SMART MARITIME

SMART MARITIME **SEA MAP** TO GREEN SHIPPING

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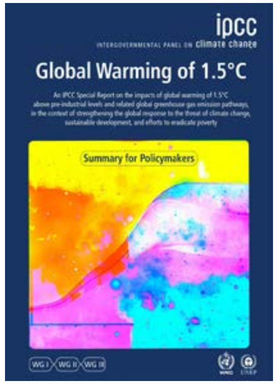
The Research Council of Norway

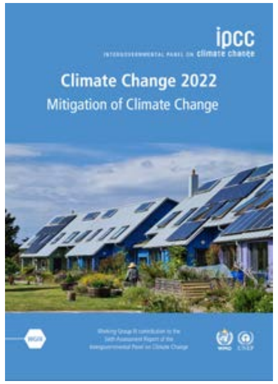
Smart Maritime sea map: In brief

What?	Summary of research on green shipping. Focus on large vessels with high energy demand (deep sea).
Purpose	Contribute to a more informed discussion, good decisions and policies. Sum up the research centres' activity for externals. Demonstrate the competence we have acquired.
Who?	SFI Smart Maritime: SINTEF Ocean + NTNU + industry partners
When?	Research 2015-2022. The report will be made public upon the closing of the SFI.
Format	Reader friendly, digested and illustrated summary of scientific articles, PhD and MSc thesis
Target	Shipowners, governments, policy makers, designers and suppliers. In Norway, EU and worldwide.

Macro: Urgency, energy efficiency, clean energy scarcity, more than GHG

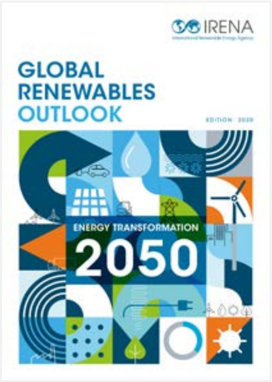


GHG: 45% reduction from 2010 to 2030 necessary to limit global warming to 1.5°C.

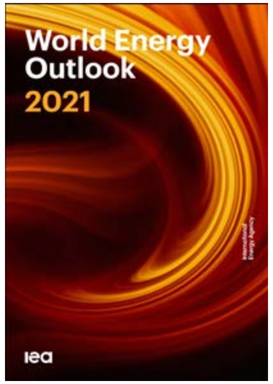


GHG must peak before 2025 to limit global warming to 1.5°C with no or limited overshoot.

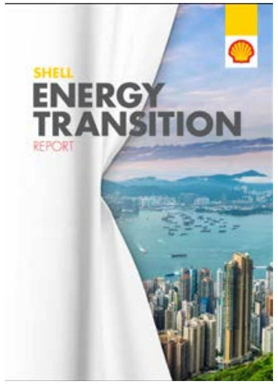
Tipping points can be exceeded even between 1 and 2°C warming.



Improvements in energy efficiency must triple.
So far, growth in renewables is cancelled by growth in energy demand.



Energy efficiency delivers > 40% of the reduction in energy-related GHG over the next 20 years.



Renewable energy overtakes fossil fuels as the primary source of energy in the 2050s.

97.3% live in areas where air pollution exceed the WHO threshold (PM2.5 > 5 µg/m³) and PM shortens the average life expectancy by 2.2 years worldwide,

Sources: IPCC SRR1.5 (2018), AR6 (2022), Lenton and Rockstrom (2022), IRENA (2020), IEA world energy outlook 2021, Shell Sky scenaiors, Greenstone et al (2022) Uni. Of Chicago

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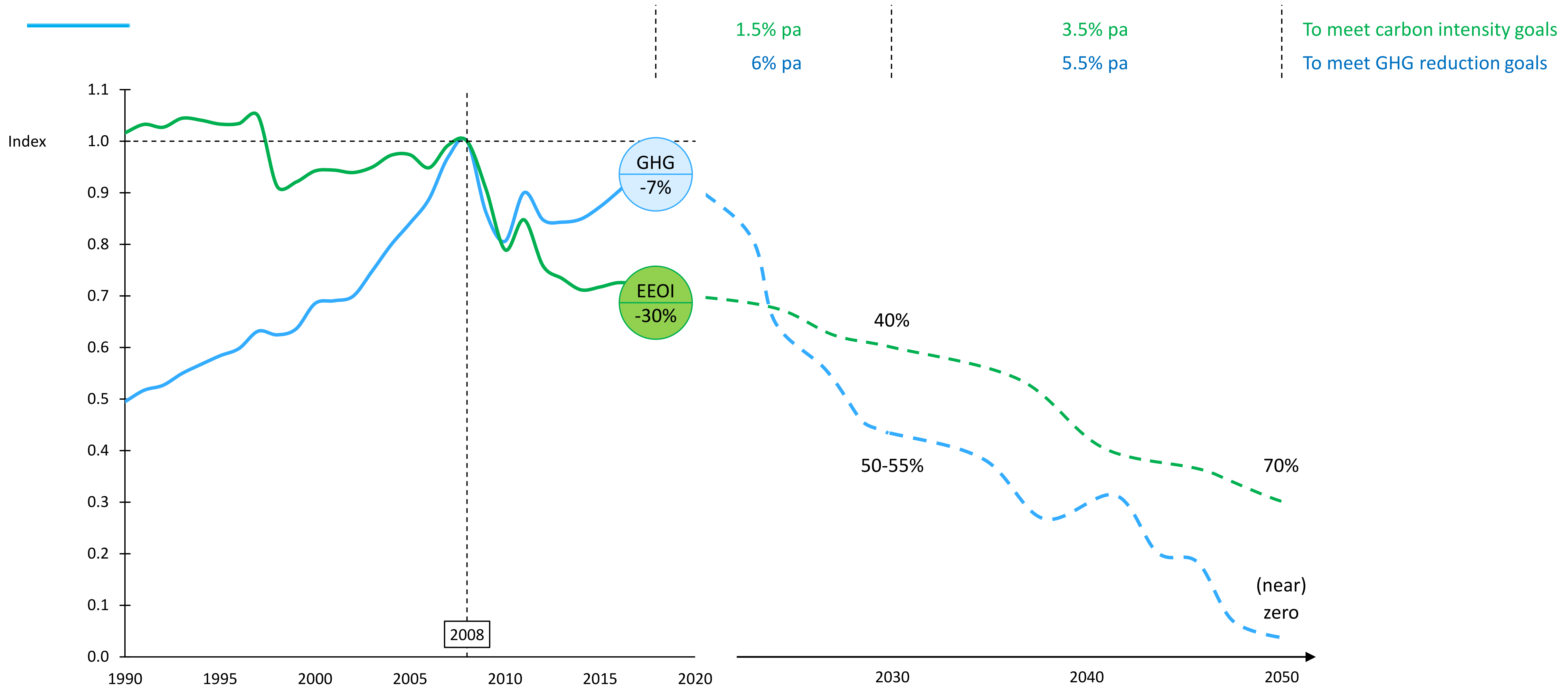
The challenge



Note: Blue: Absolute emissions. Green: Carbon intensity measured by EEOI (energy efficiency operational index).
Source historical emissions: IMO 4th GHG-study. GHG goals: Norway/EU. IMO has (per April 2018) no goal for absolute emissions for 2030, only a carbon intensity goal.

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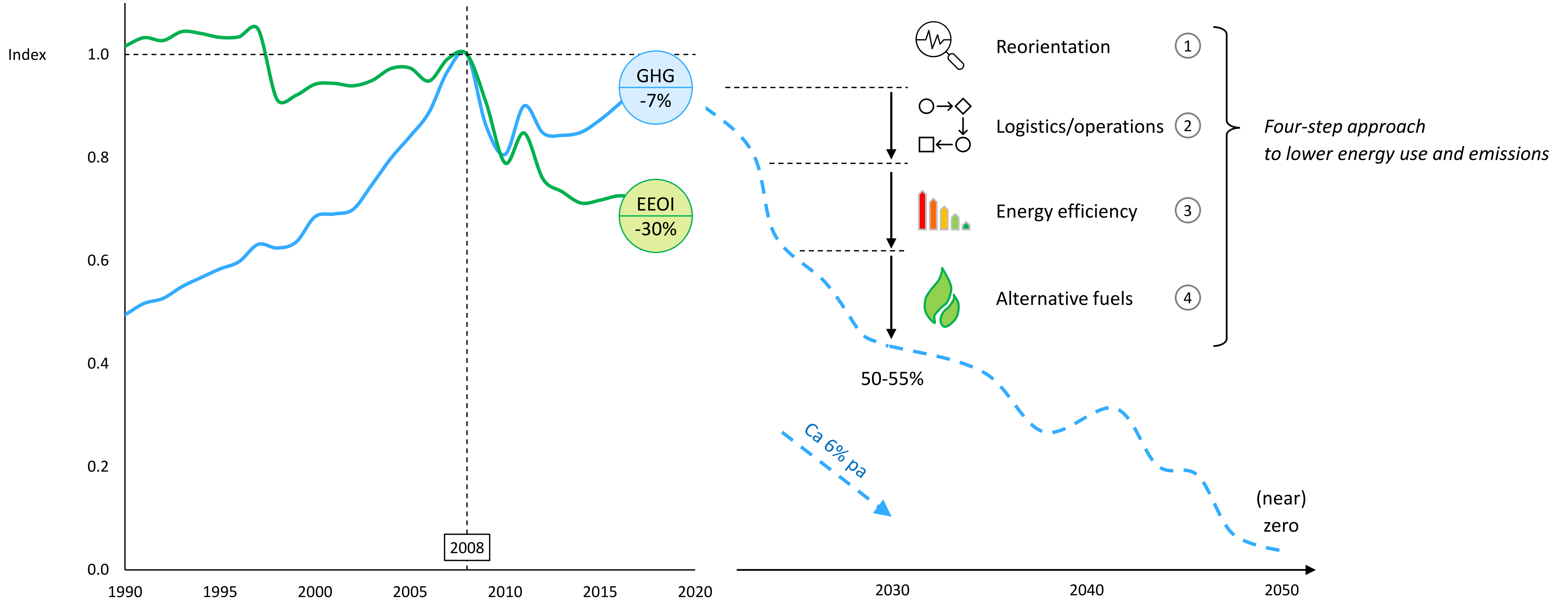
Key message: Four steps to green shipping



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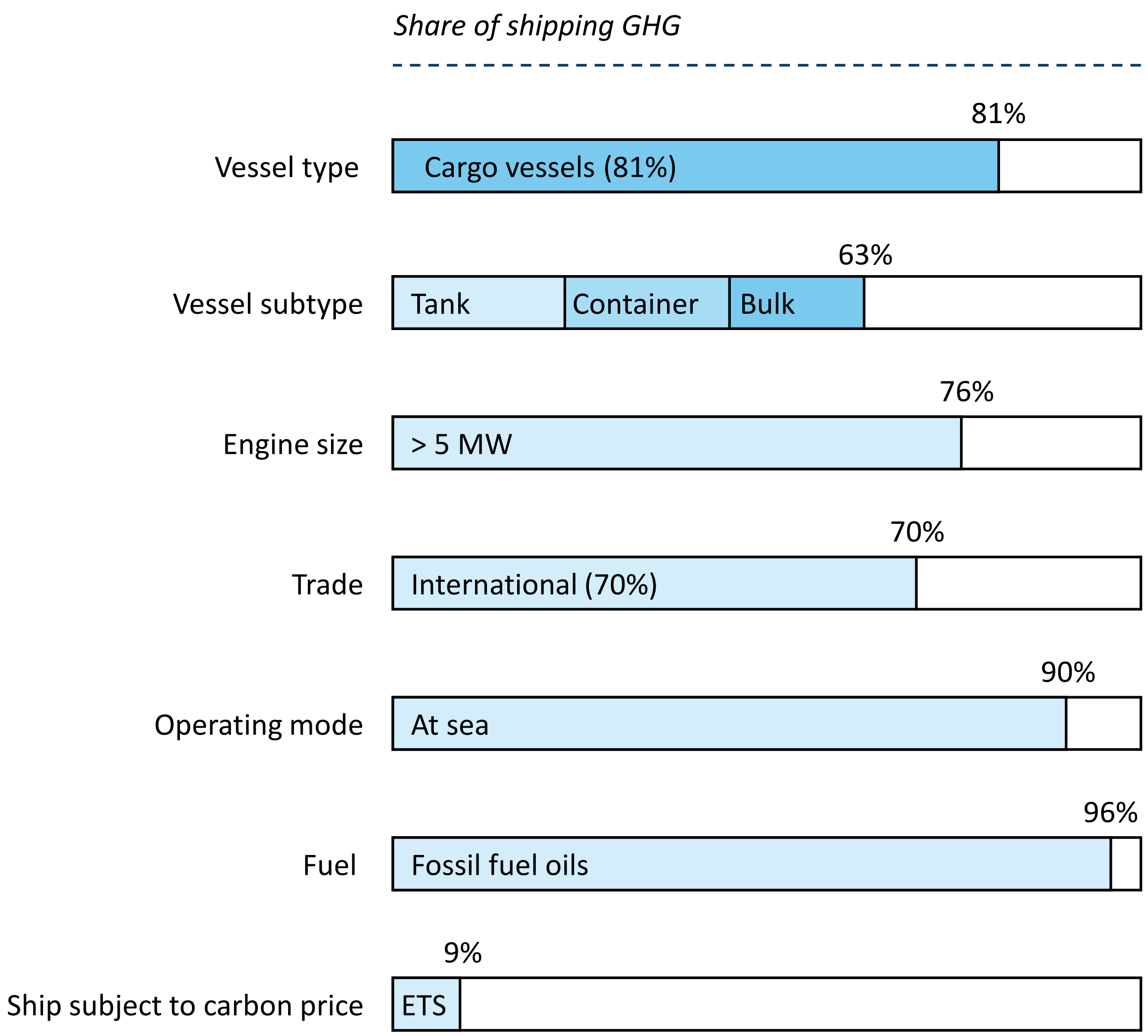
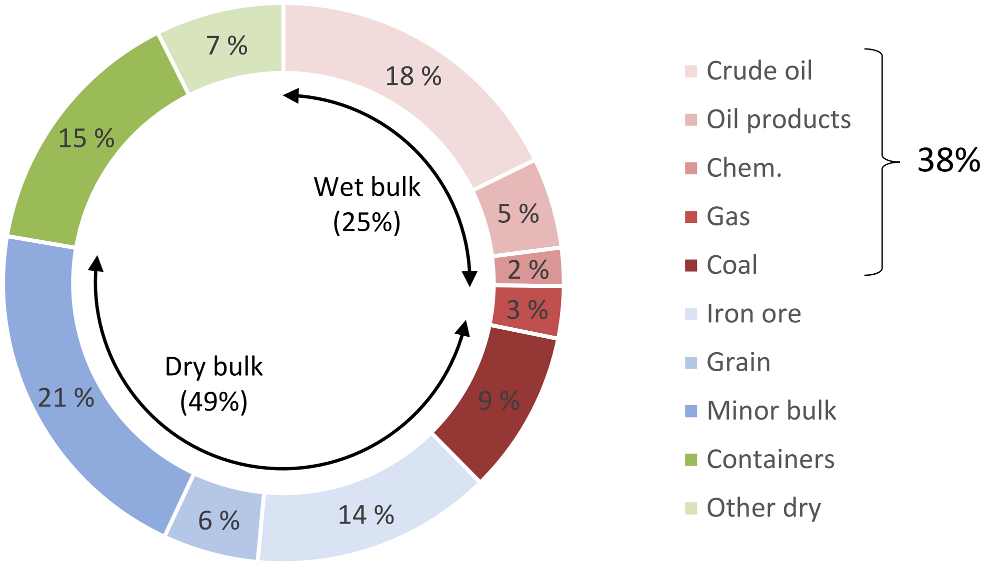
Source historical emissions: IMO 4th GHG-study. GHG goals: Norway/EU. IMO has (per April 2018) no goal for absolute emissions for 2030, only a carbon intensity goal.

Focus?



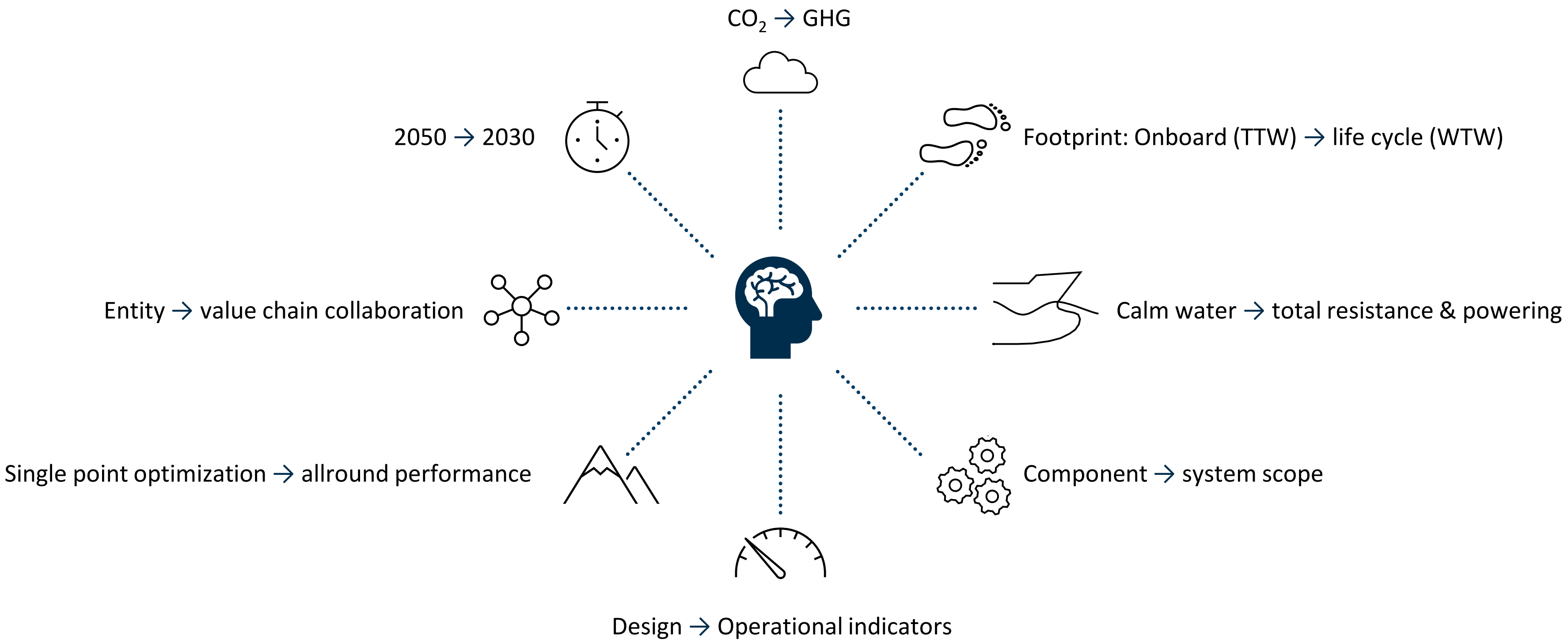
Source: IMO 4th GHG-study.
Note: Approximate percentages, from summary of emission inventories per vessel type and vessel size (IMO 4th GHG-study, table 81, page 446.

Fossil energy accounts for 38% of seaborne trade [tonne]



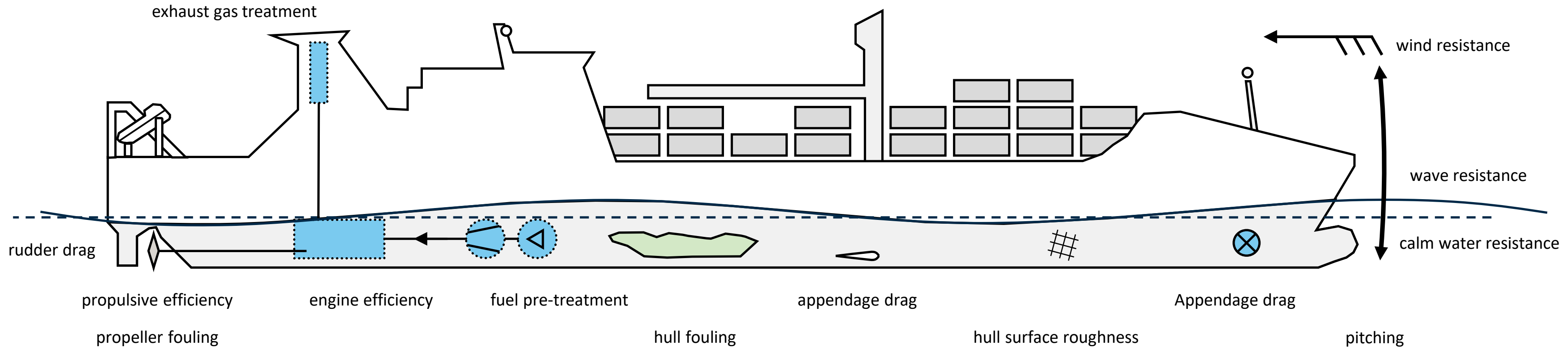
Source: IMO GHG-studies (3rd and 4th), UNCTAD, Menon 2019 (https://www.menon.no/gronn-maritim/)
Notes: Seaborne trade measured in tonnes exclude value of passenger transport and maritime services.

Rethinking everything! Mentality → technology



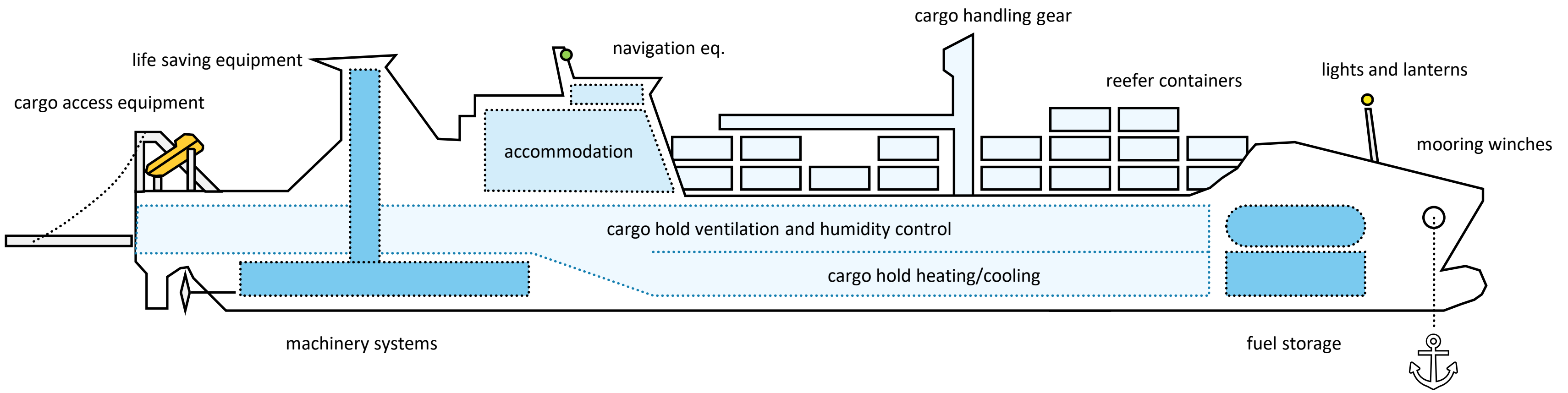
Notes: Operational indicators make the shipowner responsible for factors outside his/her control, but also opens up for more energy and emission saving measures

Energy use: Many drivers, the sum of many (small) elements



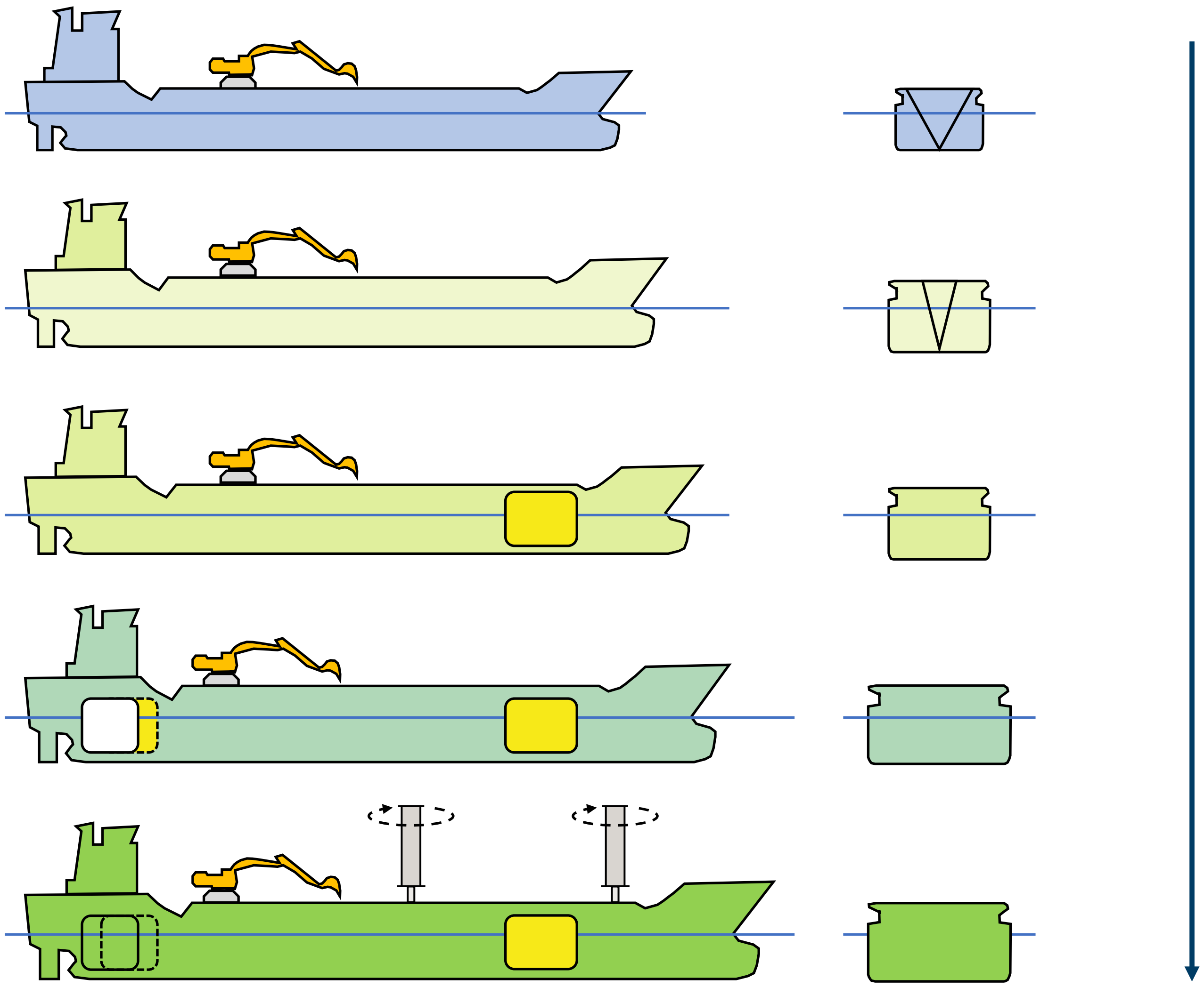
Propulsion

Ancillary systems



NOTES
Non-exhaustive overview of energy consumers onboard and factors determining the propulsive power.

Reasons to reconsider main dimensions and hull forms



Standard designs.
Old designs / vintage.
Main dimensions restricted by statutory requirements
Building was expensive, energy was cheap.

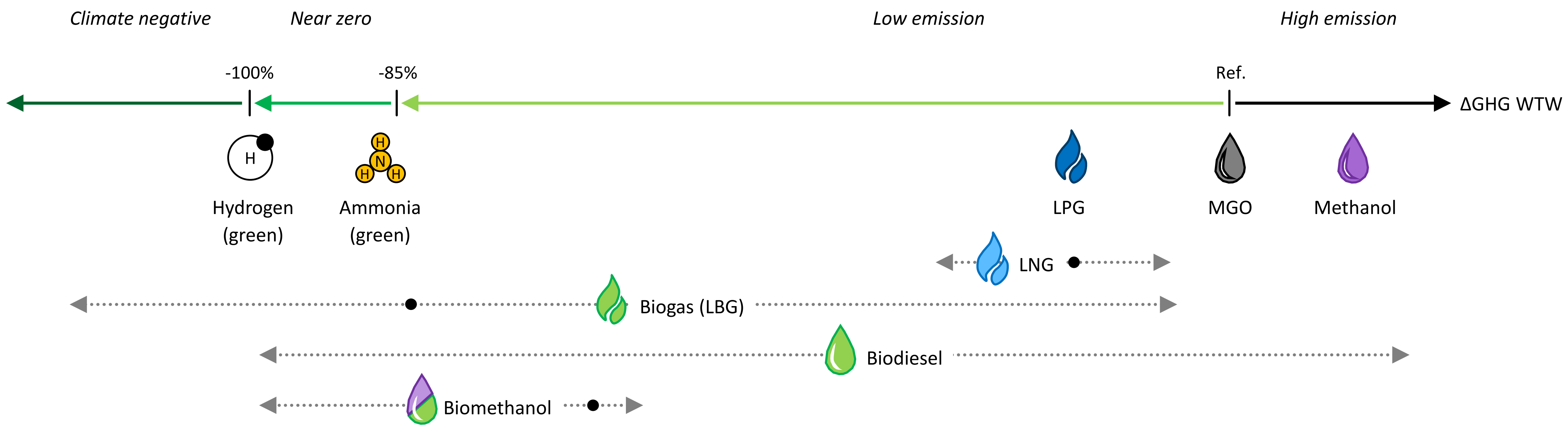
Optimized main dimensions

Larger main dimensions to accommodate alternative fuels

Larger engine room for dual fuel machinery

Hull form designed for sails

Alternative fuels overview



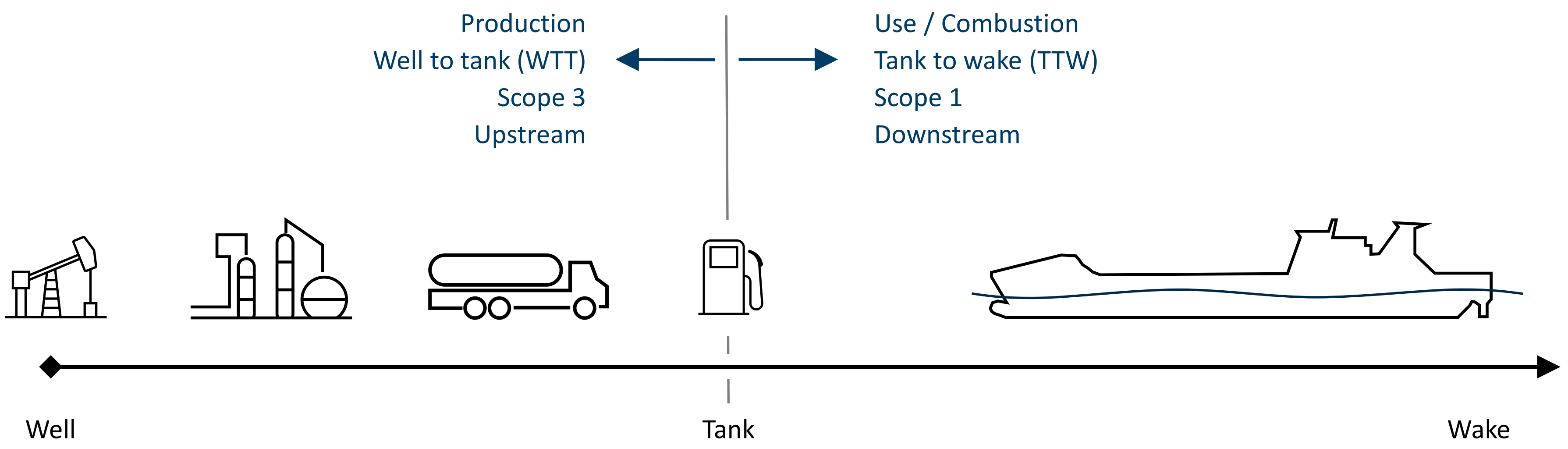
Note on terminology near zero: Author's understanding/proposal for. No consensus on the term.
GHG factors for well to wake emissions (scope 1+2+3) based on Lindstad et al, EU RED II, SINTEF Ocean estimates, IRENA Innovation Outlook: Renewable methanol.

Alt. fuels overview

	Fossil fuels	Natural gas	Biofuels	Hydrogen fuels	Synthetic fuels
Examples	HFO Residual fuel blends MGO Methanol	LNG LPG Ethane	Liquid biofuels (many variants) Biogas (many variants) Bio-methanol	Hydrogen (LH2, PH2, LOHC) Ammonia	E-diesel E-LNG E-Methanol Dimethylether (DME)
GHG (WTW)	High	Up to 30% below MGO	20-200% below MGO	Zero to 45-65% above MGO	Depending on the production
Prerequisites for low emissions	Onboard carbon capture (OCCS)	Production conditions Methane slip Onboard carbon capture (OCCS)	Sustainable biomass No methane slip	Climate neutral electricity CCS (Carbon capture & storage)	Climate neutral electricity Direct air capture (DAC)
Pitfalls	High capture rate? Energy use? Fossil fuel lock-in?	Methane slip	Sustainability? Indirect land use change? Alternative use as crops? Disruption of food chain?	N_2O from ammonia?	Climate neutral electricity Direct air capture (DAC)
Major advantage	No/little disruption Synergies with other CCS-projects	Available Clean air	Climate negative at best Wastes as raw material Small scale local production	Ammonia: Energy dense Hydrogen: Emission free	No/little change onboard
Use/supply	HFO: 64% / MGO 32%	LNG 4% / LPG: Very minor	Piloting	Grey variants only	N/A

Source:
Smart Maritime sea map to green shipping (Gamlem 2023)

New fuels shift focus from scope 1 to scope 3 emissions

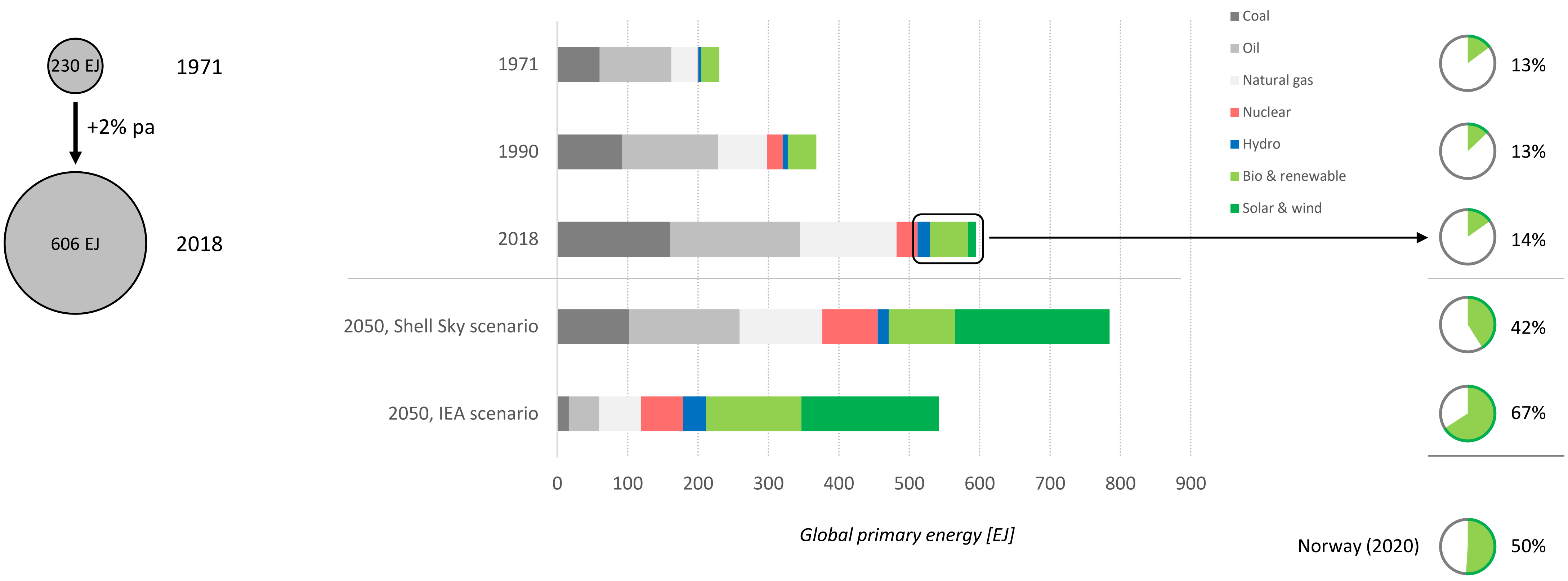


Responsible	Energy company Bunker supplier	Shipowner Ship manager and crew Charterer Port
Key factors	Raw material Production process Footprint of energy (e.g. electricity) used Supply chain Form of delivery (pressurized, liquefied)	Storage Pre-treatment Machinery's thermal efficiency and total system efficiency Waste heat recovery (WHR) Exhaust gas cleaning: carbon capture and scrubber

Source: Smart Maritime sea map to green shipping.
Note: Non-exhaustive list of key factors.

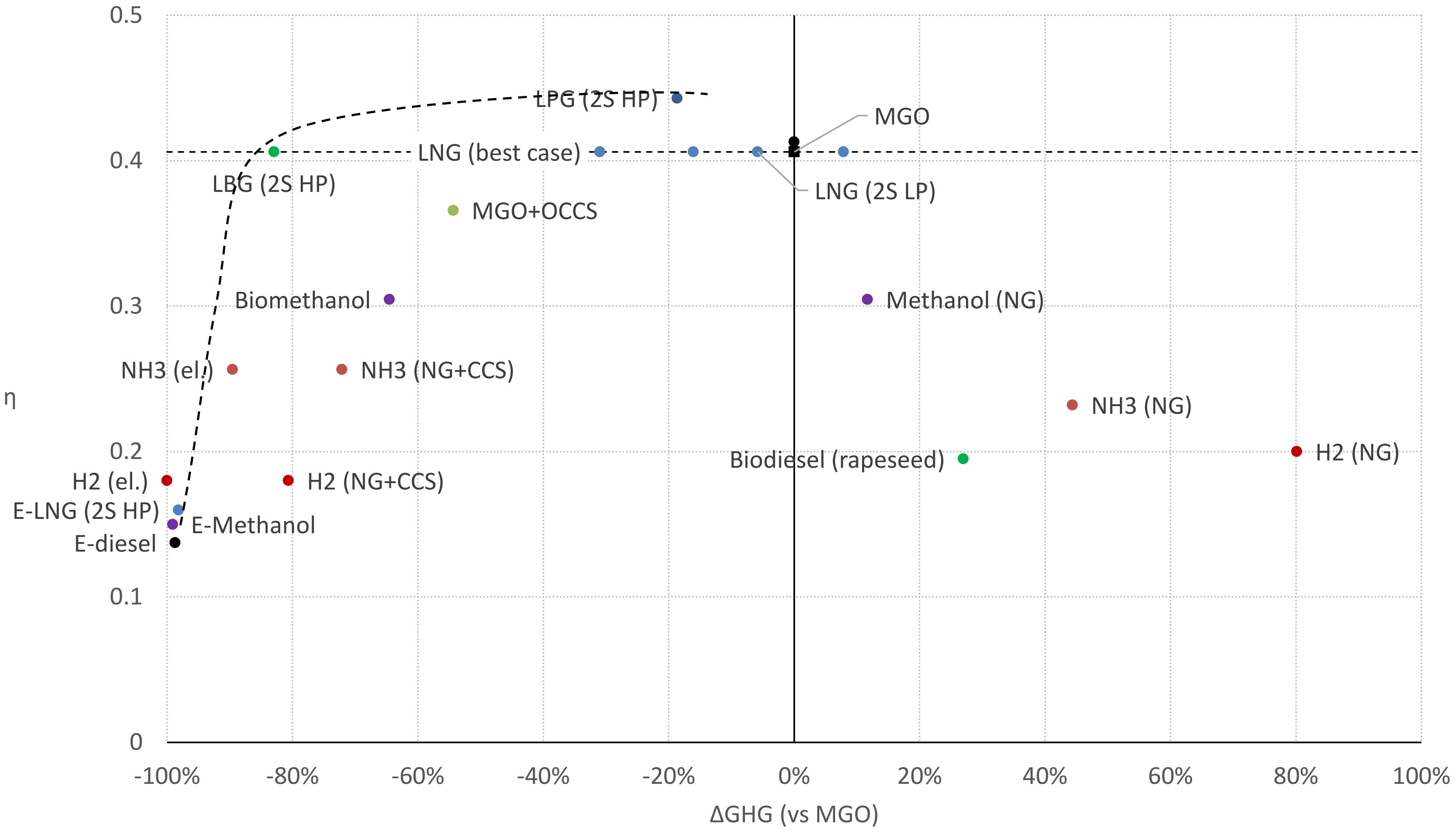
Global energy demand and primary energy mix 1971-2019

Global, annual energy use | *Breakdown of primary energy* | *Renewables*



IEA (https://www.iea.org/data-and-statistics/charts/total-primary-energy-supply-by-fuel-1971-and-2019)
Energi Norge and Thema Consulting (https://fornybarometeret.no/status-for-norsk-omstilling-til-fornybar-energi)

GHG and energy efficiency well to wake



Good utilization of energy

Sources:
Lindstad et al, LR/UMAS, EU

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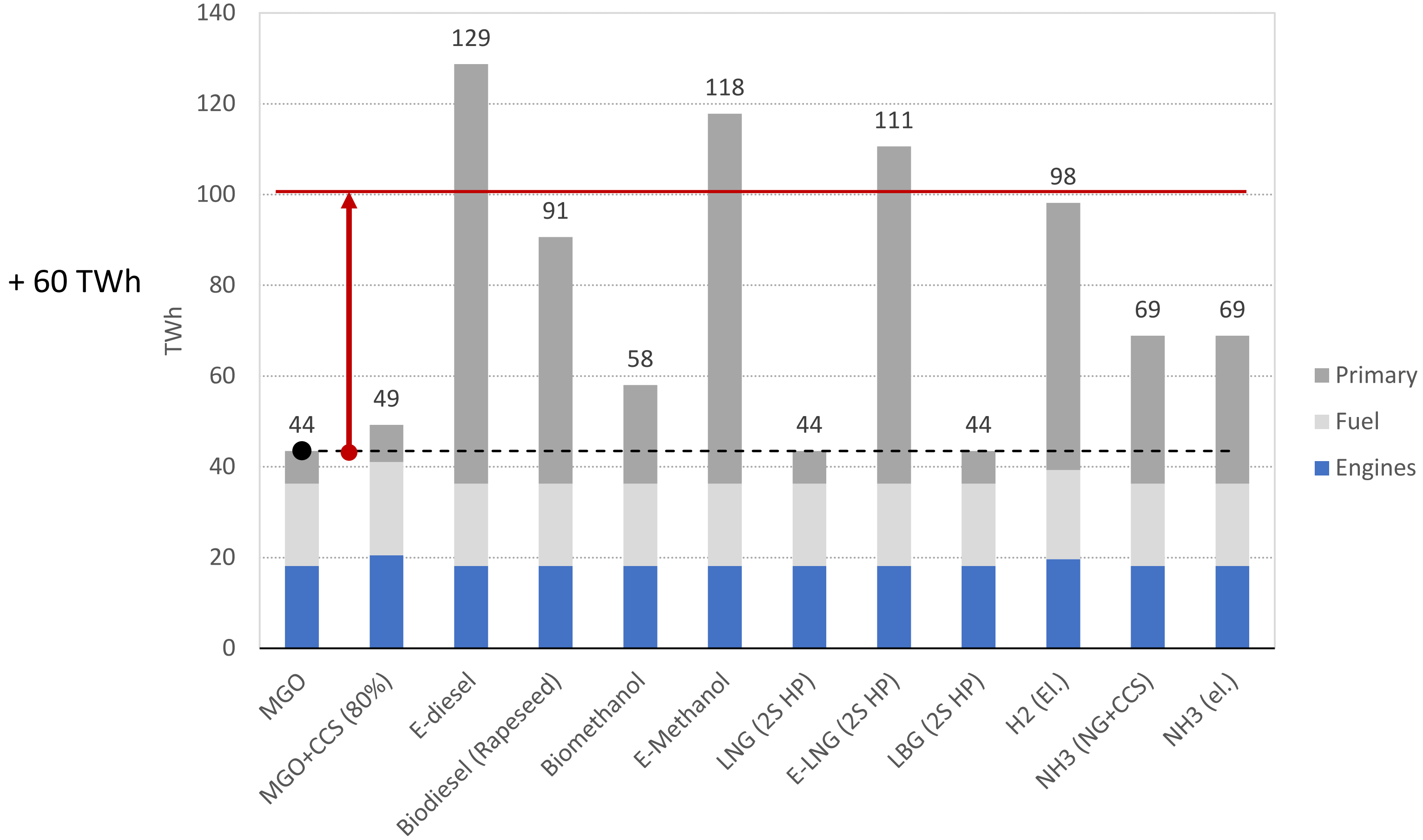
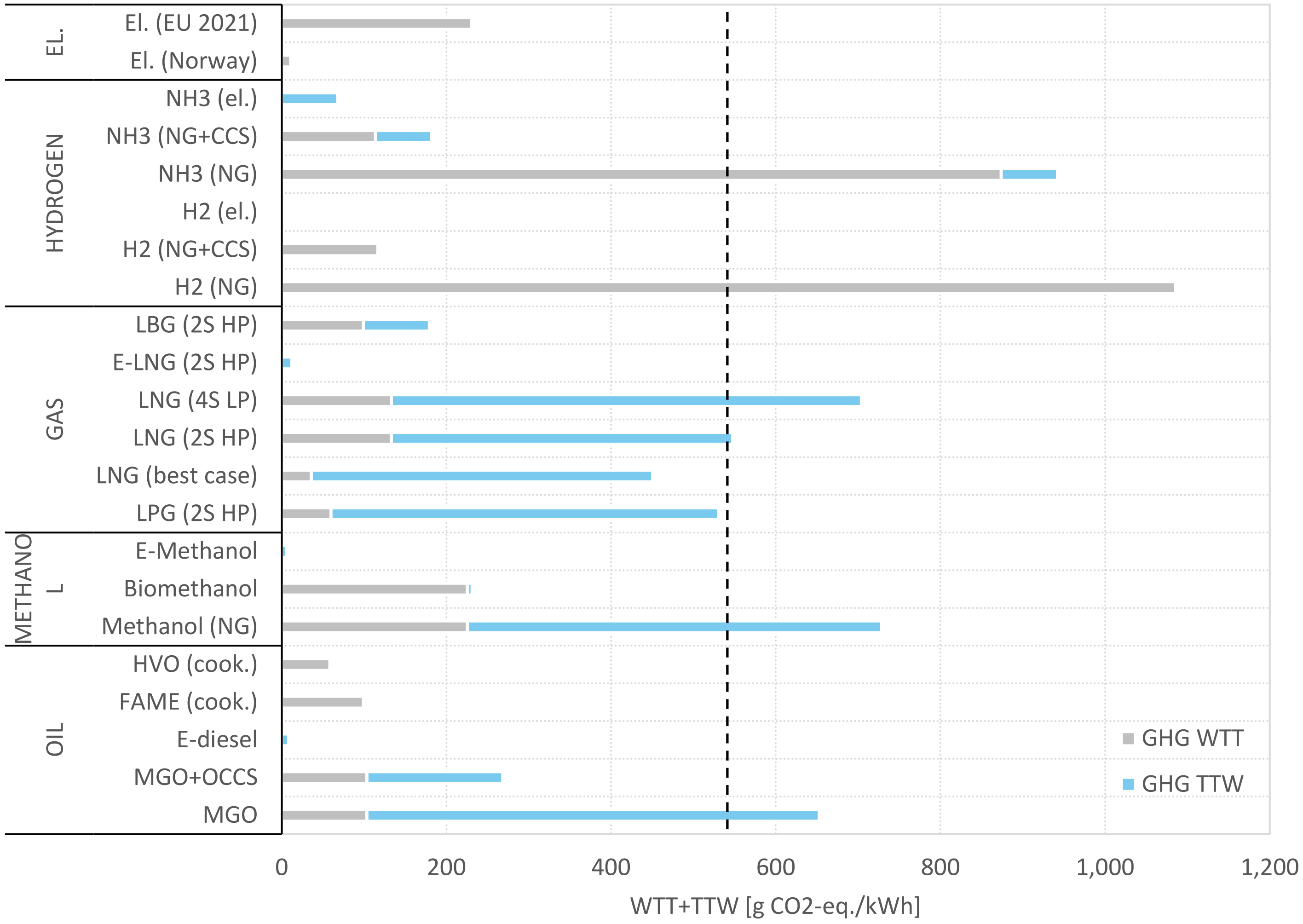
Energy demand for shipping in Norwegian EEZ (eq. to 3.1 Mt MGO)



> Målet for 2030 må være minst 40 TWh høyere fornybar kraftproduksjon fra vannkraft, vindkraft, havvind og solkraft samt 20 TWh energieffekitvisering

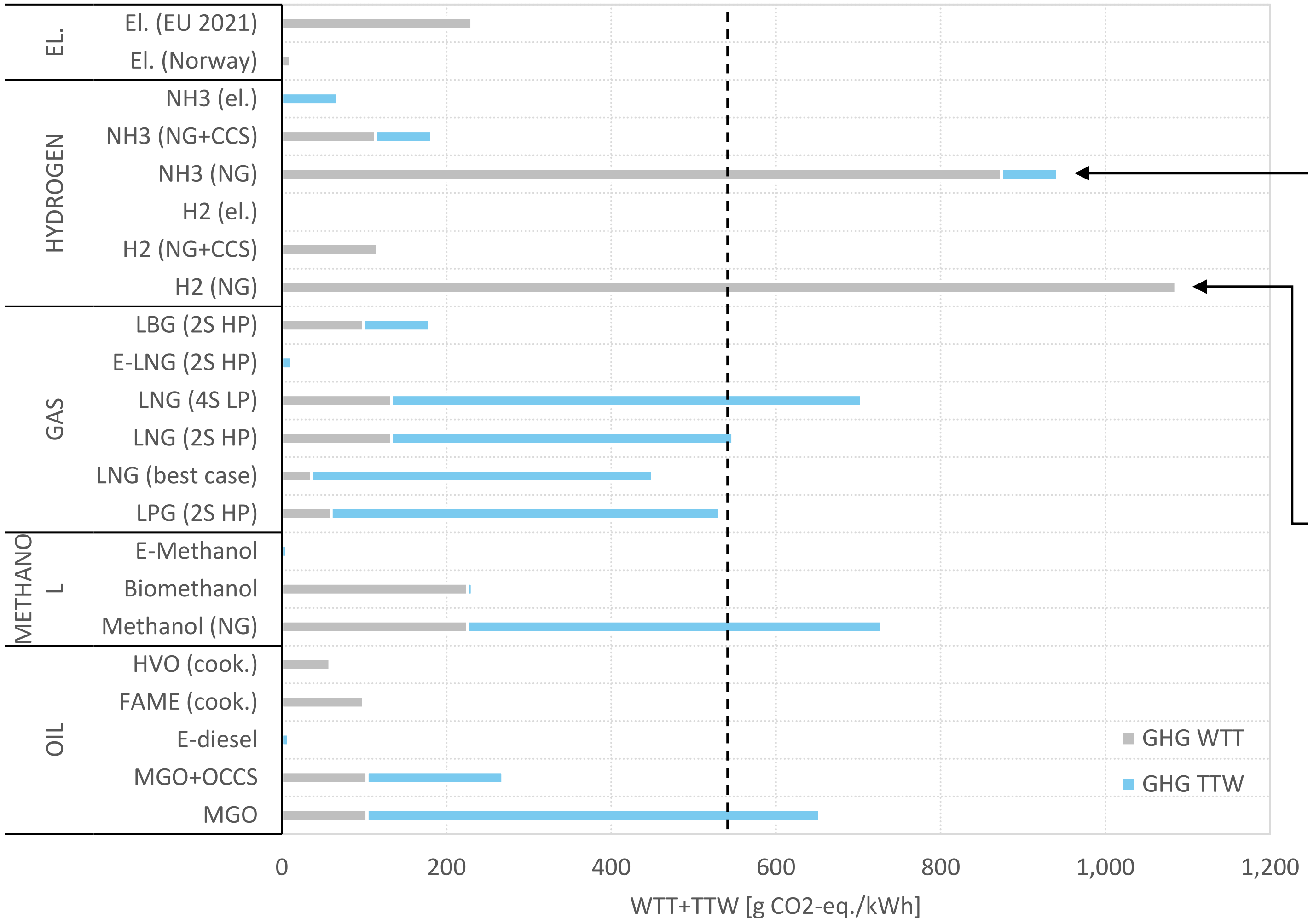
Energikommisjonen, NOU 2023:3, 1 February 2023.
Energy demand to fuel all shipping in Norwegian EEZ (domestic, international, transit) 3.1 Mt MGO.
Estimate by SINTEF Ocean based on a number of assumptions.

Alt. fuels: Decarbonising existing H_2 and NH_3 first?



Source: Lindstad et al, LR and UMAS, ABS. Zero emission for synthetic green hydrogen and ammonia and synthetic fuels depend upon renewable electricity. Data for blue H2 and ammonia and MGO+OCCS uncertain,.

Alt. fuels: Decarbonising existing H_2 and NH_3 first?



"This new report proposes a scenario for eliminating as much as 19% of carbon emissions (from EU ammonia production) by 2030…" (Dechema, January 2022)

"…perhaps 10% of hydrogen for ammonia production in 2030 would come from renewable resources. (Fertilizers Europe, 2018)

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Source: Lindstad et al, LR and UMAS, ABS. Zero emission for synthetic green hydrogen and ammonia and synthetic fuels depend upon renewable electricity. Data for blue H2 and ammonia and MGO+OCCS uncertain,.

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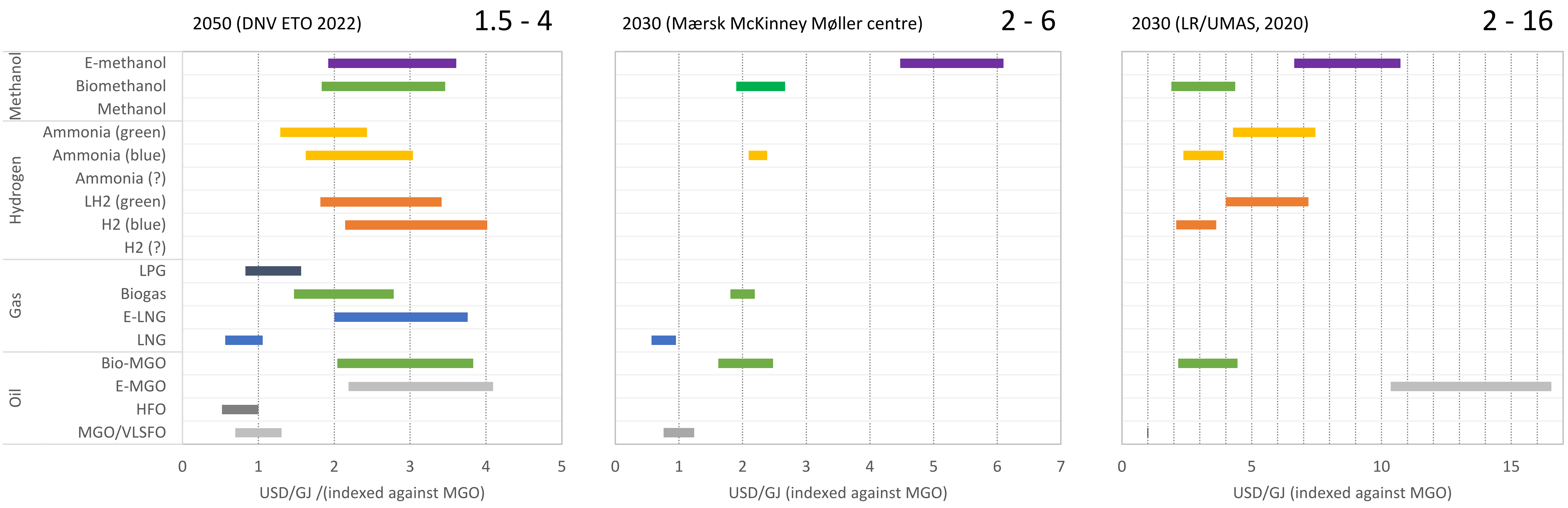
Fuel prices: Varying/uncertain forecasts but worrying nevertheless



Note: DNV ETO for 2050 while the other two sources give prices for 2030.
Source: DNV ETO 2022 (p. 75), Mærsk McKinney Møller centre, LR/UMAS Techno economic assessment of zero emission fuels (p. 43)

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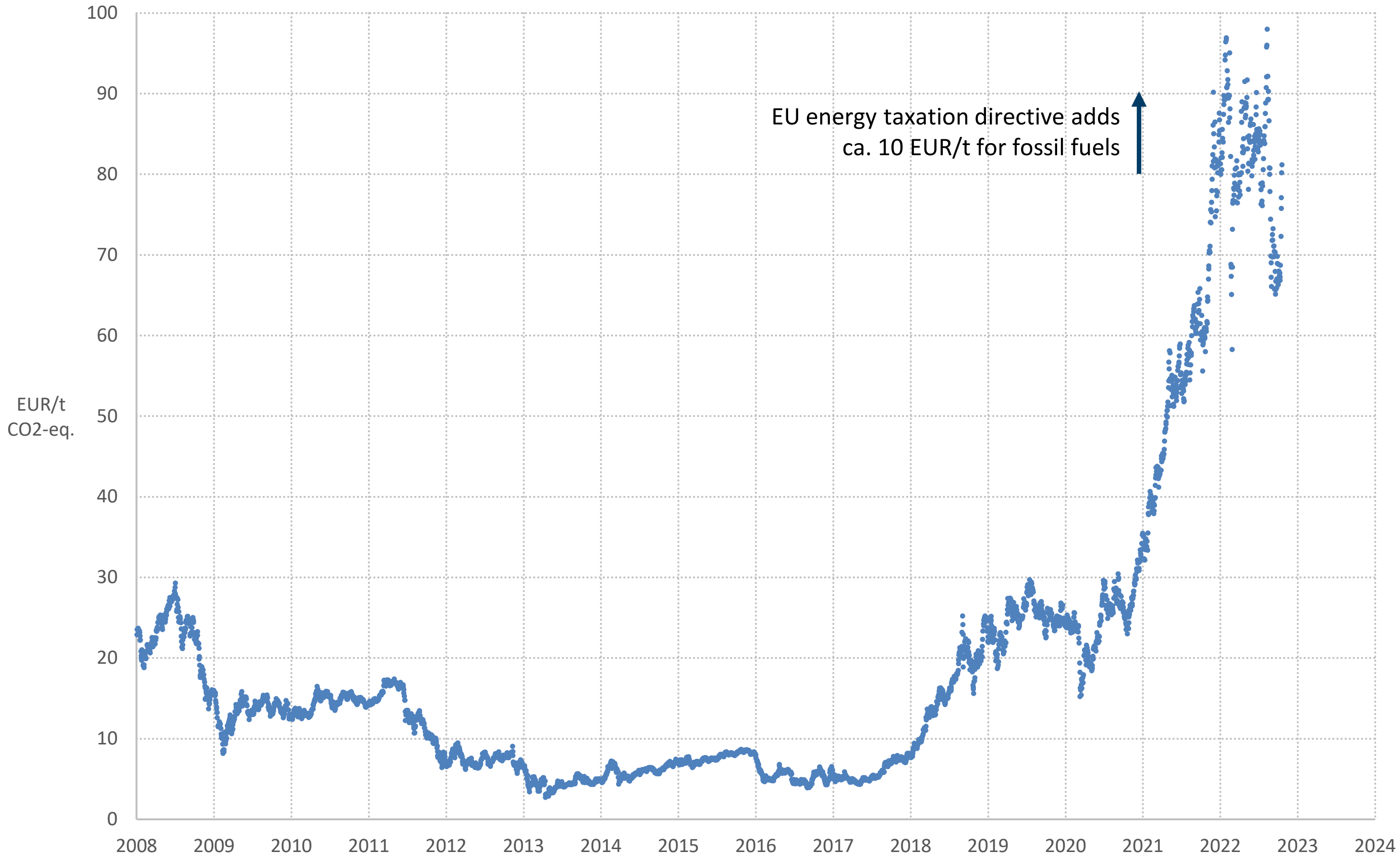
EU ETS and energy taxation directive



2012-18: 6 EUR/t

2018 -2020: 22 EUR/t

2021-Now: 66 EUR/t

Emissions

CO_2
2026: Methane and nitrous oxide (N_2O)

Geographic scope

Intra EU/EEA and at berth: 100% of emissions
To/from EU/EEA: 50%

Schedule

2024: 40% of emissions
2025: 70%
2026: 100%

Price (average 2021→ now)

66 €/t CO_2-eq. =
210 €/t MGO

Vessel scope

Cargo and pax > 5,000 GT
2026: Offshore vessels > 5,000 GT

Source
Thomson Reuters via Energi og klima (https://energiogklima.no/klimavakten/kvotemarked-eu-og-verden/)

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Key elements in a good fuel transition strategy

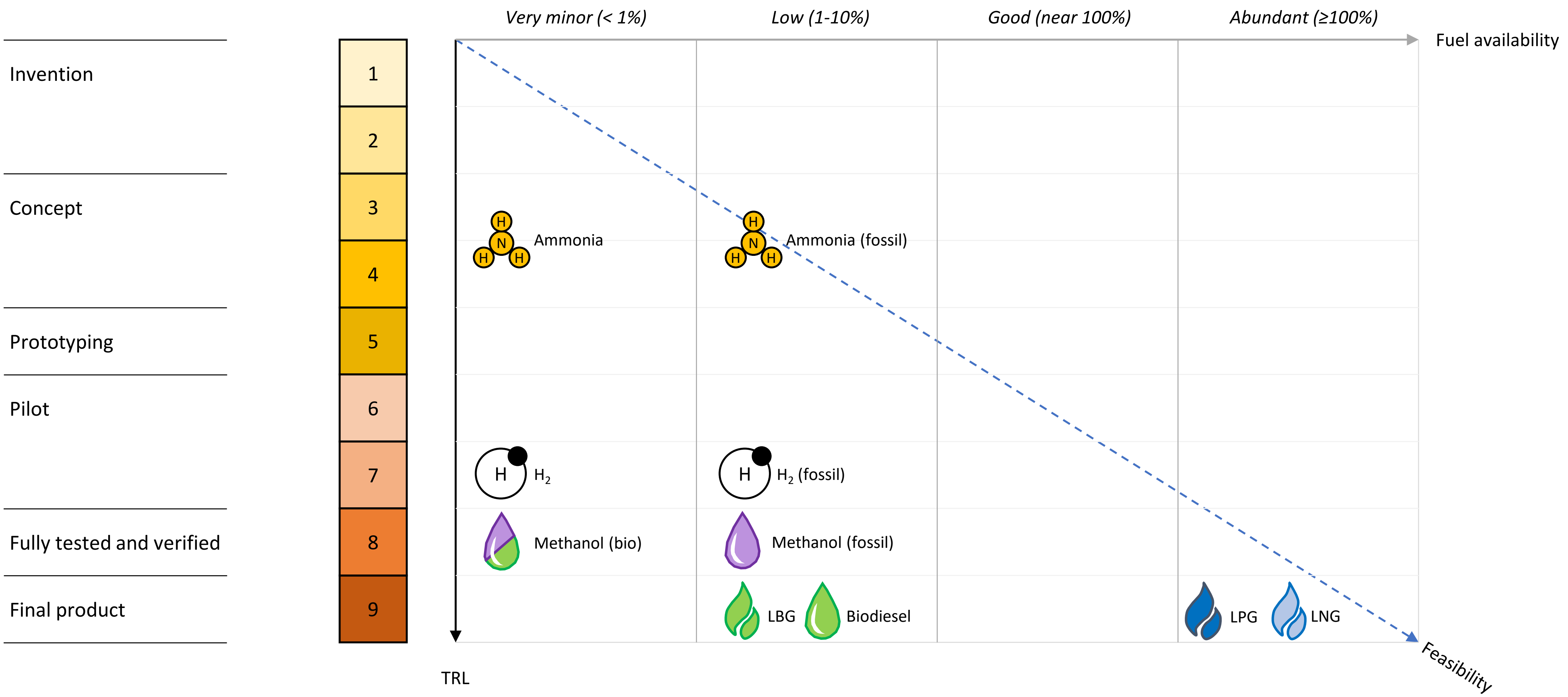
Fact	*Consequence for fuel transition strategies*
Global warming determined by concentration and thus total accumulated emissions	Fuel transition strategies should be ranked potential and when they can be implemented
Alt. fuels cost more, take up space and introduce new safety risks	Fuel transition strategies should be ranked potential and when they can be implemented
Availability in few ports only and with complex supply chains	Multi-fuel vessels will increase operational flexibility, operations area, allow redeployment and increase second hand value
Novel technology fails	Multi fuel systems ensure uninterrupted operations.
Alternative fuels cost more	Fuel blends and gradual phase in of new fuels avoid sudden (brutal) changes in operating cost.
Production capacity is limited and takes time to establish	Gradual increase in use of alt. fuels give time for scaling up production and building infrastructure
Infrastructure takes time to build, is costly and requires space on land and in ports.	Same or similar fluids or gases or blends can utilize existing infrastructure and avoid new infrastructure

Source:
Gamlem: Sea map to green shipping, 2023.

> The global climate fight will be won or lost in this crucial decade.

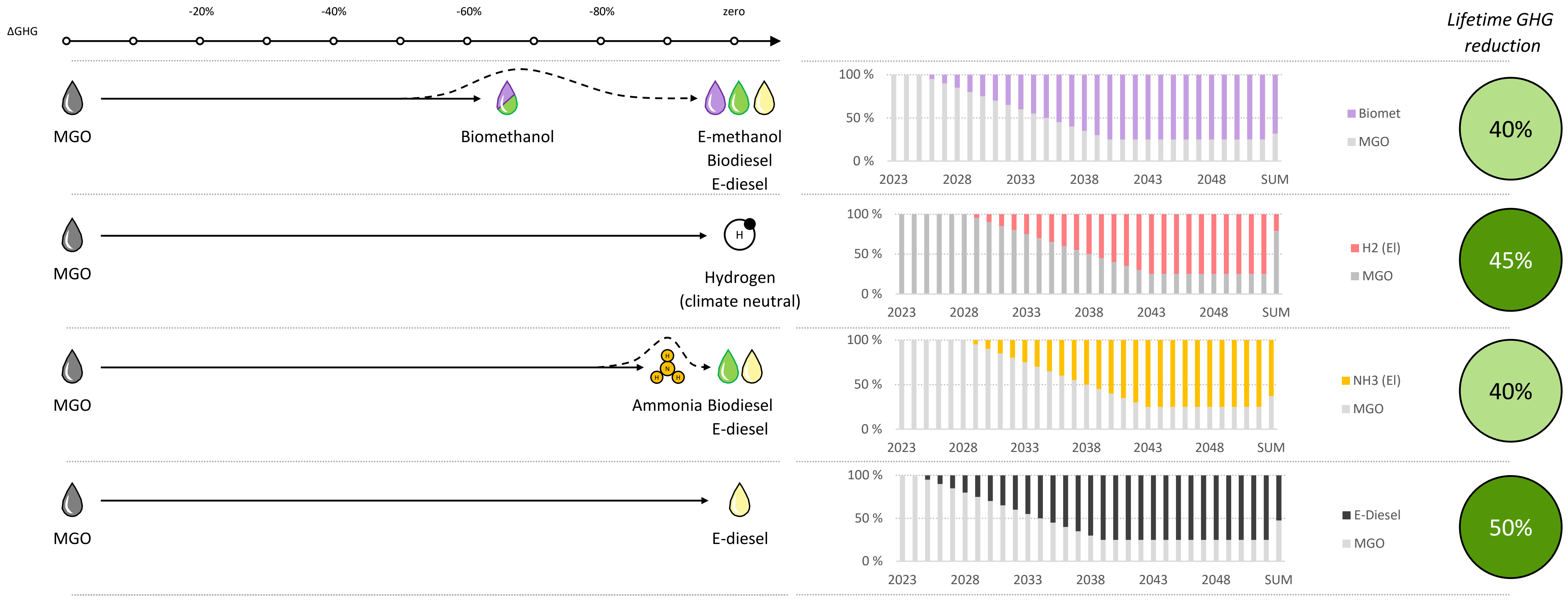
UN Secretary General
opening remarks at COP27, November 2022

Feasibility: Technical maturity • fuel availability



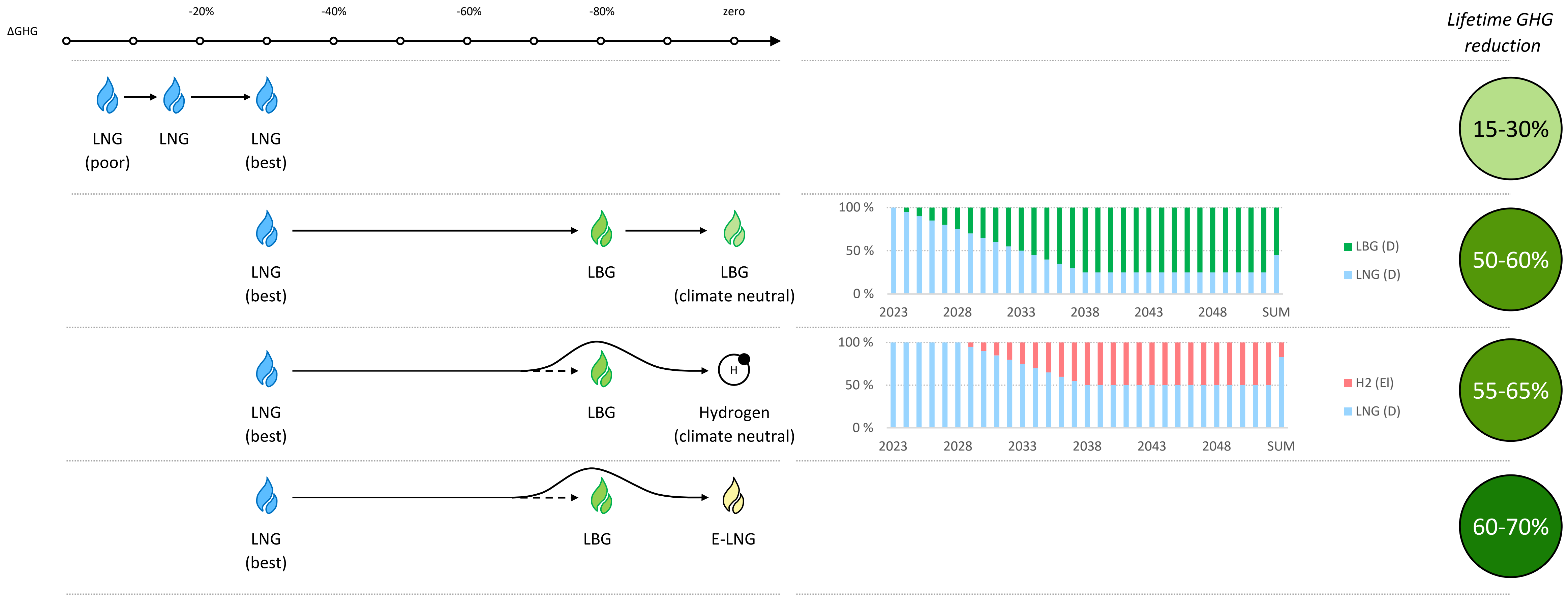
Notes:
TRL definitions from EARTO (European Association of Research and Technology Organisations, 2014, adapted and abbreviated by Gamlem.

Fuel transition strategies building on MGO



Note: Accumulated emissions depend on the emission factors, implementation schedule, max blending ratio.
Assumptions: Biogas and biomethanol becomes available first, then synthetic fuels, then hydrogen and ammonia (from 2030).

Fuel transition strategies building on LNG



Note: Accumulated emissions depend on the emission factors, implementation schedule, max blending ratio.
Assumptions: Biogas and biomethanol becomes available first, then synthetic fuels, then hydrogen and ammonia (from 2030).

Shipping: Variation in technology, operations and commercial realities

	Local	*Coastal*		*Regional*			*Deepsea*	
Ship type	Local ferry	Service vessel	Passenger ferry	Cruise	General cargo or container feeder	Small dry bulk	Transcontinental container vessel	Large dry bulk carrier
Trade	Fixed route A ↔ B	Fixed route depot → B / C / D / E	Fixed coastal: A → B → C → · · ·	Many ports within the same region	Fixed liner service between multiple ports	Tramp: Unpredictable within a region	Worldwide liner service: Fixed ports or regions	Worldwide tramp: Unpredictable worldwide
Power							High	
Range								High
Charterer	Govt. / public	Energy majors	Govt. / public	Individuals	Industry	Industry	Consumer goods	Commodity
Flexibility	Rarely redployed or sold for alternative use	Many on short contract. Some redployed and sold.	Long life. Upgrade and conversions common.	Many ports within the same region	Long service. Sometimes shifted to other trades.	Commonly sold and moved to other regions.	Usually built for lifetime service for one owner.	Asset play a key part of the game for many owners.
Critical factor	-	Relationship with energy majors	Fuel supply in a few ports on the fixed route.	Fuel supply in key ports within the region.	Dual fuel machinery. Long term (first) charter. Fuel supply in key ports.	Dual fuel machinery. Long term (first) charter. Regional fuel supply.	Global fuel supply. Dual fuel machinery.	Global fuel supply. Dual fuel machinery. Long term contract.

13%

87% of Norwegian shipping GHG

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