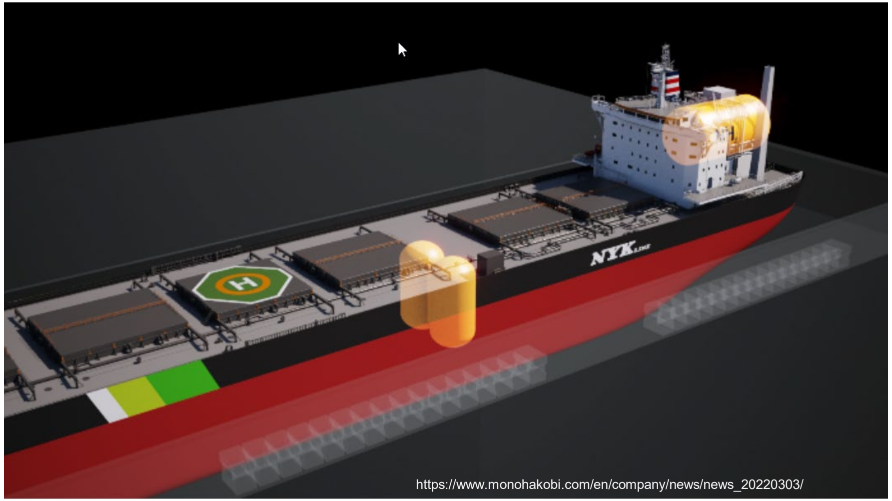
# **Fuel flexibility** and Ready notation

Building a ship for future fuel flexibility is the least risky decision and can come with a marginal cost increase compared to building for conventional fuel. The alternative fuel 'readiness' comes at different levels and costs.




Concept design for an ammonia-fuel ready LNG-fueled vessel (ARLFV) for the transition to a future marine fuel, by NYK, MTI, Elomatic.

Class ABS estimates that additional cost for upgrading stainless fuel tanks for LNG to also handle ammonia and methanol is ~ $400K.

## FUEL READY LEVELS (ABS)

**Level 1** – Concept Design Review: This is a high-level evaluation of the basic suitability of a particular vessel design to fit a specific gas or other low-flashpoint fueled ship concept in accordance with the Marine Vessel Rules.

**Level 2** – Concept Design Review – In addition to Level 1, it is divided into separate groups that identify the various components of the overall design.

**Level 3** –Detail Design Approval and Installation – The final level of the "Fuel Ready" scheme and includes the class approval of drawings, installation of parts of the system and surveys.

**Once the vessel has undergone a complete conversion and all corresponding surveys are completed, the 'Fuel Ready' notation is deleted and appropriate class notation inserted.**

The notation LNG ready or ammonia ready does not imply that it is ready to fill LNG or ammonia and run the engines on this fuel, but rather that it is possible to convert the ship to use LNG or ammonia as fuel in the future.
[i.e., become → alternative fuel compliant ]

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# **Fuel tank** solutions

## Deck fitted tanks take up less valuable cargo space


*Picture:*
*Tradewinds 08.02.21/Avenir LNG*

Tank above main
Min dist. to side shell
[0.75 + Vc * 0,2/4000]
= 0,84m (both sides)

For existing ships it can be difficult to find space for deck-fitted tanks.

*Picture:*
*VesselFinder News, May 2020*

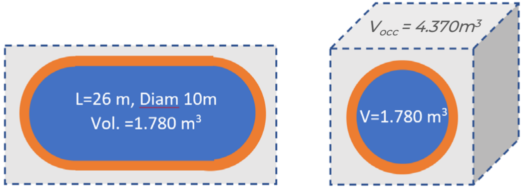
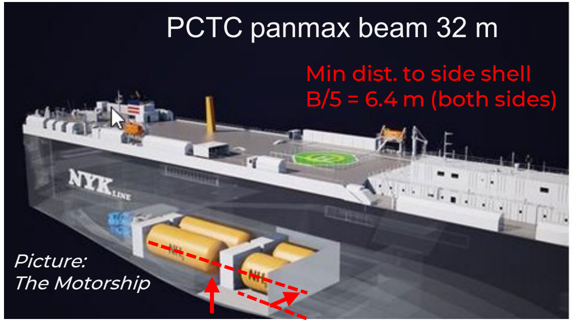



*Figure: Schematic of c-type tank with insulation – tank fitted in a confined space*

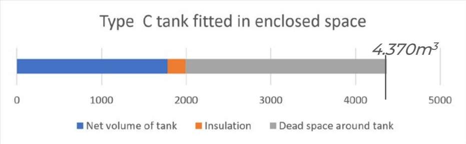
## Internal tanks can take up valuable cargo space



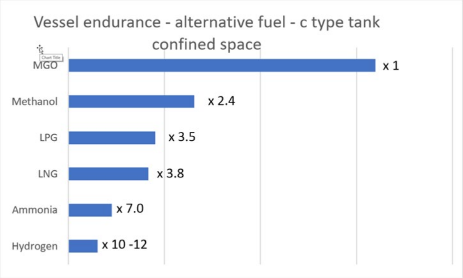

*Picture:*
*The Motorship*

Min. height above
bottom = B/15 = 2.13 m

*IGF sec. 5.3*




The min. occupied space is about 2.5 x tank volume (++)




The endurance compared to space used for conv. fuel is greatly reduced. LNG is down from 1,5 to 3,8. Ammonia from 2,9 to 7

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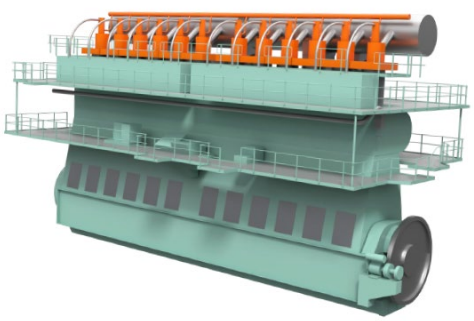
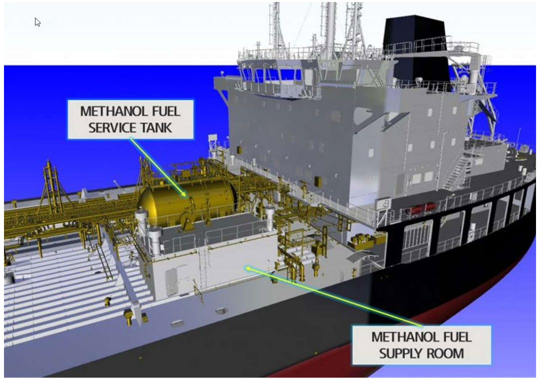
# **Conversion** of ship and engine

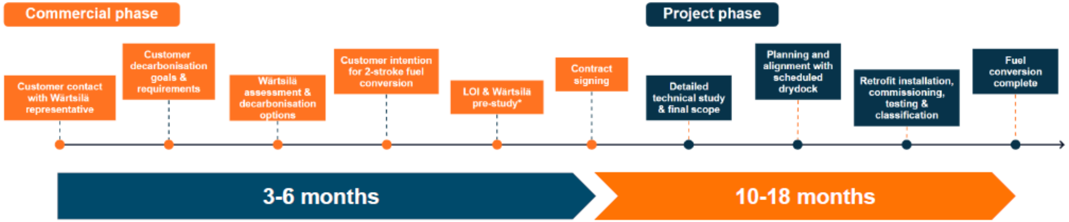
Conversion of engines to dual fuel and ship to use alternative fuel take about 2 years to complete. Delivery time for fuel tanks is typically 9-12 months.



*Source: Wärtsilä*




*Source: Diesel Gas Turbine*




*Source: Wärtsilä*

## Alternative fuel conversion

**Main engine** – Use of alternative fuel for vessels with a 2 stroke main engine running on conventional fuel, implies to convert the engine to become a **dual fuel (DF)** type. Full EIPP test required. Only possible with one DF at a time.

**Ship** – Use of fuel with flash point lower than 60 deg C, requires compliance with IGF code.

**Outfitting** – Dedicated bunkering station, storage tank and fuel preparation room for all types of alternative fuel (IGF). Gas up unit for consumption and gas combustion unit might be required.

**Safety** – Safety issues related to explosion and toxicity of fuel drives requirements for fire insulation, ventilation, inerting, firefighting, gas sensors etc. [HAZID, HAZOP].

**Auxiliary engines** – Converting auxiliary engines to alternative fuel requires engine to be retrofitted complete (new).

**Fuels** – In principle there is little difference between using LNG as fuel and the prospective ammonia – or any other gaseous fuels. Methanol can be stored in integrated fuel tanks, though comply with all other IGF requirements.

**Cost** – Approx. $18-20M for retrofit

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# Example cases

# Case 1: BW LPG

## Conversion from conventional fuel to dual fuel LPG

| | |
|---|---|
| Conversion cost | $8-9M |
| Time for conversion | 2 months |
| Engine size | 12,400 kW |
| Engine type | MAN B&W 6G60ME-C9.5-LGIP |
| Tank volume (type C) | 2 x 900 m3 |
| Other | 12 vessels completed<br>3 vessels for 2022 completion |
| Emission | Assume ~ 20% $CO_2$ reduction |

*Source: BW LPG*

*Source: BW LPG*

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# Case 2: Hapag Lloyd

## Conversion from LNG ready to dual fuel LNG compliant

| | |
|---|---|
| Conversion cost | $35M |
| Time for conversion | ‘Several months’ |
| Engine size | 47,400 kW |
| Engine type | MAN B&W 9S90ME-C |
| Tank volume | Use of GTT tank type 6,700 m3 |
| Other | Part of 17 LNG ready ships. Tank occupies space for 390 containers. Its 16 sister vessels remain LNG ready. |
| Emission | Potential ~ 15-30% $CO_2$ reduction. Aiming for $CO_2$ neutral with synthetic natural gas (SNG) |

*Source: Hapag Lloyd*


*Source: Hapag Lloyd*

*Source: Hapag Lloyd*

*Source: GTT*

LNG Block™ Concept

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# Summary and key findings

# Summary and key findings

The global investments needed in order to reach the net-zero emission targets by 2050 are huge. It will lead to an entirely new energy economy and requires an annual increase in investments of $ 2.5-3.5 tr/year compared to current level. The reduction in shipping related $CO_2$ emissions has slowed down, and new and stricter regulations will be phased in.

## EMISSIONS AND REGULATIONS IN SHIPPING

### WELL TO WAKE EMISSIONS

Well-to-wake (WTW) emissions, or life-cycle emissions, are the sum of upstream (well-to-tank, WTT) and downstream (tank-to-wake, TTW) emissions.

### GHG AND OTHER EMISSIONS

The greenhouse gas (GHG) emissions related to the combustion of fuel are carbon dioxide ($CO_2$), methane ($CH_4$), and nitrous oxide ($N_2O$). The largest component is $CO_2$. For each tonne of fossil fuel combusted, about 3.1 -3.8 tonnes of $CO_2$ is generated. The combined GHG accounting is often expressed in $CO_2$ equivalents ($CO_2$ e). Other (pollutant) emissions from the use of fossil fuels are particulate matters (PM), also called black carbon (BC), sulphur oxides (SOx) and nitrogen oxides (NOx).

### IMO

- Reduce the average carbon intensity by 40% in 2030 and 70% in 2050 compared to 2008 ($CO_2$ emission per transport work)
- Reduce total Greenhouse Gas (GHG) emissions from shipping by at least 50% in 2050 compared to 2008 (mt $CO_2$e)

### EU – Fit for 55

- Estimated 90% reduction in maritime transport emissions relative to 1990 is needed by 2050.

The IMO and EU will include the full life cycle approach for emission regulations (Well to Wake). Both carbon intensity measures will be applied as well as overall GHG emission targets.

# Summary and key findings (2)

**SHIPPING SECTOR**

The number of ships in the world fleet is steadily increasing, and as per 2020 figures, there were 94,000 ships above 500 GRT (volume). Also, the average size of the ships has increased. About 34,000 ships in the world fleet were 15 years or younger in 2020. Only about 7,000 of those existing ships will be 20 years or younger in 2035

**EMISSIONS BY SHIPPING SECTOR AND SEGMENT**

- The annual fuel consumption in shipping is about 300 – 330M t fuel/ year.
- The annual emissions are about 1B $tCO_2eq$/year (TTW) and about 1.3-1.5B $tCO_2eq$/year (WTW).
- About 80% of the GHG emissions from the world fleet come from the three sectors: bulk, tank and container ships over 5,000 tdw. These three sectors (bulk, tank, and container) have the largest ships that consume the most fuel. The vessels above 25,000 GRT, about 19,000, consume about 65% of the total fuel consumed in shipping. 21% of the number of ships in the world fleet fall into this category.
- Segmenting only the ultra-large ships shows that about 10-12% of the number of ships in the world fleet account for about 50% of the total fuel consumption in shipping.
- To be successful in reducing GHG emissions in shipping, it is crucial to include the three sectors (bulk, tank, and container) and the segment of the largest vessels, which has been the focus of this study.

**ALTERNATIVE FUEL TYPES**

- The conventional fossil fuels (MGO/HFO/LSHFO) have the highest energy density, with fossil gas (LNG and LPG) following closely.
- Current alternative fuels are LNG, LPG, and methanol with derivatives. They are all based on fossil fuel sources (oil or coal).
- Some BioFuel exist and can be used as (drop-in) fuel to reduce emissions.
- The GHG emissions from the production of grey low or zero-carbon fuels are so large that they exceed the emissions from the use of fossil fuels in a WTW perspective (eFuels).
- Use of eDiesel with the current manufacturing process will triple shipping energy consumption – WTW.

# Summary and key findings (3)

### ALTERNATIVE FUELS UPTAKE AND GREEN CORRIDORS

- Uptake of green alternative fuels in shipping is expected to gain momentum around 2035-2040. Access to renewable energy and carbon capture technology will be key to developing green fuels.
- There will not be one type of fuel that suits all needs, and it should be alternatively opted for future fuel flexibility if decisions are taken now. Incompatibility between alternative fuels will require multi-supply chains with sufficient scale and feedstock to be developed. Each type of fuel will have its own schedule and is assumed to follow an s-shaped uptake.
- Ships operating between ports where alternative fuels are available can trade in green corridors. Deploying ships to other areas can make them stranded assets if fuel flexibility is not accounted for.
- Referring to the development of bunkering infrastructure for LNG as an alternative fuel has proven that it takes a long time (20 years +). The current number of LNG bunker vessels can provide fuel volumes that amount to about 5% of the world fleet's annual fuel consumption (equivalent). The same comparison for ammonia would be 3.5% of the world fleet's fuel consumption.

### SHIPPING VALUE CHAIN, FUEL COST AND TAXATION

- The risk of investing in ships prepared for low or zero-carbon fuel should be shared across the whole value chain. Ship owners will have to face front-loaded investment and take ships out of service to retrofit them for use of alternative fuels - or to make them more energy efficient. The horizontal shipping value chain does not necessarily cater for payback for needed investments carried out in vertical integrations. Ships owned by leasing houses and B/B out to tonnage providers (i.e. owners in name) add to the complexity of decision processes.
- Comparing voyage cost of the use of 1) conventional fuel as is, with 2) conventional fuel with future $CO_2$ tax and 3) with the use of eFuel at 3 x cost of conventional fuel, shows that $CO_2$ taxation (carbon tax) must reach very high levels before being effective (200%). Regulatory enforcement is needed to drive transition to reduce emissions.
- Enforcing a carbon tax on shipping would be an incentive to reduce the overall fuel consumption and thereby also the emissions. Also, a carbon tax will benefit ships that use the least amount of fuel overall (called "ECO ships") because they are the most energy-efficient.

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# Summary and key findings (4)

### REDUCTION OF SPEED TO LOWER EMISSIONS

- Reduction of ship speed is a very powerful way to reduce emissions. For each 10% reduction in speed, the fuel consumption, and thereby emissions, is reduced by -27%. A reduction in speed from 15 knots to 12 knots will lower fuel consumption and emissions by about -50%.
- If world seaborne trade continues to grow, more ships will be needed to cover for reduced speed of the world fleet.

### TECHNICAL MEASURES

- Reduction of fuel consumption improves both Cii and EEXI as carbon intensity measures. It also reduces the ship's overall GHG emissions.
- Optimising the bow, propeller and retuning of the main engine for lower speed can be very efficient technical measures.

### OPERATIONAL MEASURES

- Maximized energy utilisation for ships can be achieved by voyage planning and weather routing for transits.
- Optimised load on auxiliary generator engines will also lead to the best possible fuel consumption. Overall energy conservation in all aspects of operation (light, A/C, heating etc.) will lead to fewer emissions.
- Regular cleaning of the underwater hull and propeller will contribute to keeping the lowest possible fuel consumption.

### EMISSION ABATEMENT TECHNOLOGY

- At present, there is limited use of GHG emission abatement technologies in shipping, except for scrubber systems handling SOx (which is not a GHG). Testing of carbon capture and storage (CCS) in shipping is ongoing and in its early stages. Deploying technologies for abatement of carbon dioxide ($CO_2$), methane ($CH_4$) and nitrous oxide ($N_2O$) would all contribute to reduced GHG emissions. The use of ammonia as a fuel will require the installation of emission abatement technology for ammonia slip and nitrous oxide ($N_2O$). The ammonia slip is similar to the methane slip from the use of LNG as fuel.
- Carbon capture, utilisation, and storage (CCUS) will be part of the future decarbonization and circular economy. Captured carbon combined with green hydrogen can be used to produce e.g. green methanol, as well as captured carbon potentially being used in other industrial applications.

# Summary and key findings (5)

**FUEL FLEXIBILITY, READY NOTATION AND SHIP CONVERSION**

- Building new ships for future fuel flexibility comes at a relatively modest cost. There are several degrees of alternative fuel readiness with class. The increased cost of stainless fuel tanks to use LNG/ammonia/ methanol as fuel is about $400K.
- The retrofit cost for dual fuel installation of existing ships is in the region of $18-20M. Example cases show a span from $8-9M to $35M.
- Comparably, the cost of installing dual fuel propulsion machinery at new building stage is about $9-10M, much lower than the retrofit cost.
- For many existing ships, it will be technically very difficult to comply with the IGF requirements. For tanker ships, the additional cost is less than for dry ships (container and bulk).
- The current fleet of vessels consists of 2,700 ships with electronically controlled 2 stroke main engines that are candidates for retrofit to use alternative fuels. The corresponding potential for reducing emissions is 100M tonnes $CO_2$/ year.
- Deck fitted fuel tanks take up less valuable cargo space compared to tanks located inside the ship hull. Due to IGF requirements, the lost space when using internal fuel tanks can be huge, and vessel endurance reduced compared to using conventional fuel. The lost space is in practise at the expense of available cargo volume.
- With less energy density in alternative fuels, ships will have to alter their trading patterns (route and speed) and/or bunker more often.
- Use of biofuel as a drop-in to conventional fuel will help reduce $CO_2$ emissions. However, incompatibility in storing with conventional fuel can require a retrofit with more fuel tanks and the fitting of a fuel preparation module (drop-in).
- Combining retrofit to alternative fuel with jumboising the vessel can prove economically viable for some ships. Jumboising a vessel will also improve Cii. However, it will not lead to reduced fuel consumption or fewer GHG emissions.

**TECHNICAL LOCK-IN**

- Rightfully, attention has been drawn to possible technical lock-in if developing infrastructure for LNG as fuel, as there are material incompatibilities with what is required for use of ammonia as fuel. Provided the material used is stainless steel, the bunker systems, tanks and infrastructure can be used for both LNG, LPG, ammonia and methanol – whereas the issue of technical lock-in is greatly reduced. Recent LNG bunker vessels are now designed with stainless steel tanks and piping.

# Summary and key findings (6)

## LNG AS REFERENCE IN THIS REPORT

In principle, there is very little difference between building or retrofitting a ship for use of LNG as fuel compared to e.g. using methanol or ammonia. Ships that shall use fuels that fall into the IGF criteria will all have to comply with the same regulations which a.o. mean a dual fuel engine installation. The reference to LNG in this report is because the technical installations, cost, and delivery timeline are known and representative for all alternative fuels (in the IGF category).

## COMBINING DIFFERENT MEASURES TO REDUCE EMISSIONS

Transition from the current use to conventional fuel to the use of low or zero-carbon fuel will take a long time, partly due to the current lack of green fuel, infrastructure and ships that are technically compliant to use alternative fuels. The transition process will imply the combination of different measures to reduce GHG emissions, where the most obvious are 1) reduction of energy consumption, 2) use of drop-in biofuel/eFuel and 3) emission abatement technologies – all in combination.

## DIGITALISATION

Digitalisation and knowledge of its operation are key to maximising energy utilisation and reducing emissions. Optimising ship fuel consumption that is continuously affected by multivariable parameters benefits from the efficient use of real-time data compared with realistic simulations and forecasts. Future compliance reporting will require documentation of fuel consumption as well as other operational data on an aggregated level. Access to reliable data makes reporting more efficient and increases transparency, if relevant.

## SKILLS AND COMPETENCE

The transition to using green low or zero-carbon fuels in shipping will imply using energy carriers with different characteristics compared to the conventional fuels used today. There will be issues related to protecting safety due to alternative fuels being gaseous, explosive, and/or toxic. The transition to new fuels will require an update of skills for people in many different parts of the marine industry, not only first line ship operators and ship crew. It will require a massive training of seafarers to meet the new types of fuel coming, and ship management companies will have to adapt their safety management systems to cater for other risks than with the use of conventional fuel.

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# *Disclaimer*

*This report was created to compile the most important elements of how existing ships can contribute to the reduction of GHG emissions. External references and sources have been referred to where relevant.*

*The aim is to describe the current situation and the realistic outlook for the conversion of existing ships to use green alternative fuels in the next 3-5 years.*

*The intention is not to serve as a political argument or take a political stance, but merely refer to the current situation seen from the perspective of the marine industry in general and the shipping sector in particular, and state some of the premises for abatement of harmful emissions from ships.*

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