Decarbonizing Shipping

Principles of Naval Architecture

Aalto University

Prepared by: 16.11.2023 FS/Joonatan Haukilehto

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Joonatan Haukilehto, M.Sc. (Nav. Arch.)
Lead Consultant, Newbuilds & Decarbonization
M: +358 41 5061 747 **E:** joonatan.haukilehto@foreship.com

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Foreship Ltd.
Hitsaajankatu 20
FI-00810 Helsinki
Finland
www.foreship.com

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Decarbonizing Shipping

Regulatory Landscape

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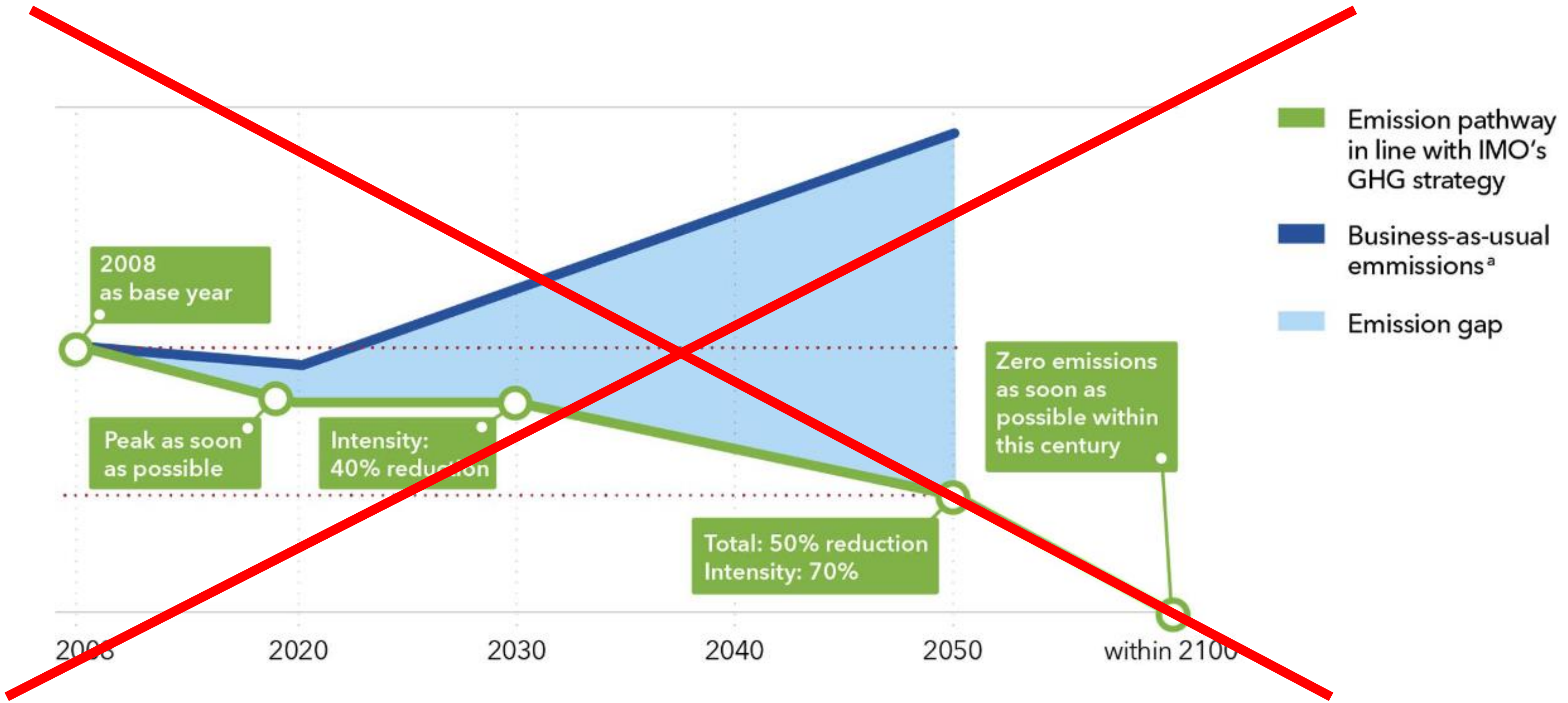
IMO Strategy on Reduction of GHG Emissions

2018



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IMO Strategy on Reduction of GHG Emissions

2023

Press releases

A.P. Moller - Maersk accelerates Net Zero emission targets to 2040 and sets milestone 2030 targets

12 January 2022

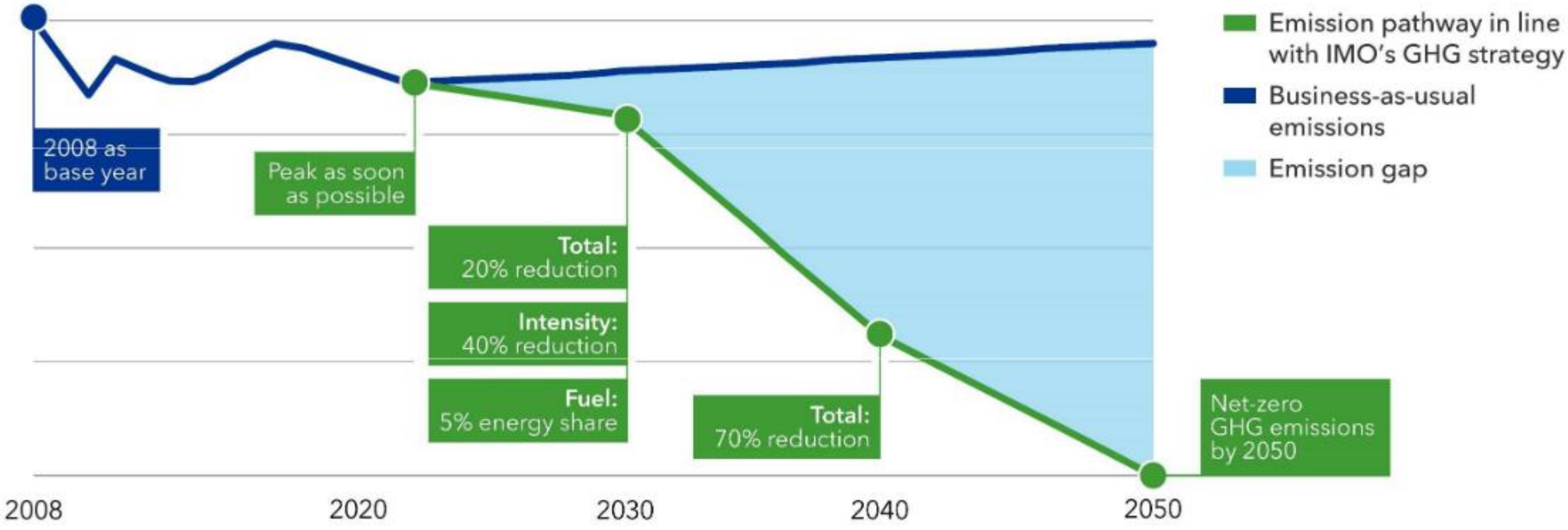
Decarbonisation Sustainability

MAERSK

The Climate Pledge

amazon

We believe we have an obligation to stop climate change, and reducing carbon emission to zero will have a big impact. We want to reach net-zero carbon emissions by 2040, a decade ahead of the Paris Climate Agreement, and we are on a path to powering our operations with 100% renewable energy by 2025 as part of our goal to reach net-zero carbon.



Regulatory GHG Landscape 2023-2050

Main Regulatory Drivers:
- IMO
- EU ETS
- Well-to-wake coming regulations

IMO current measures:
- Carbon intensity Indicator (CII)
- Ship Energy Efficiency Management Plan (SEEMP)
- Energy Efficiency Existing Ship Index (EEXI)
- Life Cycle Assessment guidelines for fuels (LCA)

EU current measures:
The Green Deal (Fit for 55)
- EU ETS
- FuelEU Maritime
- RED: Renewable Energy Directive
- AFIR: Alternative Fuels Infrastructure Regulation

Also, other regional regulations exist:
- (UK) RTFO - Renewable Transport Fuel Obligation
- RFS (US) - Renewable Fuel Standard
- CARB (US) - California Low Carbon Fuel Standard
- LCFS - (CAN) - Clean Fuel Standard

IMO

EU

CO_2

GHG Strategy

2023
-EEXI
-SEEMP & CII
-LCA 1st Version
-MEPC 80 GHG Strategy 1st Revision
-RED biennial reporting

2024
-IMO Revised Data Collection System: CII rating
-EU-ETS for shipping (>5 000 GT)

2025
-IMO CII & EEXI regulation review
-EEDI phase 3 (all ship types)
-FuelEU Maritime / GHG fuel standard (well-to-wake)
- AFIR phase in

2026
-EU ETS: Feasibility of including ships <5 000 GT
Inclusions of non-CO_2 emissions in ETS reporting

2030
-IMO target: 20% GHG reduction
Intensity: 40% reduction
-EU Target: 55% emissions reduction
-Container & Passenger ships to connect to shore power (Zero emission in port)

2040
-IMO Target: 70% GHG reduction

2050
-IMO target: Net-Zero GHG emissions
-EU target: climate-neutrality

United States current measures:
Inflation Reaction Act (IRA)
- Include various incentives to produce low carbon hydrogen, hydrogen derivates, clean energy and port decarbonization equipment

Infrastructure Investments and Jones Act (IIJA)

IMO possible measures (2025-2027)
- Marine Fuel Standard for regulating the reduction of GHG intensity
- GHG emissions pricing system

Regional regulations, Norway (2026)
- Zero Emission in heritage fjords and Bergen
- Batteries, hydrogen and Ammonia considered zero emission technology

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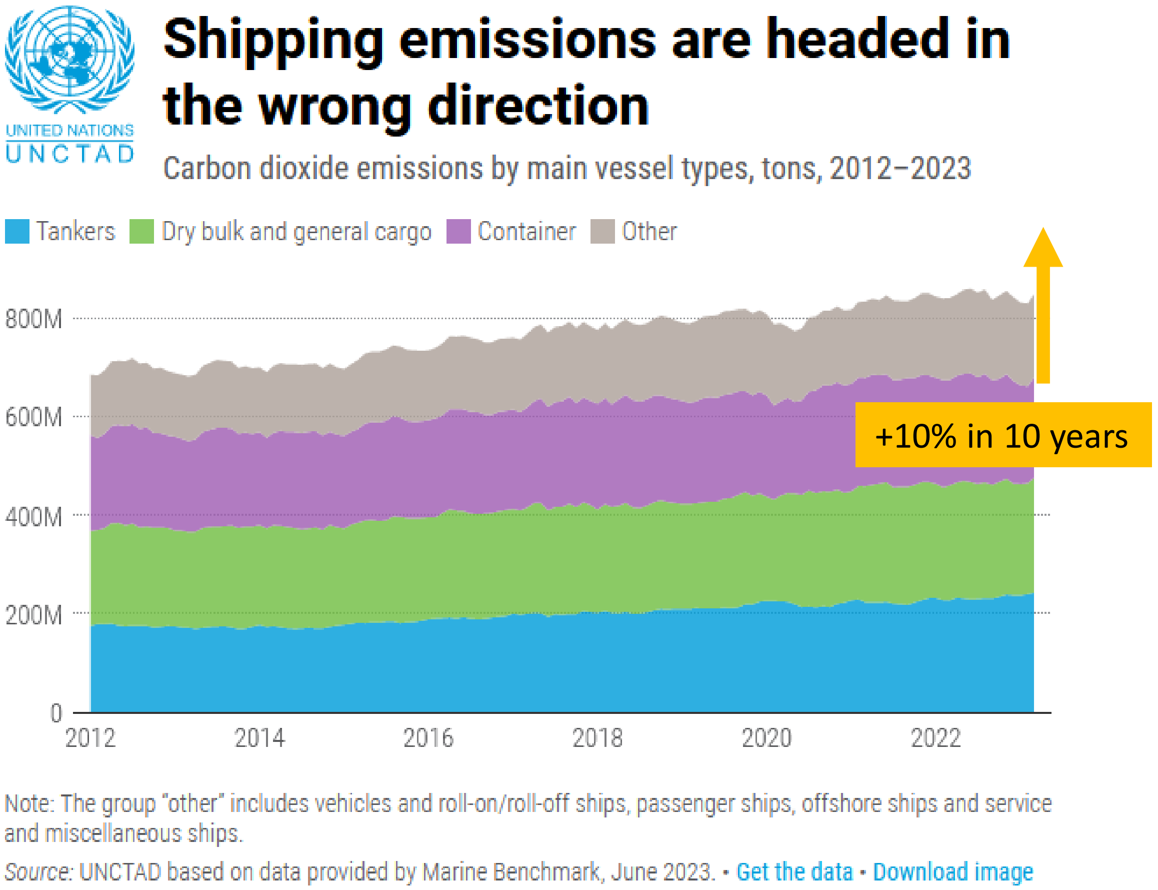
EU ETS (Emission Trading System)

- All ships above 5,000 GT transporting passengers or cargo from 2024. Ships above 400 GT by end of 2026. Offshore service vessels from 2027.
- Tank-to-wake CO_2 emissions. CH_4 and N_2O from 2026
- 50% of CO_2 emissions into or out of EU, 100% CO_2 between EU ports
- First reporting year is 2024, phase-in completed by 2026 (40%/70%/100%)
- Shipping companies need to surrender emission allowances annually, starting April 2025

EU Carbon Permits - 2023 Data - 2005-2022 Historical - 2024 Forecast - Price - Quote (tradingeconomics.com) 10/10/2023

Shipping's GHG Emissions



Decarbonizing Shipping

Energy Efficiency – The First Alternative Fuel

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Improvements to Vessels in Operation

25% energy savings by...

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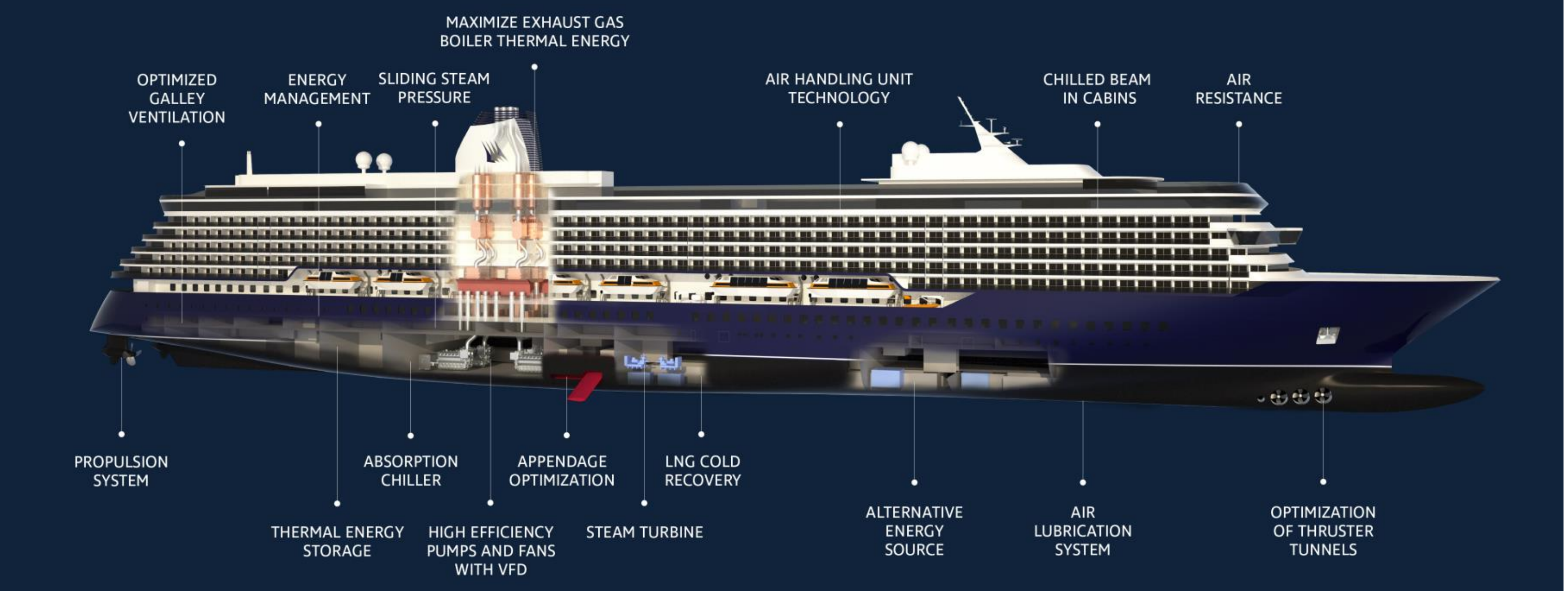


HULL AND PROPULSION
8% SAVINGS +

HULL FORM OPTIMIZATION FOR CORRECT SPEED AND CONDITIONS

- Appendage optimization
- Air resistance
- Air lubrication
- Propulsion system
- Optimization of thruster tunnels
- Energy Advisory

HVAC
5% SAVINGS +

CHILLER PLANT AND AIR CONDITIONING OPTIMIZATION

- Absorption chillers
- VFD driven AC chillers
- LNG cold recovery to CW
- Air Handling Unit technology
- Optimized galley ventilation
- Chilled beam in cabins
- CFD simulation for air conditioning

THERMAL ENERGY UTILIZATION
3% SAVINGS +

MAXIMIZED ENERGY UTILIZATION ONBOARD WITH WASTE HEAT RECOVERY TECHNOLOGY

- Two stage exhaust gas boilers
- Steam turbine
- Thermal Energy Storage
- Sliding steam pressure
- Common WHR circuit

HOTEL AND ELECTRICAL
5% SAVINGS +

IMPROVE BASE PROCESSES ONBOARD FOR HIGHER EFFICIENCY

- Fresh water production
- AWP
- Power plant configuration, variable speed main engines
- High efficiency pumps and fans
- Energy Management

ALTERNATIVE ENERGY SOURCES
<5% SAVINGS

ALTERNATIVE ENERGY SOURCES TO IMPROVE EFFICIENCY AND ENVIRONMENT

- Feasibility studies for Battery Energy Storage
- Feasibility studies for fuel cell technology and fuel alternatives

Upcoming Technologies, Examples

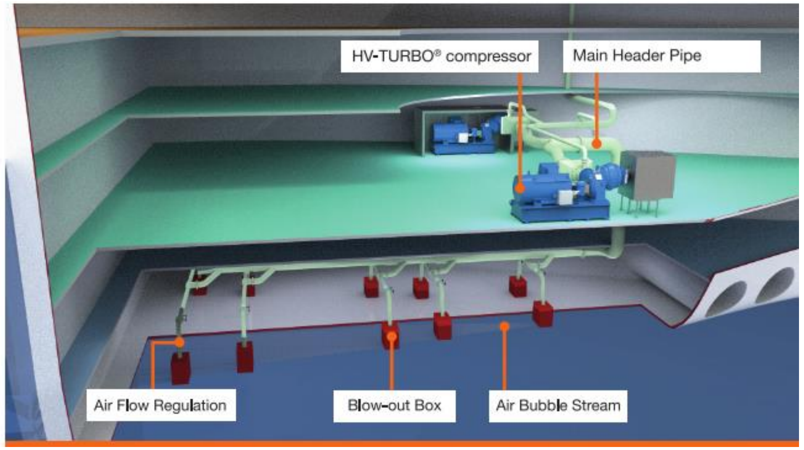
Wind Assisted Ship Propulsion (WASP)

Vale and Anemoi to Install Rotor Sails on World's Largest Ore Carrier

400,000 dwt ore carrier will become the world's largest wind power installation (Anemoi)

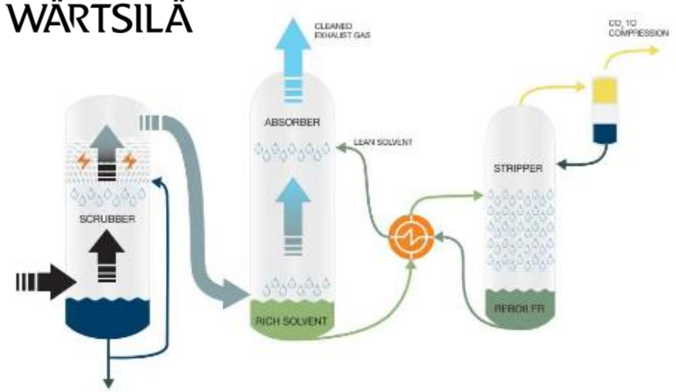
PUBLISHED NOV 8, 2023 1:35 PM BY THE MARITIME EXECUTIVE

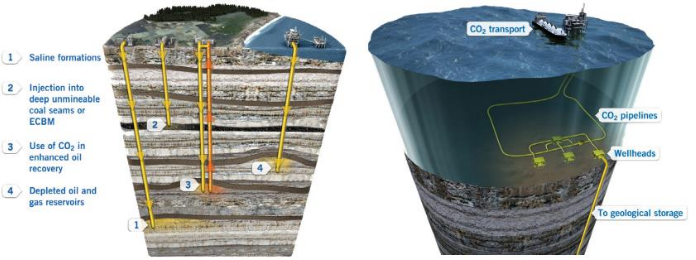
Air Lubrication System (ALS)

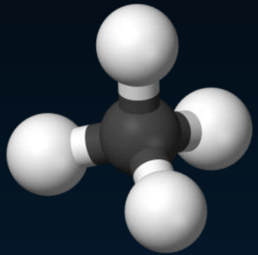
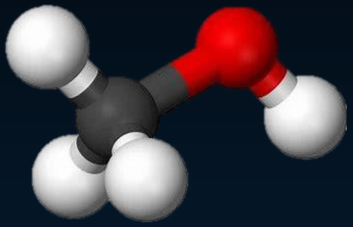
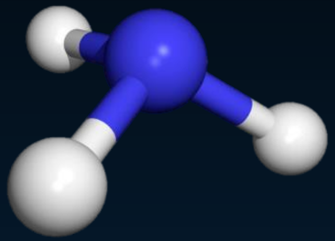


Carbon Capture and Storage (CCS)

WÄRTSILÄ






New / Upcoming Fuels

HVO, LNG, MeOH, NH_3, LH_2...

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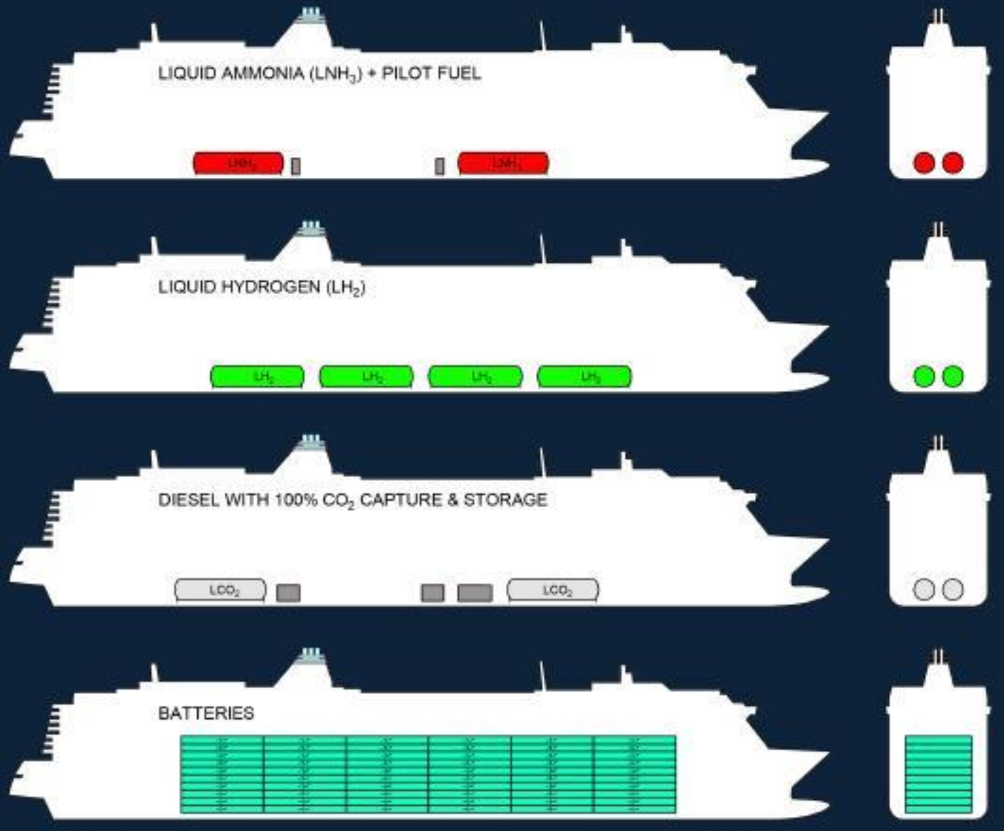
The onboard storage challenge



The comparison makes the following assumptions:

- Illustration shows fuel storage only (tank hold space, bunkering, ventilation, etc. systems are not shown)
- Fuel to energy conversion factor is 0.45 in all cases except batteries, where 0.97 applies
- Diesel is MGO (Marine Gas Oil)
- LNG, methanol and LNH3 ships have dual-fuel engines and include pilot fuel (MGO) as part of 10 GWh
- Effect on displacement, technical feasibility, etc. not considered. For example, shown battery capacity is impossible due to weight and space reasons

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Summary of fuels (1/3)

MGO

MGO is basically the same fuel than diesel cars and trucks use. MGO is a low sulfur fuel, having less than 0.1% sulfur. There are currently no areas where MGO burning cruise ships could not operate.

MGO (even as pilot fuel) ship needs SCR (Selective Catalytic Reduction) units to reduce NOX emissions to required level (IMO Tier II/III).

Changing MGO to HVO or Bio-diesel does need minor or no modifications at all.

HVO

Hydrotreated Vegetable Oil (HVO) is a biofuel made through hydrocracking (breaking large modules into smaller, using hydrogen) or hydrogenation (adding hydrogen) to vegetable oil. Renewable HVO is made of high-quality renewable waste or leftover vegetable oil (like waste oil from deep fat friers).

HVO does not have the problems of “standard“ biodiesel (aging, hygroscopic properties, effect on engine performance…). Instead, HVO can be considered even a better fuel than MGO and can be blended with MGO (not with HFO) to achieve “adjustable” GHG reduction.

The GHG reduction depends on the source material, transportation CO_2, hydrogen sourcing, and such, and can vary, for example, between 50% - 90%.

LNG

Liquified Natural Gas, LNG – which is mostly methane (CH_4) - is today a popular fuel for larger cruise ships and ferries. Does not contain sulfur.

Engines on larger LNG passenger ships are dual-fuel engines; they can be run on both gas and diesel, but in gas mode the engines still need a small amount of diesel as a “pilot fuel”.

With regards to Tank-to-Wake CO_2 emissions, natural gas is about 30% better than diesel fuel, due to the lower amount of carbon atoms contained in fuel. However, natural gas itself, consisting mostly of methane, is a powerful greenhouse gas, and the unburnt methane going through the engine - called “methane slip” - negates a part of this benefit, together with other well-to-tank emissions; thus, the Well-to-Tank GHG emissions are about 17% less than for HFO.

Summary of fuels (2/3)

Methanol (CH_3OH)

Methanol (CH_3OH, or often MeOH). Methanol can be used in combustion engines with help of pilot fuel, or in fuel cells equipped with reformers which separate carbon from hydrogen used in the fuel cell.

Compared to diesel fuel, methanol has significantly lower energy content, meaning more storage space is needed. Methanol can be stored in normal ambient temperatures, but it is also a low flash point fuel needing adequate safety measures.

Methanol has around 12% less CO_2 than HFO, but when Well-to-Tank is considered, "gray" methanol has 13% MORE CO_2 emissions than HFO. Thus, long-term methanol fuel needs to be bio- or E-methanol.

Interestingly, methanol, unlike other fuels, could be stored in double bottom tanks if there is a cofferdam between methanol tanks and other spaces on the ship; properly designed, this cand provide a space efficient design for a cruise ship. Methanol is corrosive and requires a proper coating for tanks.

Ammonia (NH_3)

Ammonia (NH_3) is a carbon free molecule, and thus a CO_2 free fuel when Tank-to-Wake GHG emissions are considered. However, initial indications from the engine makers are that ammonia requires significant amount of pilot fuel, impacting the total GHG emissions even when using bio-diesel as pilot fuel. For "gray" ammonia, the Well-to-Wake emissions are higher than for HFO. Thus, ammonia fuel should be E-Ammonia produced with renewable energy.

Ammonia, like methanol, can be used in combustion engines with help of pilot fuel. Ammonia can be used also in fuel cells equipped with crackers separating nitrogen from hydrogen.

Like methanol, ammonia has significantly lower energy content than diesel fuel. Ammonia needs to be stored in a pressurized tank in -33°C temperature. Using ammonia in combustion creates nitrogen oxides (NO_X), which needs to be taken care of with an SCR system. Ammonia is corrosive and ammonia vapor is heavier than air.

Ammonia is highly toxic, which can mean that using ammonia on passenger ships is questionable. It can even be that use of ammonia will be limited to cargo ships. Port authorities in densely populated areas could also limit access for ammonia ships.

Summary of fuels (3/3)

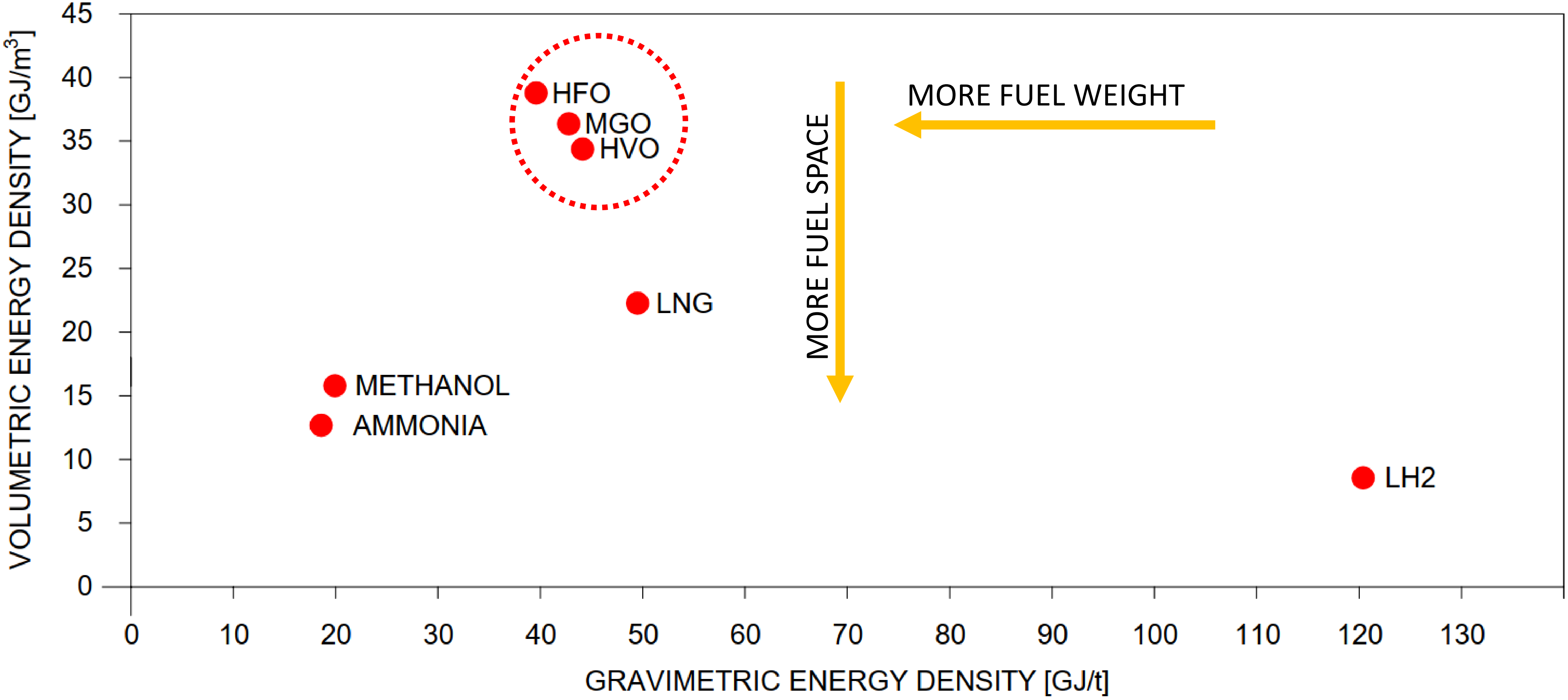
Hydrogen (H_2)

Hydrogen (H_2) is frequently mentioned as a possible future fuel. If hydrogen was produced using renewable or clean energy, then a hydrogen powered ship could be theoretically emission free assuming no hydrogen emissions during hydrogen production, transport and utilization (depending on source GWP100 of H_2 is up to 11.6, whereas for methane CH_4 it is 25 and for CO_2 1).

Hydrogen, however, has significant challenges in ship use:

- Even liquified hydrogen (LH_2) has a very low volumetric energy density: to provide the same energy than HFO, about 4.5 times more volume is needed for LH_2. When compared to LNG, LH_2 needs 40% more volume.
- Compressed hydrogen (CGH_2) used on hydrogen road cars would need even more volume: at 350 bar 14 times and at 700 bar 8.5 times more than HFO.
- Saturation temperature of liquid hydrogen is about -253 °C; this means that all surrounding air will liquefy on contact with hydrogen, which means the required insulation further increases the space required for storage tanks.
- Hydrogen particles are very small compared to e.g. methane (main component of LNG), increasing the risk of leakage.
- Unlike the case with LNG, due to low saturation temperature, nitrogen (N_2) cannot be used as inert gas for hydrogen. Instead, the more expensive and difficult to handle helium (He) is needed.
- Technology for (liquid) hydrogen handling in transport applications is still in early phases of development and e.g. no pumps for pumping liquid hydrogen in larger volumes currently exist (up to 3t/h pumps are indicated to be available).

Volumetric & Gravimetric Energy Density



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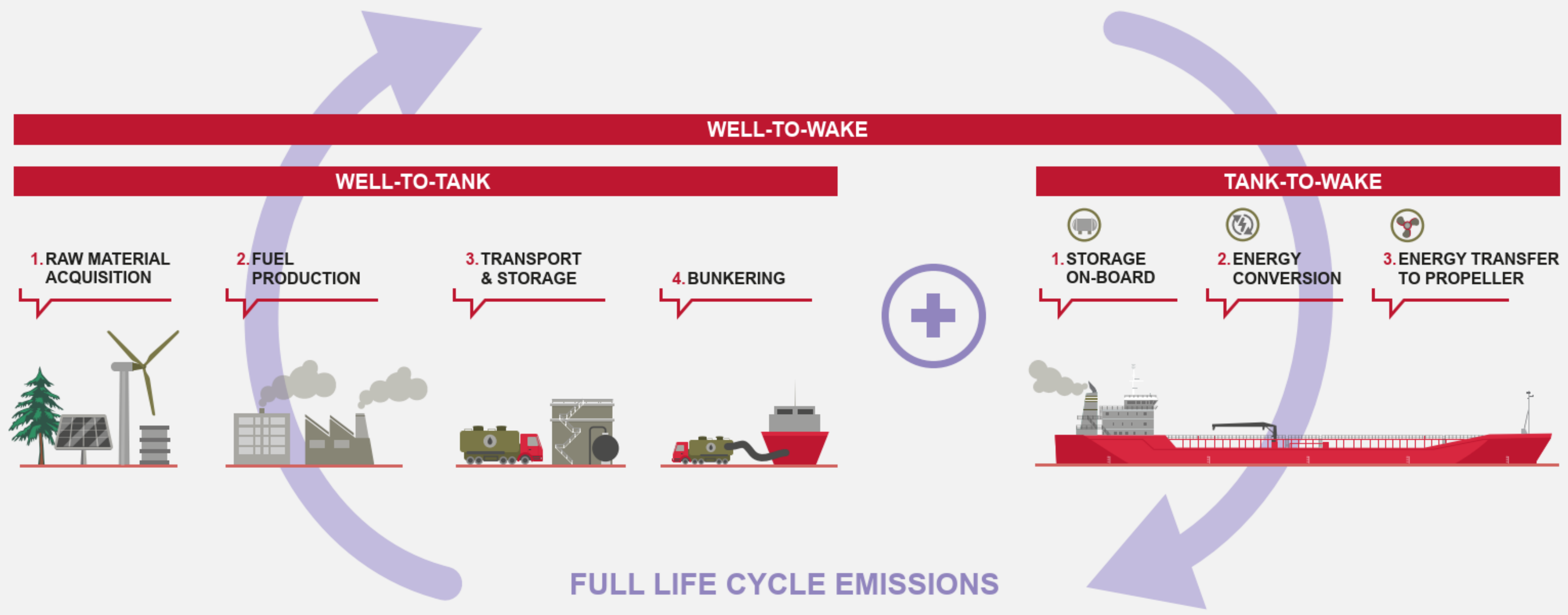
Tank-to-Wake (TTW) → Well-to-Wake (WTW)

- Currently IMO regulations only consider Tank-to-Wake emissions.
- Work is ongoing to include whole life cycle (LCA), Well-to-Wake.

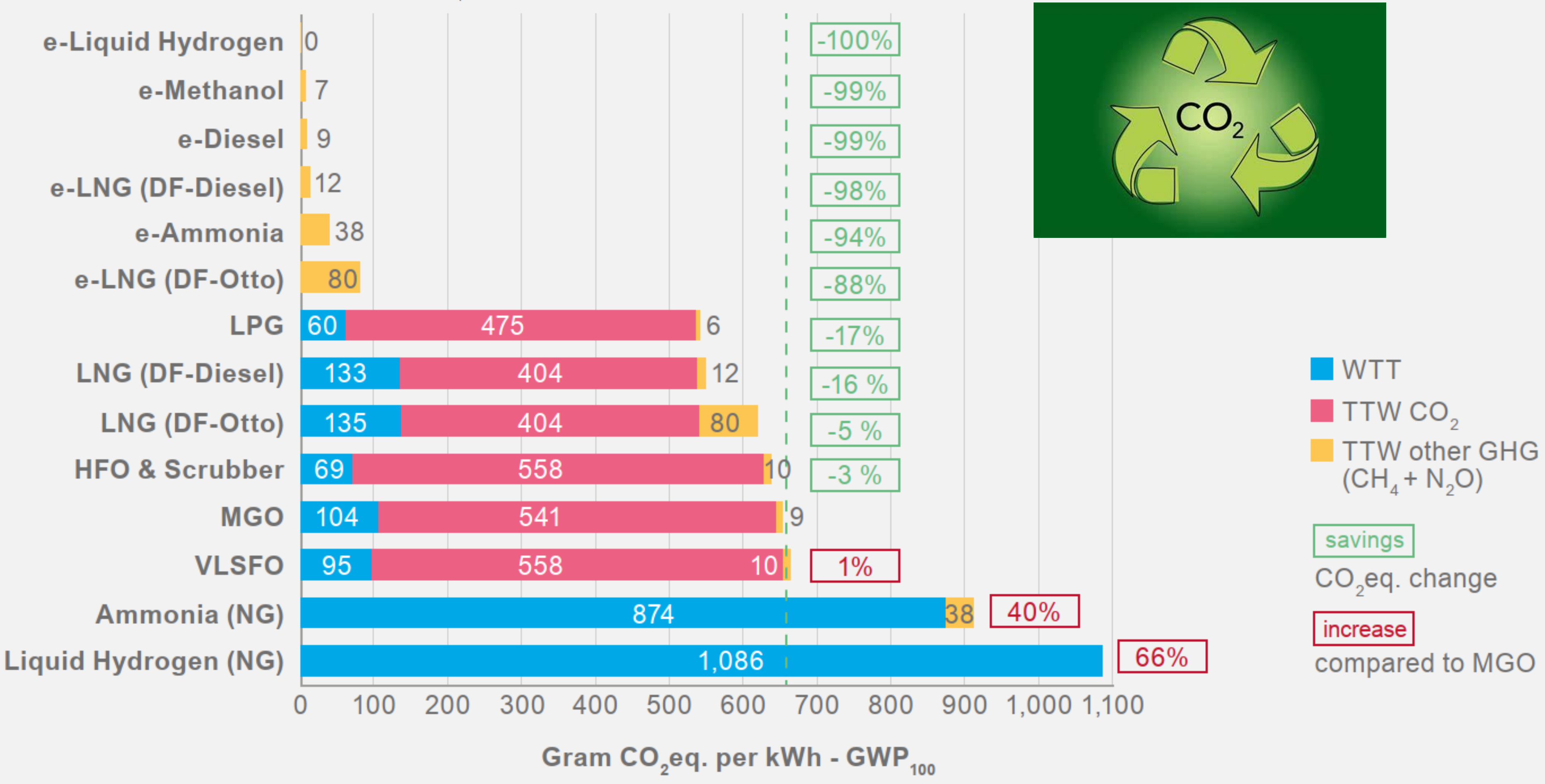
FIGURE 21: WTW EMISSIONS EXPLANATION



Source: Bureau Veritas

Only e-Fuels Will Make a Big Difference

FIGURE 24: WTW EMISSIONS (gCO_{2eq}/kWh)



Source: SINTEF & NTNU

Alternative Fuels: Future price scenario

Source: DNV 2022. The prices include both production and distribution cost and are global mean average from all regions. Fossil fuel prices do not include carbon price.

Decarbonizing Shipping

Conclusions

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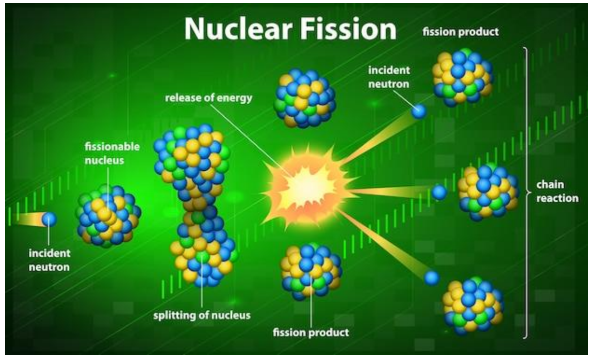
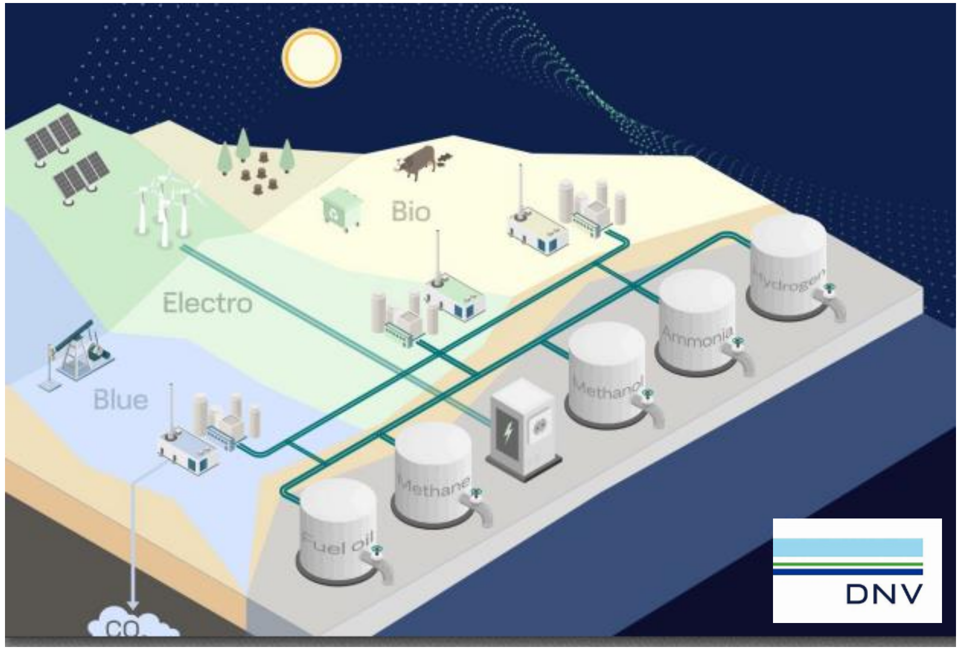
Considerations

- Number of ships and volume of shipping is projected to grow.
- Regulations push for decreasing emissions, but often slower than company ambitions (e.g. net-zero pledges).
- Complexity (and cost) of ships and fuel infrastructure is increasing.
- Life Cycle Analysis will be the future basis for GHG evaluations – increasing complexity both up- and downstream.
- Major, systematic changes are needed in order to make significant reductions in the GHG footprint of shipping.
- Not all the answers are known yet – there are plenty of opportunities for fresh new ideas!





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