Internal combustion engines will power maritime decarbonisation

Mikael Wideskog

Director, Sustainable Fuels & Decarbonisation

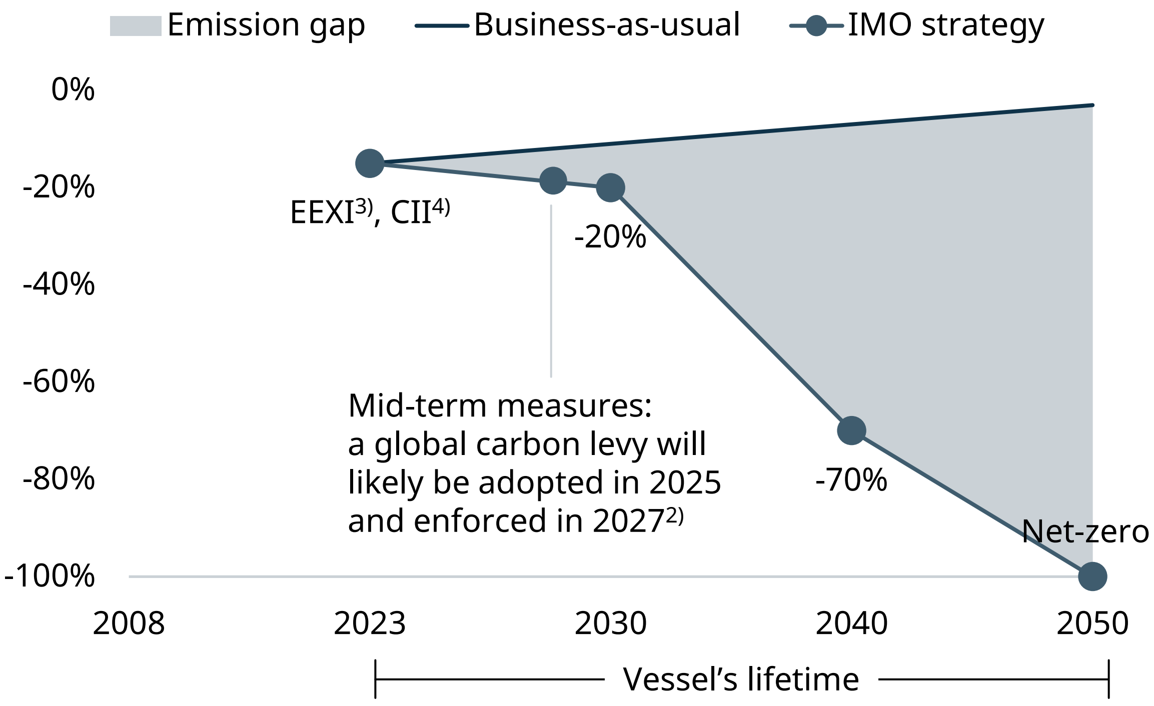
30 May, 2024

After IMO net-zero commitment last year, the regulatory focus has moved to "mid-term measures"

For vessels operating in EU waters, fuel cost may double due to emission fees by 2030, compared to 2023

IMO GHG Strategy[1)]

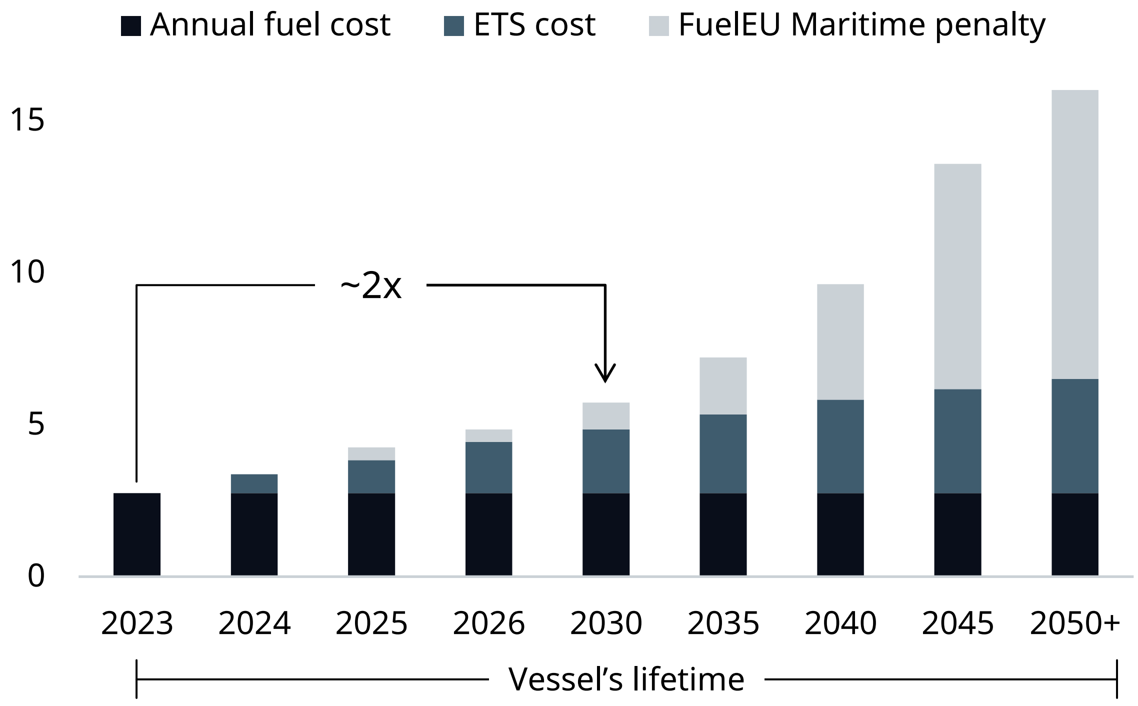
GHG emission reduction % vs 2008



Mid-term measures: a global carbon levy will likely be adopted in 2025 and enforced in 2027[2)]

EU Fit-for-55

Fuel-related costs for Handymax bulker operating in EU, MEUR[3)]



---

1) Source: IMO; data refers to well-to-wake Green House Gases (GHG) emissions; 2) E.g., goal-based marine fuel standard, GHG emissions pricing mechanism; 3) Assuming 5 000 tons/year VLSFO (Very Low Sulphur Fuel Oil) consumption subject to EU Fit-for-55, VLSFO at EUR 550/ton; EU ETS allowances from EUR 100/ton today to EUR 230/ton in 2050 (source: Transport & Environment NGO)

Decarbonisation can be reached through different pathways; net-zero targets will require a fundamental shift towards sustainable fuels

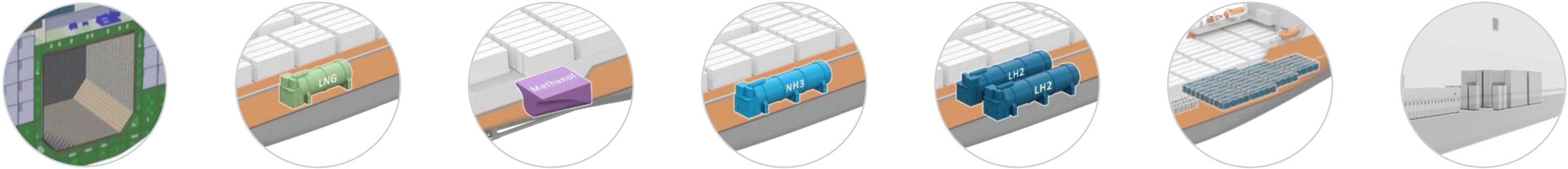
Decarbonisation pathways

Burn less fuel1)		Clean up emissions1)	Use alternative energy sources	
Vessel efficiency	**Operational efficiency**	**Emission abatement**	**Sustainable fuels**	**Electrification**
▪ Reduction of GHG emissions and fuel cost ▪ E.g., energy efficiency improvement of engine, propulsion, hull, other systems	▪ Reduction of GHG emissions and fuel cost ▪ E.g., speed reduction, route optimisation, onboard energy management	▪ Significant reduction of GHG emissions through onboard carbon capture, regardless of the fuel ▪ CO2 offloading infrastructure, onboard storage and value chain needed	▪ Significant / total reduction of GHG emissions ▪ Technology available; infrastructure and supply under development	▪ Zero GHG emissions through battery-electric propulsion ▪ Viable on short ranges due to low energy density
Approximate greenhouse gas (GHG) emission reduction potential				
25%	**25%**	**70%**	**100%**	**100%**

---

1) These pathways shall be combined with the utilisation of alternative fuels to support long term IMO targets

Cost of emissions will close the price gap between fossil and sustainable fuels; fuel selection impacts the vessel structure



Fuel type	**Low Sulphur Fuel Oil** @ 20°C	**Liquified Natural Gas** @ -162°C	**Methanol** @ 20°C	**Ammonia** @ -33°C	**Liquid Hydrogen** @ -253°C	**Compressed Hydrogen** @ 350bar	**Marine Battery Rack**
Fuel price factor (per GJ)[1]	1x	1.1x – 4.6x[2]	2.6x – 5.5x[3]	2.4x – 4.3x[4]	3.6x – 4.6x[4]	2.1x – 3.1x[4]	2.0x – 5.3x[8]
Fuel price factor in 2035, incl. carbon tax[1] [5]	1x	0.8x – 1.4[2]	0.8x – 1.6x[3]	0.7x – 1.2x[4]	1.2x – 1.5x[4]	0.6x – 1.0x[4]	0.8x – 2.0x[8]
Gross tank size factor[6]	1x	1.7x – 2.4x[7]	1.7x	3.9x	7.3x	19.5x	~40x (~20x potential)

1) Fuel production cost estimate for 2025 and 2035; source: Maersk Mc-Kinney Møller Center for Zero Carbon Shipping – NavigaTE 2023; 2) Price range spans between fossil & electro- methane; 3) Price range spans between bio- & electro- methanol; 4) Price range spans between blue- & electro- ammonia/hydrogen; 5) Assuming 100% consumption subject to EU Fit-for-55, EU allowances at EUR 159/ton (source: Transport & Environment NGO); 6) Gross tank estimations based on Wärtsilä data; 7) 1.7x membrane tanks, 2.4x type C tanks; 8) Shore energy price EUR 0.1-0.27/kWh

Our offering can support all decarbonisation pathways, making us our customers’ preferred business partner in their decarbonisation journey

Technology


Multi-fuel engines


Propulsion systems


Catalyst systems


Fuel gas supply systems


Exhaust gas treatment and carbon capture


Hybrid systems


Electrification solutions


Voyage and fleet optimisation


Port optimisation and simulators


Shaft line solutions

Services


Spare parts

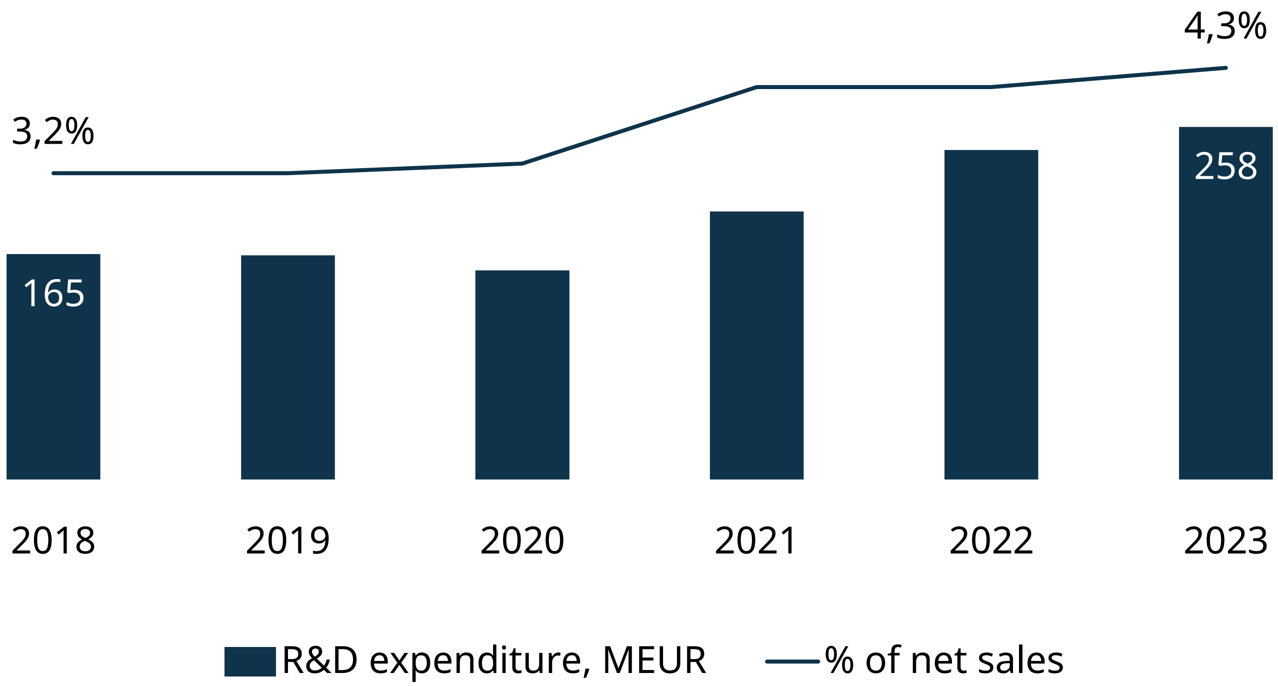

Maintenance services

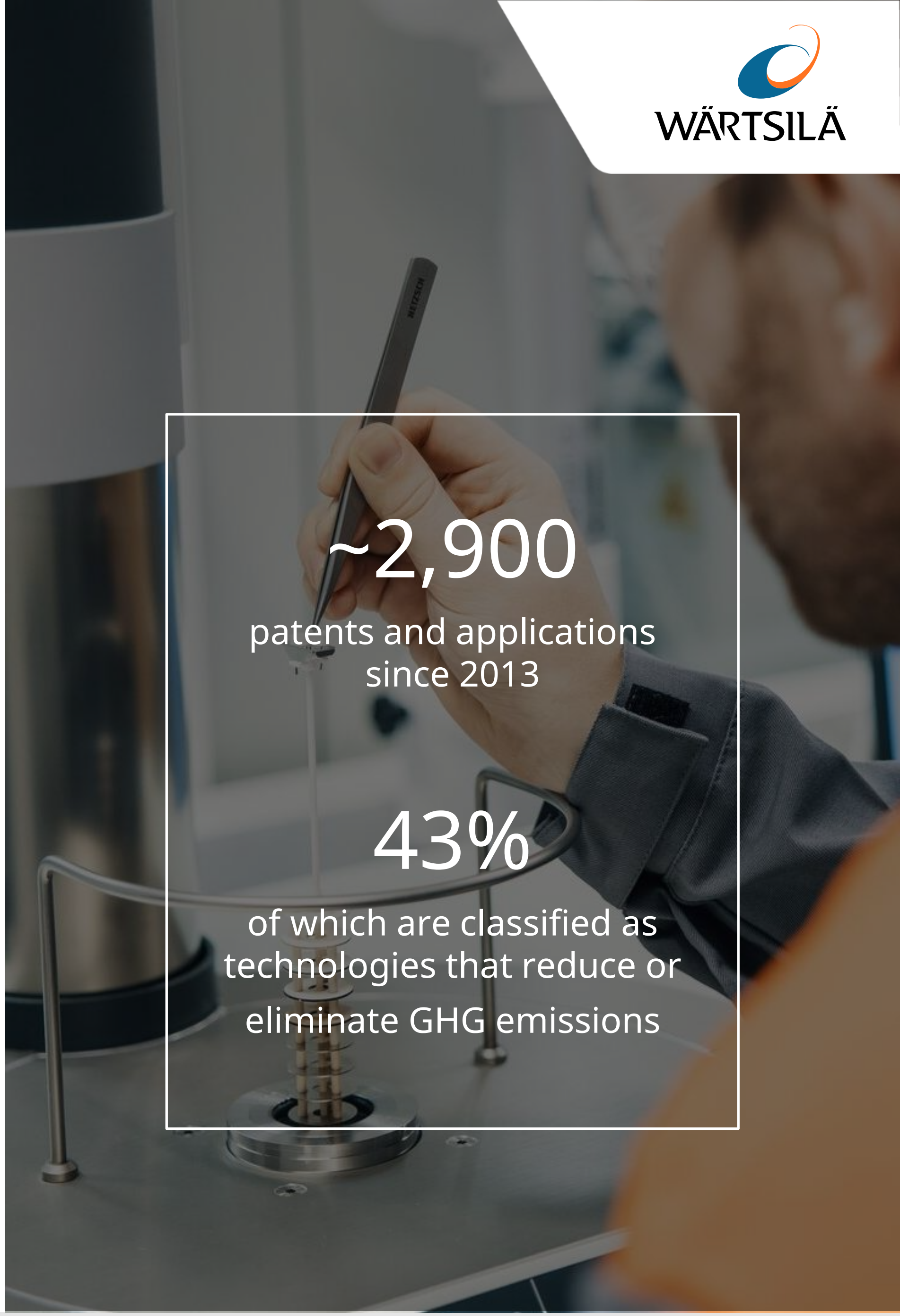

Performance based agreements


Upgrades & retrofits


Decarbonisation services

To support our decarbonisation technology development, we increased our R&D spending from historical average of ~3% of net sales to ~4%





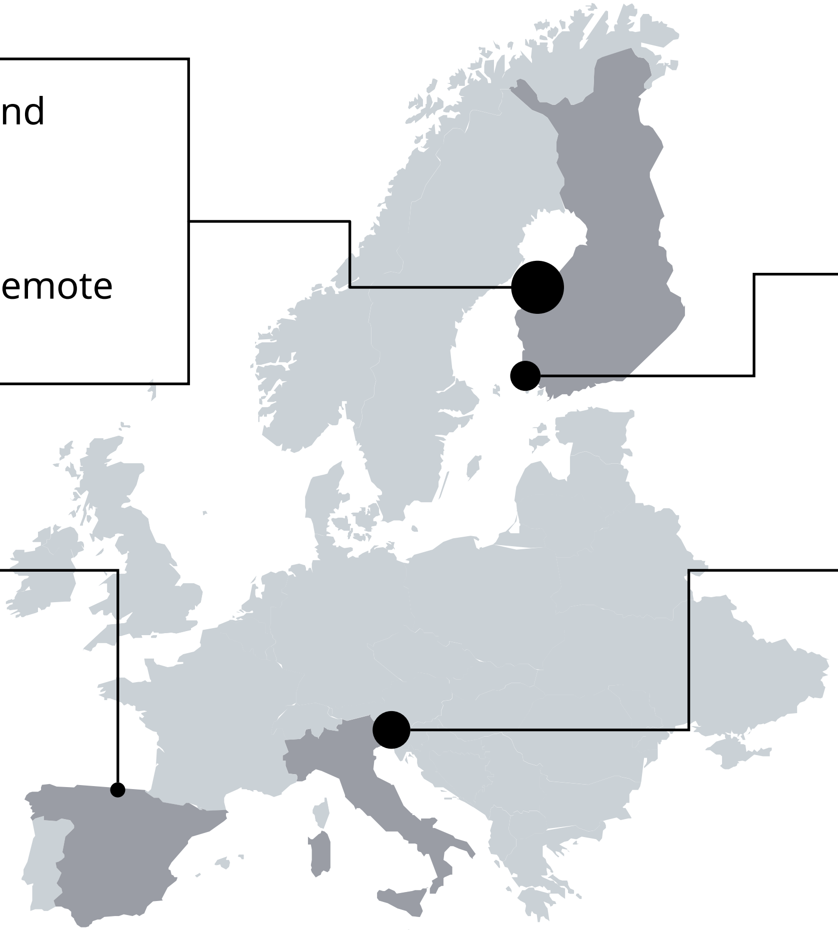
~2,900

patents and applications since 2013

43%

of which are classified as technologies that reduce or eliminate GHG emissions

We develop our engine technologies in four R&D facilities located in Europe



Sustainable Technology Hub, Vaasa, Finland

- Top level research laboratories
- University collaboration
- Integrated with production and services remote monitoring

Turku, Finland

- University collaboration
- Connection to marine cluster

Bermeo, Spain

- Top level hydrogen test facility
- Gas pipeline connection
- Local funding for energy production

Trieste, Italy

- 2-stroke engines testing
- University collaboration
- Connection to marine cluster

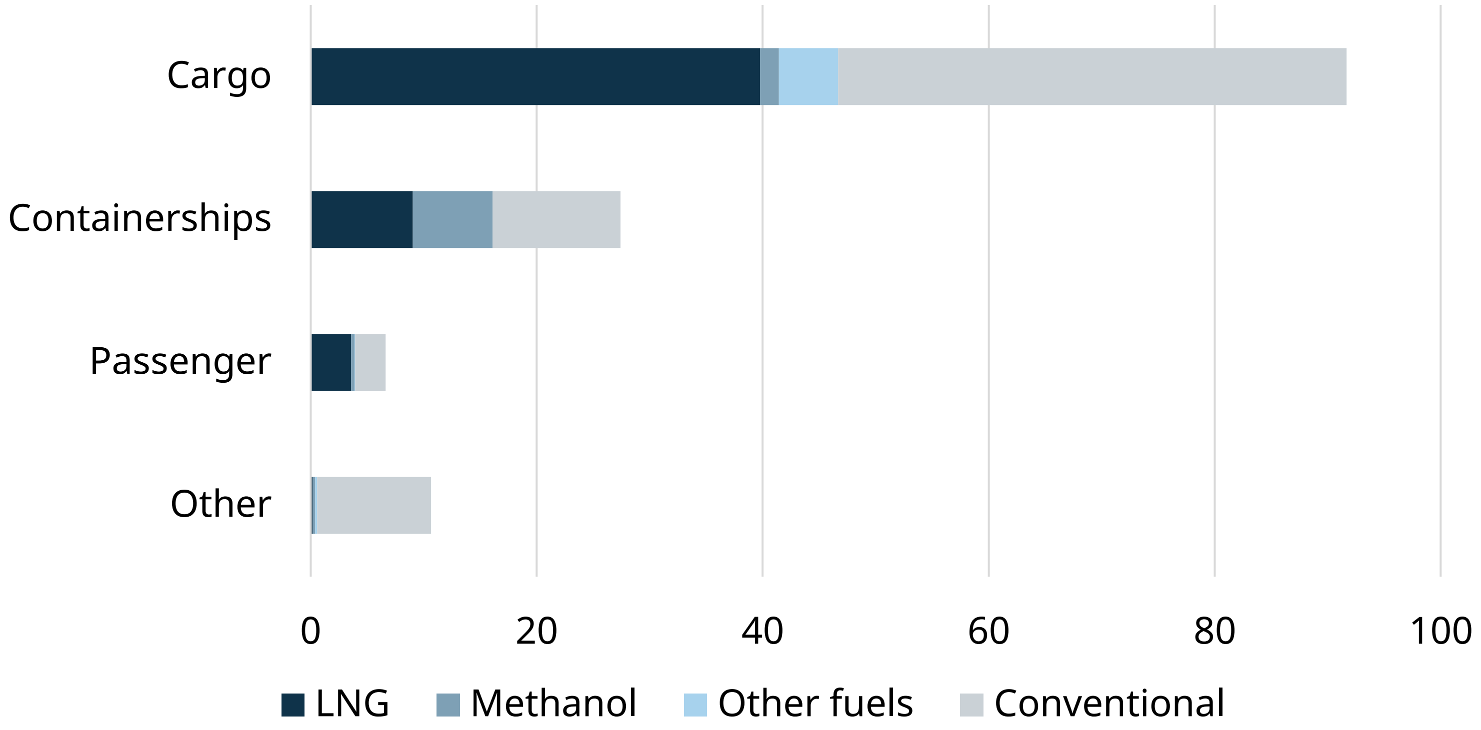
We lead in fuel flexibility and fuel efficiency, having the industry's most comprehensive offering for alternative fuels

	Fuels[1]	2015	2022	2023	2024	2025
LNG	LNG Diesel	Over 15 years of experience on field in Marine, over 30 years in Energy				
Methanol	Methanol Diesel	▪ First retrofit	▪ Sales release	▪ First delivery		
Ammonia	Ammonia Diesel			▪ Sales release		▪ First delivery
Hydrogen	Hydrogen	15%[2] hydrogen blends possible on LNG DF engines				▪ 100% hydrogen[3]
Fuel supply system		Over 13 years of experience on field in LNGPac		▪ MethanolPac first delivery ▪ AmmoniaPac sales release		▪ AmmoniaPac first delivery

Timeline may be subject to change based on market demand and other factors; hydrogen technology development (both blending and pure hydrogen) is ongoing, with focus on Energy market; 1) Multi-fuel engines can switch seamlessly between alternative and conventional fuels anytime; all fuels can be fossil, bio or synthetic; 2) Based on fuel volume; 3) Technology concept

Across the markets, LNG is still the most popular alternative fuel choice, followed by methanol; uncertainty remains over long-term fuel mix

Fuel uptake by segment, mCGT on orderbook



~50%

of total shipbuilding orderbook is set to run on alternative fuels

~55%

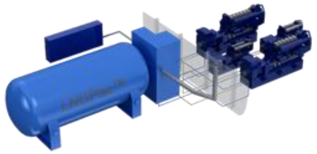
of passenger vessels are set to run on LNG

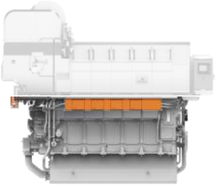
~60%

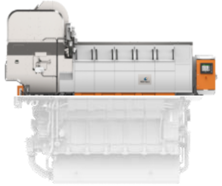
of containerships on orderbook are alternative fuel capable, out of which ~45% are set to run on methanol

Source: Clarksons Research May 2024, vessels above 2000 GT; mCGT = Compensated Gross Tonnage, millions; ‘Other fuels’ includes ammonia, biofuels, ethane, LPG, hydrogen and nuclear; hydrogen fuel cell pilots not included; segment ‘Other’ includes offshore, fishing vessels, dredgers, yachts, tugs, etc.

Our engines have built-in upgradability to future fuels, with significant part commonality between different fuel versions and a modular design







LNG DF[1] engine to run on:	Fuel System	Engine base	Engine top
Bio/Synthetic diesel	No changes	No changes	No changes
Bio/Blue/Green methane	No changes	No changes	No changes
Ammonia	Replace with AmmoniaPac	No changes	Change fuel injection system and power pack[2]
Methanol	Replace with MethanolPac	No changes	Change fuel injection system and power pack[2]
Hydrogen blend[3]	Move to alternative fuel handling system	No changes	No changes

Replacement of fuel handling and storage system has bigger impact in terms of CapEx, cargo space and vessel range

Upgrading a multi-fuel engine to a new fuel requires limited investment thanks to high modularity and part commonality

---

1) DF – Dual Fuel; 2) I.e., piston, cylinder liner, connecting rod; 3) Up to 15% on fuel volume

Hybrid-Electric will challenge 2-stroke as prime-mover for LNG carriers, enabling higher efficiency and increased cargo capacity

Wärtsilä Hybrid-Electric LNG carrier

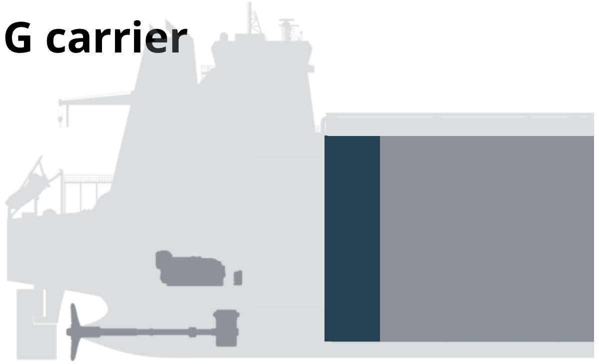
~185k cbm capacity

3x 4-stroke spark-gas gensets

2x 4-stroke dual fuel gensets

2 MWh batteries

■ Extra cargo capacity

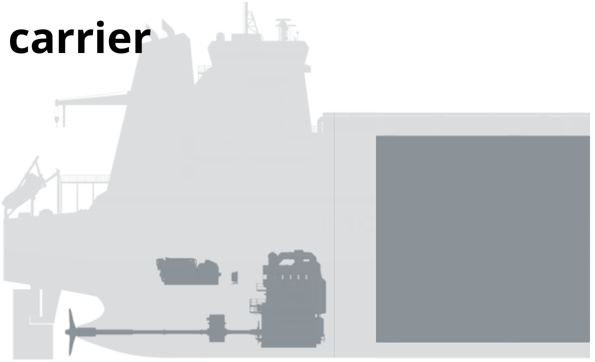


Conventional 2-stroke LNG carrier

174k cbm capacity

2x 2-stroke main engines

4x 4-stroke aux engines

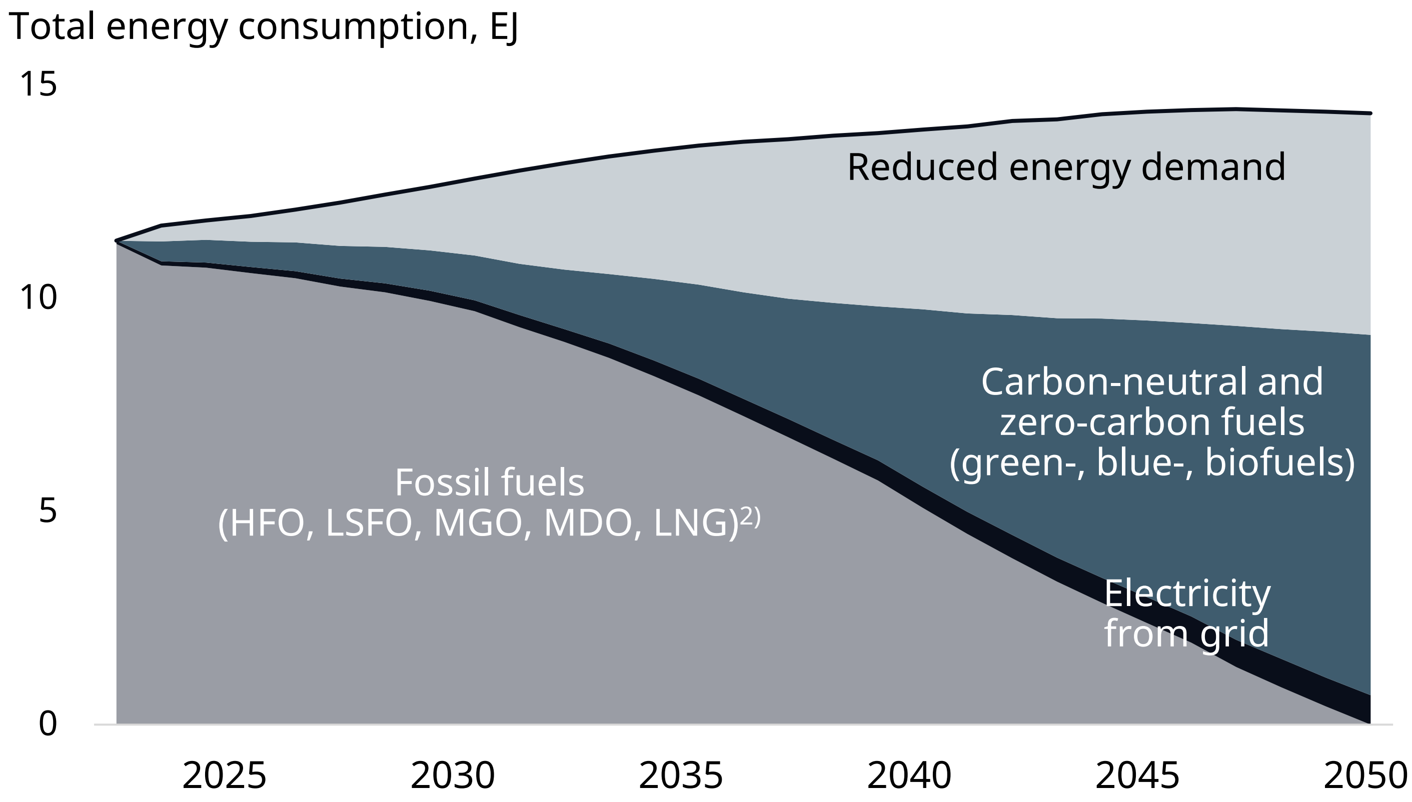


- ✓ **Launched at Gastech in 2023**
  with Shell and Hudong-Zhonghua Shipbuilding
- ✓ **6% extra cargo capacity**
  with same ship dimensions
- ✓ **>10% lower fuel consumption and emissions**
  with optimal efficiency across all speeds
- ✓ **20% lower maintenance costs**
  with fewer engine running hours
- ✓ **Superior redundancy, uptime, flexibility**
  as it can operate with fewer engines
- ✓ **Future proof**
  as it can integrate alternative power sources

Values refer to a comparison with a conventional 174k cbm LNGC (2x 2-stroke low pressure DF main engines, 4x 34DF 4-stroke aux engines), calculated on full year cycle real operating profile with average speed of 15 knots in laden and 13.5 knots in ballast; cargo increase confirmed by Hanwa Ocean and Hudong-Zhonghua shipyards in their general arrangements and outline specifications

Our engines can burn fuels regardless of their source, enabling a flexible pathway towards IMO net-zero targets

Sustainable fuel uptake scenario for net-zero in 2050[1)]



- ✓ **Green fuels**
  Produced from hydrogen made through electrolysis using renewable energy
- ✓ **Blue fuels**
  Produced using fossil fuels, with carbon captured and stored during the fuel production process
- ✓ **Biofuels**
  Produced from non-edible crops or natural products such as wood, or agricultural residues
- ✓ **Blending of fuels**
  Green, blue and biofuels can be blended with fossil fuels for a gradual emission reduction

1) Source: DNV Maritime Forecast 2050; 2) HFO – Heavy Fuel Oil; LSFO – Low Sulphur Fuel Oil; MGO – Marine Gas Oil; MDO – Marine Diesel Oil

LNG is a mature fuel, with ~2,000 ships in services and on order

✓ **Pros**

- Safe to use, proven technology
- ~20% reduction on tank-to-wake GHG emissions vs Heavy Fuel Oil (HFO)
- No need for aftertreatment to reach Nitrogen Oxides (NOx) Tier III compliancy
- Very low Sulphur Oxides (SOx) and Particulate Matter (PM) emissions

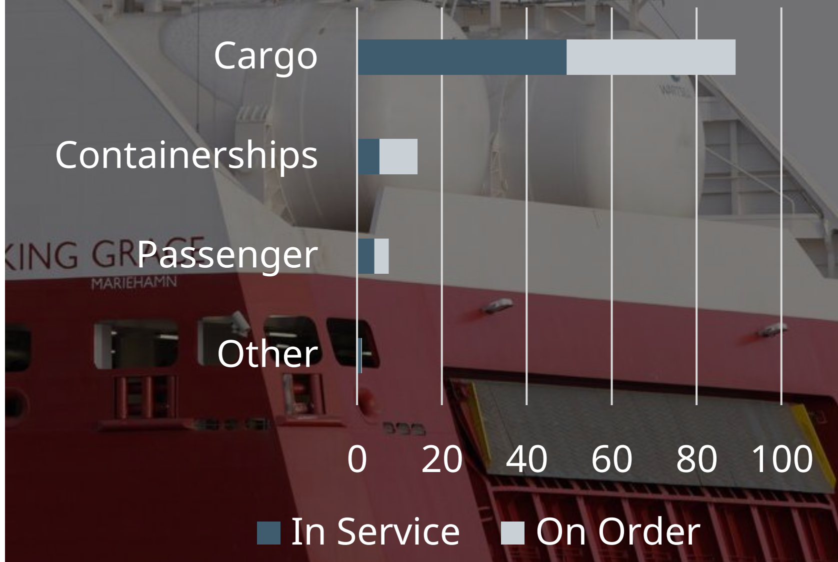
✓ **Cons**

- Methane slip

✓ **Wärtsilä positioning**

- 15+ years of experience in Marine
- Complete offering from fuel supply system to engine

LNG uptake by segment, mCGT[1)]



LNG vs. Low Sulphur Fuel Oil

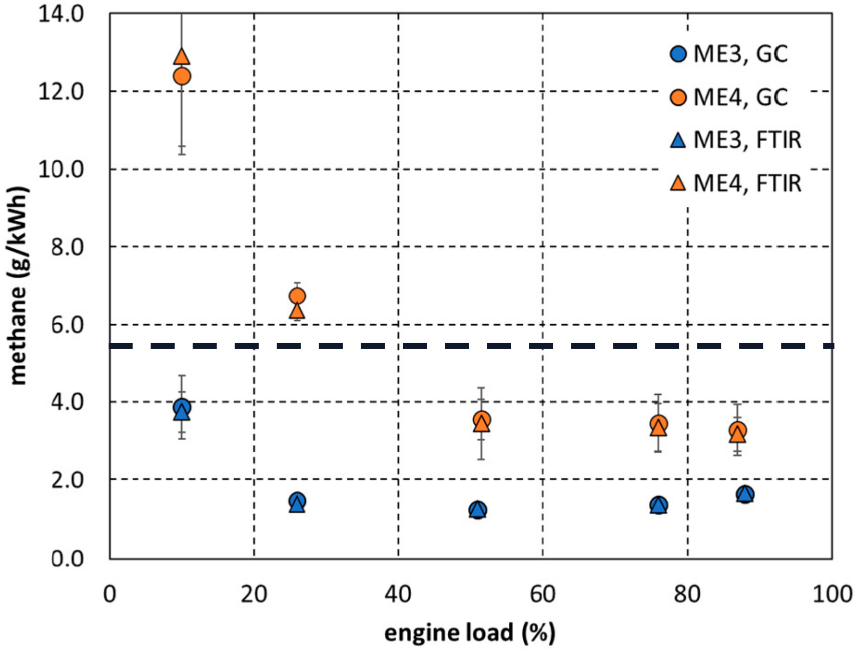
Fuel price factor in EU in 2035[2)3)]	Gross tank size factor[5)]
0.8x – 1.4[4)]	1.7x – 2.4x[6)]

---

1) Source: Clarksons, May 2024, vessels >2000 GT; mCGT = Compensated Gross Tonnage, millions; 'Cargo' includes gas carriers; 'Other' includes offshore, fishing vessels, dredgers, yachts, tugs, etc.; 2) Fuel production cost estimate for 2035; source: Maersk Mc-Kinney Møller Center for Zero Carbon Shipping – NavigaTE 2023; 3) Assuming 100% consumption subject to EU Fit-for-55, EU allowances at EUR 159/ton (source: Transport & Environment NGO); 4) Price range spans between fossil and electro- methane; 5) Estimations based on Wärtsilä data; 6) 1.7x membrane tanks, 2.4x type C tanks

Independent third-party measurements show that we are well below default methane slip values defined in regulations

Measurement results[1)]



– – Default value from IMO 4th GHG Study

State of the art technology

- Standard Wärtsilä 31DF has methane emission clearly below the default factors of recent EU regulations and IMO LCA[2)] guidelines, which is based on the 4th IMO GHG study
- Wärtsilä has introduced a new ultra-low emissions version of its already efficient Wärtsilä 31DF engine, the EnviroPac
- Whilst operating on LNG, this new version can further reduce methane emissions on a 50% load point by up to 56% and nitrogen oxide (NOx) by up to 86%
- On a weighted average, this new technology can reduce methane emissions by 41% more than the standard Wärtsilä 31DF engine, which has already the lowest emission levels on the market

DF = Dual Fuel; ME = Main Engine; 1) Methane emissions measured as a function of engine load with Gas Chromatography (GC) and Fourier Transform InfraRed spectroscopy (FTIR); ME3 – standard 31DF engine, ME4 – 31DF with EnviroPac; error bars show the standard deviations; source: third-party peer-reviewed scientific article, Atmosphere 2023, 14(5), 825; 2) IMO Guidelines on Life Cycle GHG Intensity of Marine Fuels

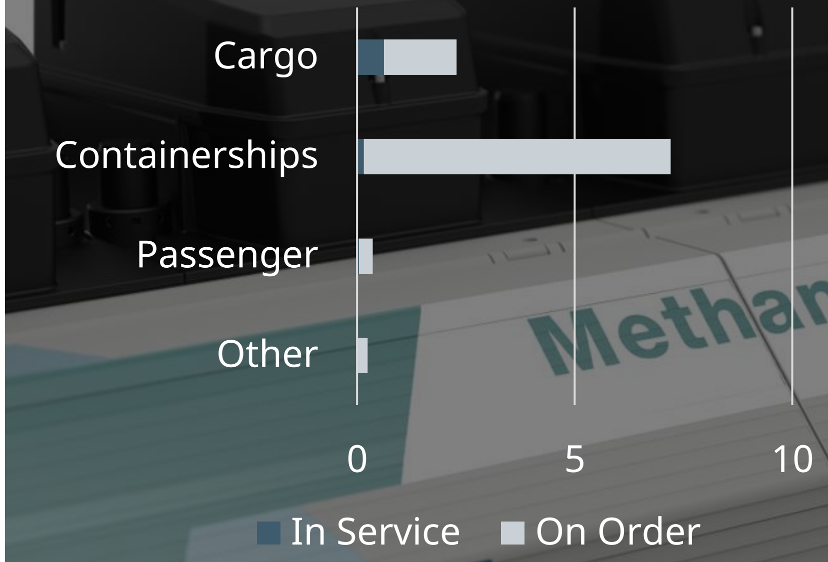
Methanol has rapidly become the preferred choice for containerships and is expanding to other sectors

✓ **Pros**
- Fuel handling simpler than LNG
- Very low Sulphur Oxides (SOx) and Particulate Matter (PM) emissions
- Retrofit potential: easier engine and less costly conversion than LNG

✓ **Cons**
- Toxic and flammable
- Aftertreatment needed to reach Nitrogen Oxides (NOx) Tier III compliancy

✓ **Wärtsilä positioning**
- Pioneer in methanol engines market
- >160 engines sold to date

Methanol uptake by segment, mCGT 1)



Methanol vs. Low Sulphur Fuel Oil

Fuel price factor in 2035 2)3)	Gross tank size factor 5)
0.8x – 1.6x 4)	1.7x

---

1) Source: Clarksons, May 2024, vessels >2000 GT; mCGT = Compensated Gross Tonnage, millions; 'Cargo' includes gas carriers; segment 'Other' includes offshore, fishing vessels, dredgers, yachts, tugs, etc.; 2) Fuel production cost estimate for 2035; source: Maersk Mc-Kinney Møller Center for Zero Carbon Shipping – NavigaTE 2023; 3) Assuming 100% consumption subject to EU Fit-for-55, EU allowances at EUR 159/ton (source: Transport & Environment NGO); 4) Price range spans between bio- and electro- methanol; 5) Gross tank estimations based on Wärtsilä data

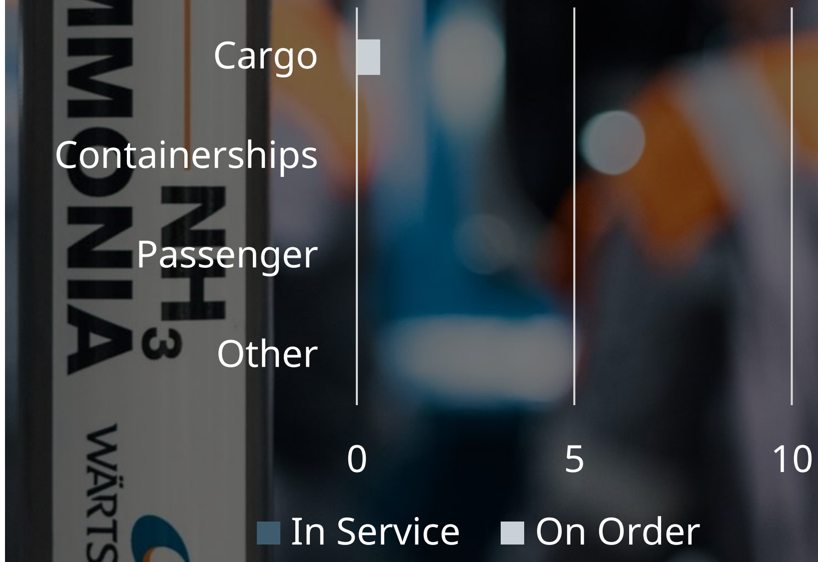
Ammonia as fuel is gaining interest

- ✓ **Pros**
  - Zero carbon fuel
  - Very low Sulphur Oxides (SOx) and Particulate Matter (PM) emissions

- ✓ **Cons**
  - Toxic and corrosive
  - Lower energy density compared to LNG, i.e., it requires bigger volumes to store the same amount of energy
  - Aftertreatment needed to reach Nitrogen Oxides (NOx) Tier III compliancy

- ✓ **Wärtsilä positioning**
  - World's first 4-stroke ammonia solution for marine launched in Dec 2023
  - Target to sign first contract in 2024

Ammonia uptake by segment, mCGT[1)]



Ammonia vs. Low Sulphur Fuel Oil

Fuel price factor in 2035[2)3)]	Gross tank size factor[5)]
0.7x – 1.2x[4)]	3.9x

---

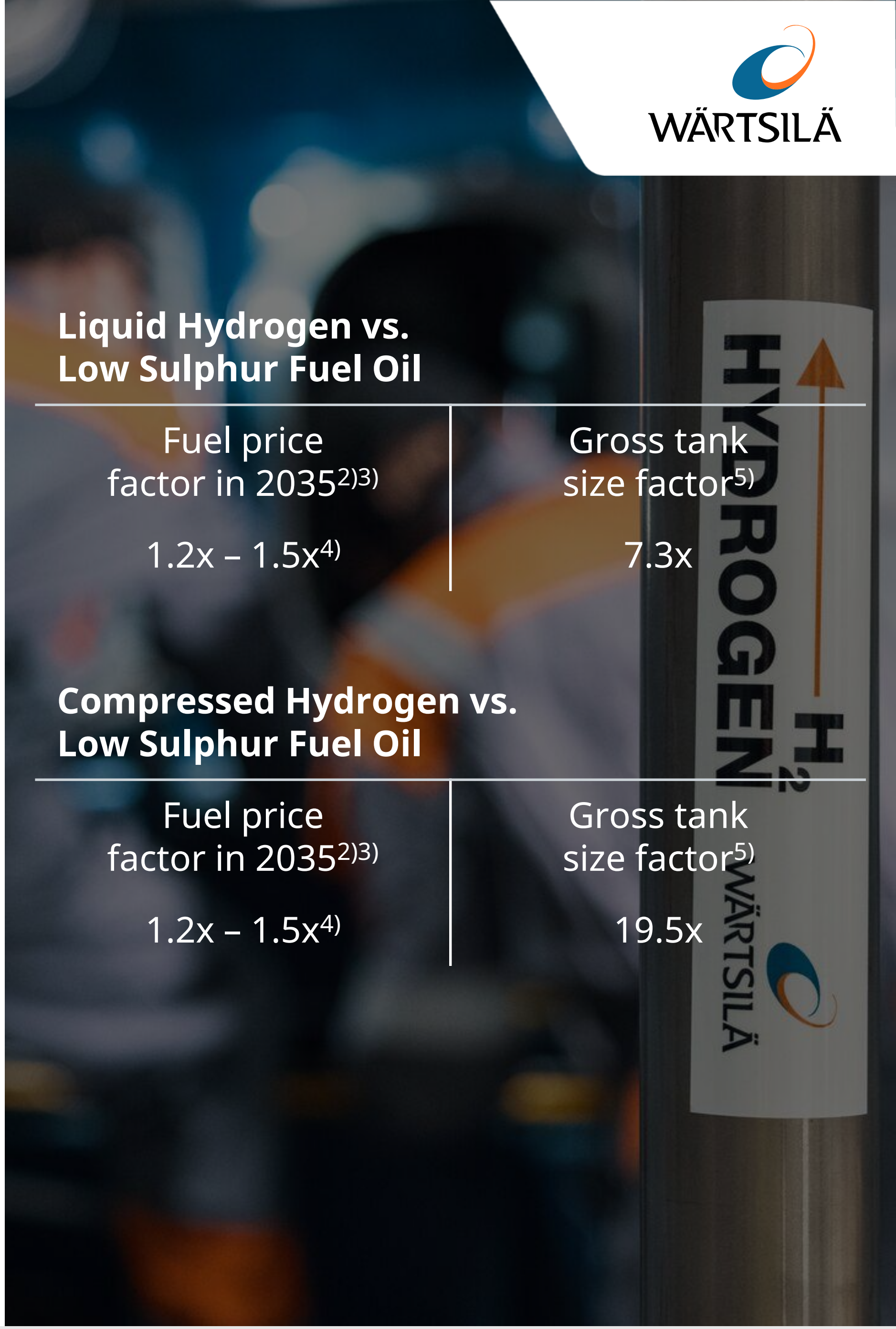
1) Source: Clarksons, May 2024, vessels above 2000 GT; mCGT = Compensated Gross Tonnage, millions; 'Cargo' includes gas carriers; segment 'Other' includes offshore, fishing vessels, dredgers, yachts, tugs, etc.; 2) Fuel production cost estimate for 2035; source: Maersk Mc-Kinney Møller Center for Zero Carbon Shipping – NavigaTE 2023; 3) Assuming 100% consumption subject to EU Fit-for-55, EU allowances at EUR 159/ton (source: Transport & Environment NGO); 4) Price range spans between blue- and electro- ammonia; 5) Gross tank estimations based on Wärtsilä data

Hydrogen's transportation and storage challenges will limit the uptake in marine

- ✓ **Pros**
  - Zero carbon fuel
  - No need for aftertreatment to reach Nitrogen Oxides (NOx) Tier III compliancy
  - Very low Sulphur Oxides (SOx) and Particulate Matter (PM) emissions

- ✓ **Cons**
  - Very low energy density limits the application in shipping
  - Expensive and challenging to store as a liquid at -253°C

- ✓ **Wärtsilä positioning**
  - 15%[1] hydrogen blends possible on LNG dual fuel engines
  - 100% hydrogen technical concept ready by 2025 for Energy market



Liquid Hydrogen vs. Low Sulphur Fuel Oil

Fuel price factor in 2035[2][3]	Gross tank size factor[5]
1.2x – 1.5x[4]	7.3x

Compressed Hydrogen vs. Low Sulphur Fuel Oil

Fuel price factor in 2035[2][3]	Gross tank size factor[5]
1.2x – 1.5x[4]	19.5x

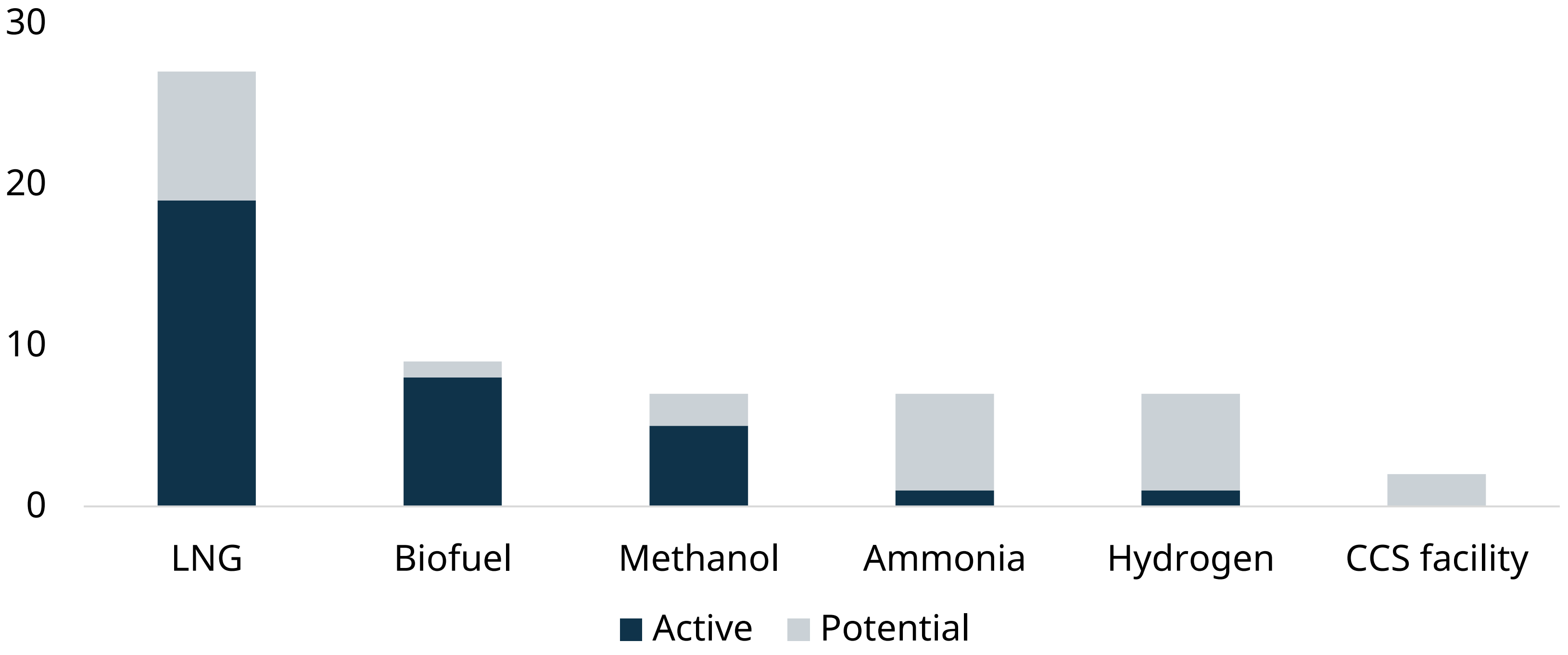
---

1) Based on fuel volume; 2) Fuel production cost estimate for 2035; source: Maersk Mc-Kinney Møller Center for Zero Carbon Shipping – NavigaTE 2023; 3) Assuming 100% consumption subject to EU Fit-for-55, EU allowances at EUR 159/ton (source: Transport & Environment NGO); 4) Price range spans between blue- and electro- hydrogen; 5) Gross tank estimations based on Wärtsilä data

The alternative fuel ecosystem must develop to support the maritime green transition

Alternative fuel uptake at ports infrastructures

Alternative fuels bunkering facilities in the world's top 50 ports[1)], no. ports

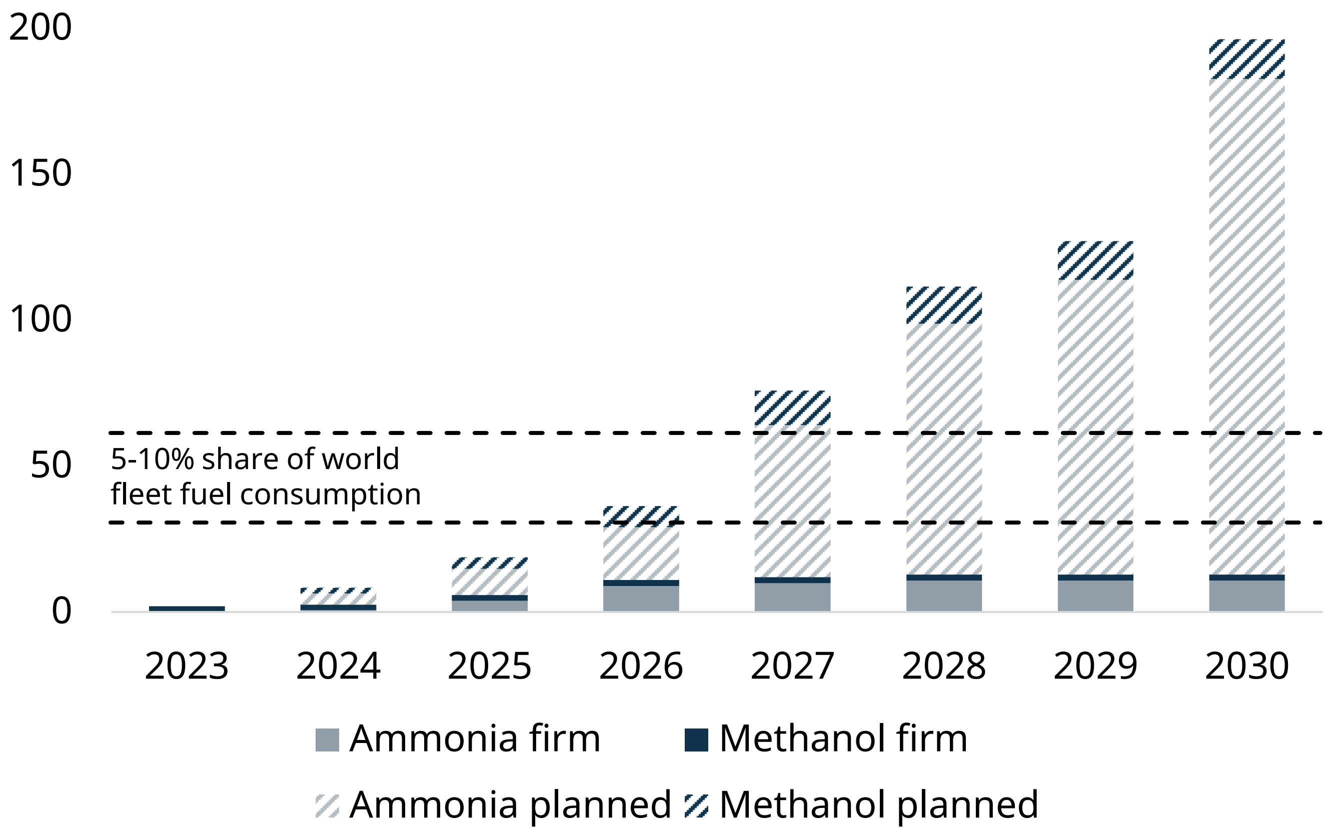


- ✓ ~60% of the top 50 ports worldwide have or plan to build alternative fuel bunkering infrastructure
- ✓ LNG is available in over 190 ports worldwide, with further projects under discussion
- ✓ ~40 ammonia and ~40 hydrogen bunkering projects are currently under discussion

Source: Clarksons, May 2024; CCS = Carbon Capture and Storage 1) By number of ports calls in 2023; 'Potential' includes any announced project pre-construction; bunkering facilities include also truck-to-ship and ship-to-ship methods

By 2030, the confirmed global production capacity for sustainable ammonia and methanol is ~2% of the planned fuel need

Projected production of sust. methanol and ammonia[1], million tonnes



Key considerations

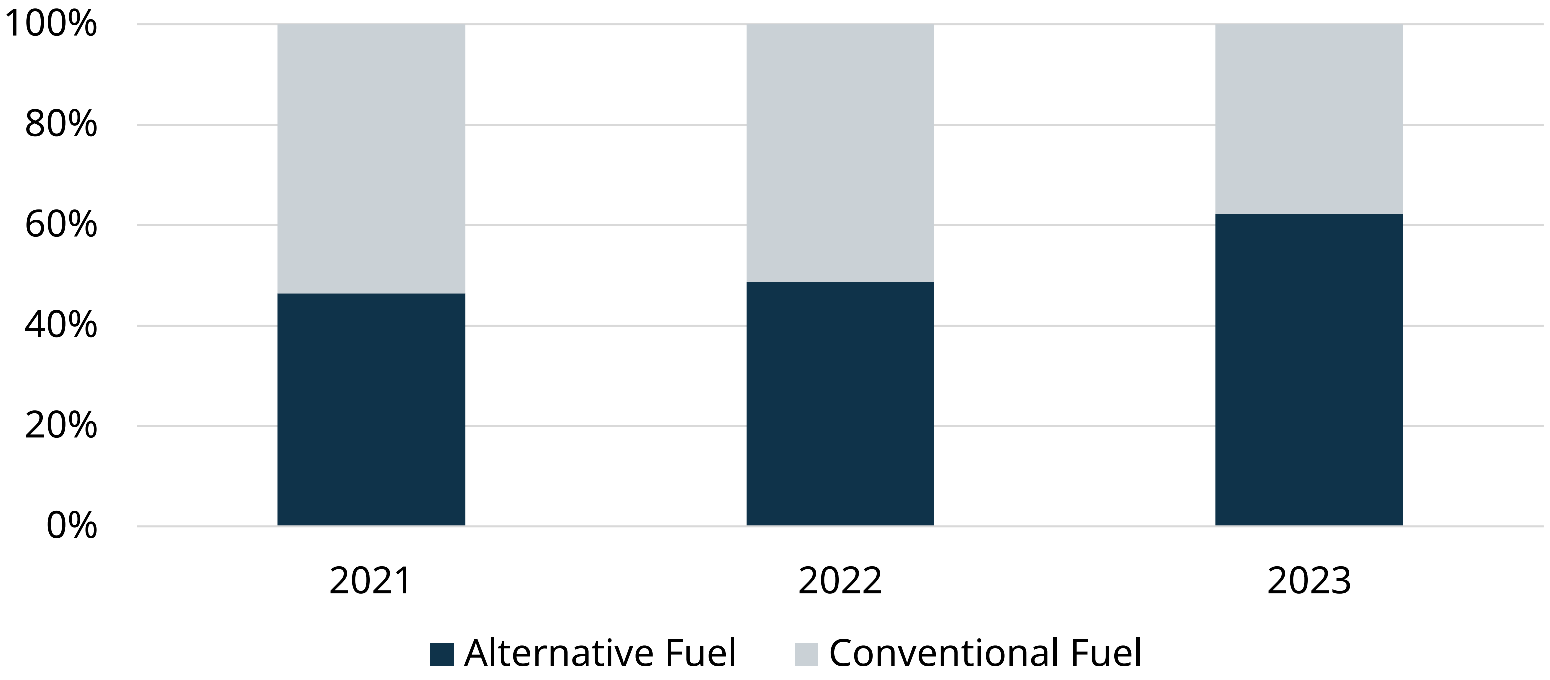
- The estimated world fleet bunker fuel consumption 2023 was ~280 million tonnes[2]; if the world fleet would rely solely on ammonia and methanol as bunker fuel, it would require ~600 million tonnes of fuel due to their lower energy content
- The announced production capacity plan for sustainable methanol and ammonia is adding up to ~190 million tonnes by 2030; green and blue ammonia account for >90%, while the share of green and bio methanol is <10%
- Competition with other verticals may amplify under-supply; current global ammonia production is ~180 million tonnes per year[3], while global methanol production is ~100 million tonnes per year[4]; a significant share of sustainable ammonia and methanol production will not be available as bunker fuel, as it will be used to reduce CO2 emissions from today's applications

1) Source: DNV AFI; 2) Clarksons; 3) Yara; 4) Methanol Institute

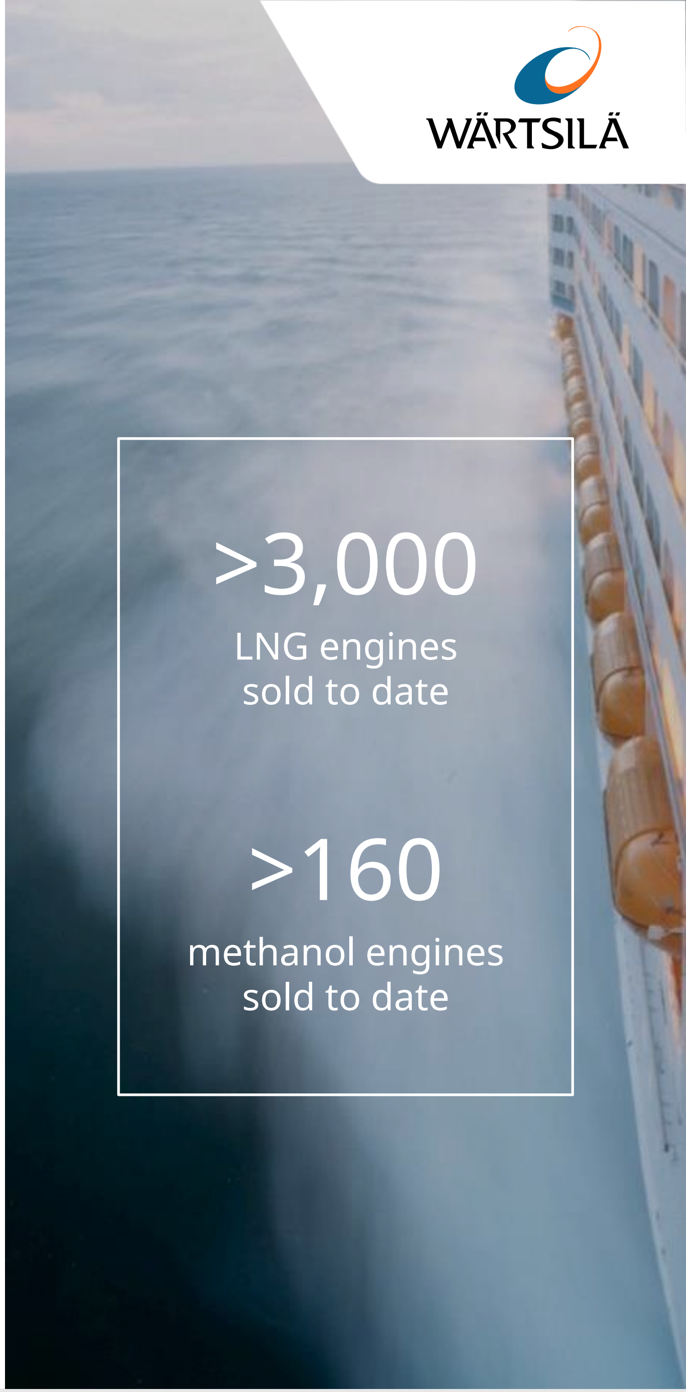
The share of our alternative fuel-capable engine orders is steadily growing, standing at >60% MW in 2023

Alternative fuel-capable engine order intake

% 4-stroke engine orders, alternative vs conventional fuel-capable, MW



‘Alternative fuel’ includes LNG and methanol



>3,000

LNG engines sold to date

>160

methanol engines sold to date

Internal combustion engines will power maritime decarbonisation

Net-zero targets will require a fundamental shift towards sustainable fuels, and multi-fuel engines provide the most flexible pathway

WÄRTSILÄ