14-15.09.2021 SZCZECIN

8. MIĘDZYNARODOWY KONGRES MORSKI | INTERNATIONAL MARITIME CONGRESS

Zasilanie statków przyjazne środowisku

Environmentally friendly supply for ships

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Akademia Morska w Szczecinie

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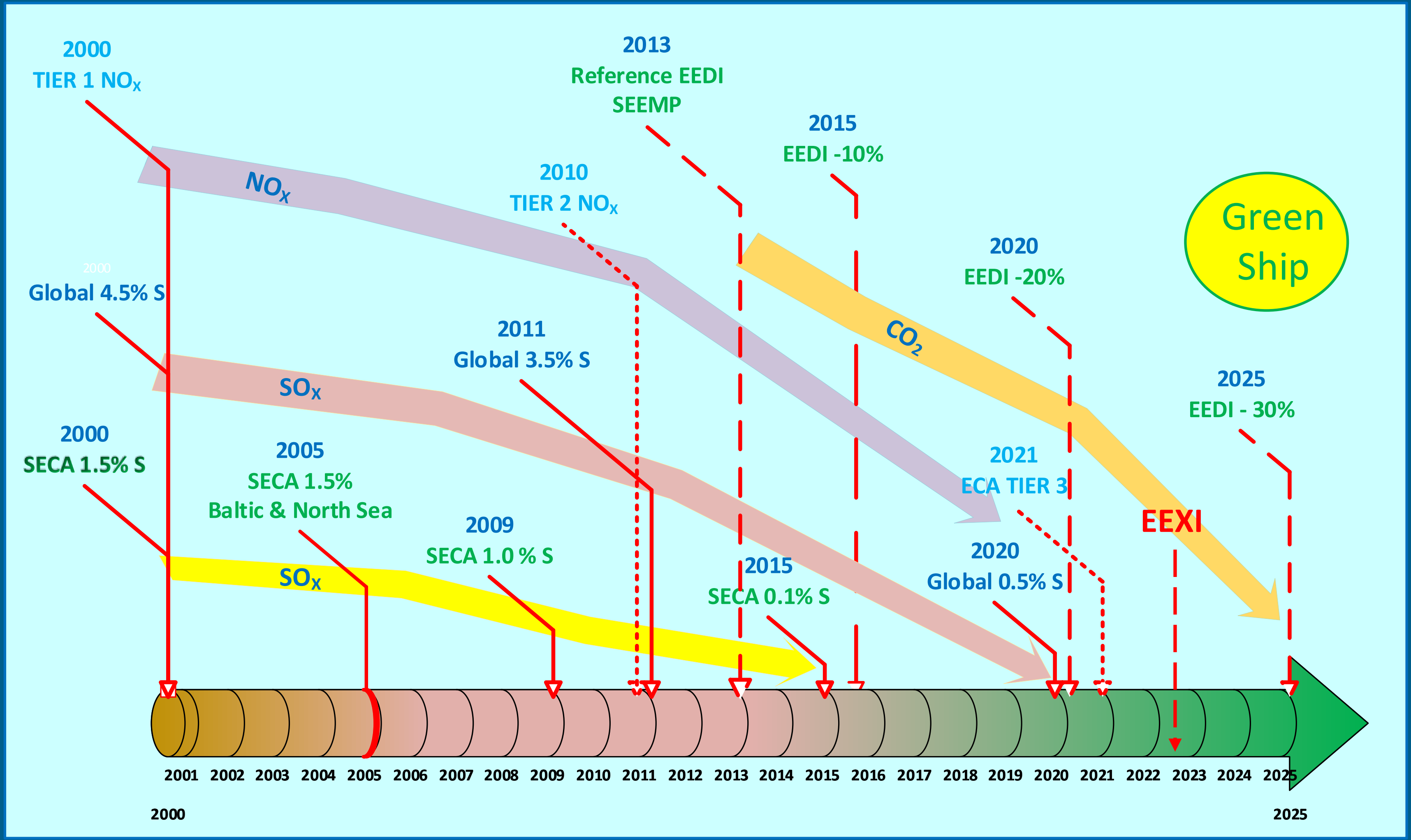
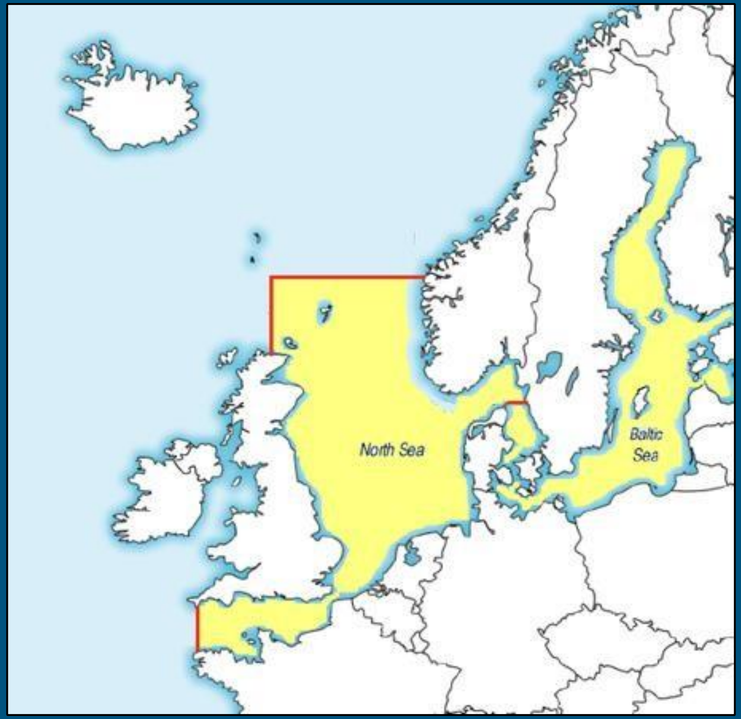


Maritime regulations on exhaust emissions in force

Tier III Emission Control Areas (NECAs) for NO_X emission control

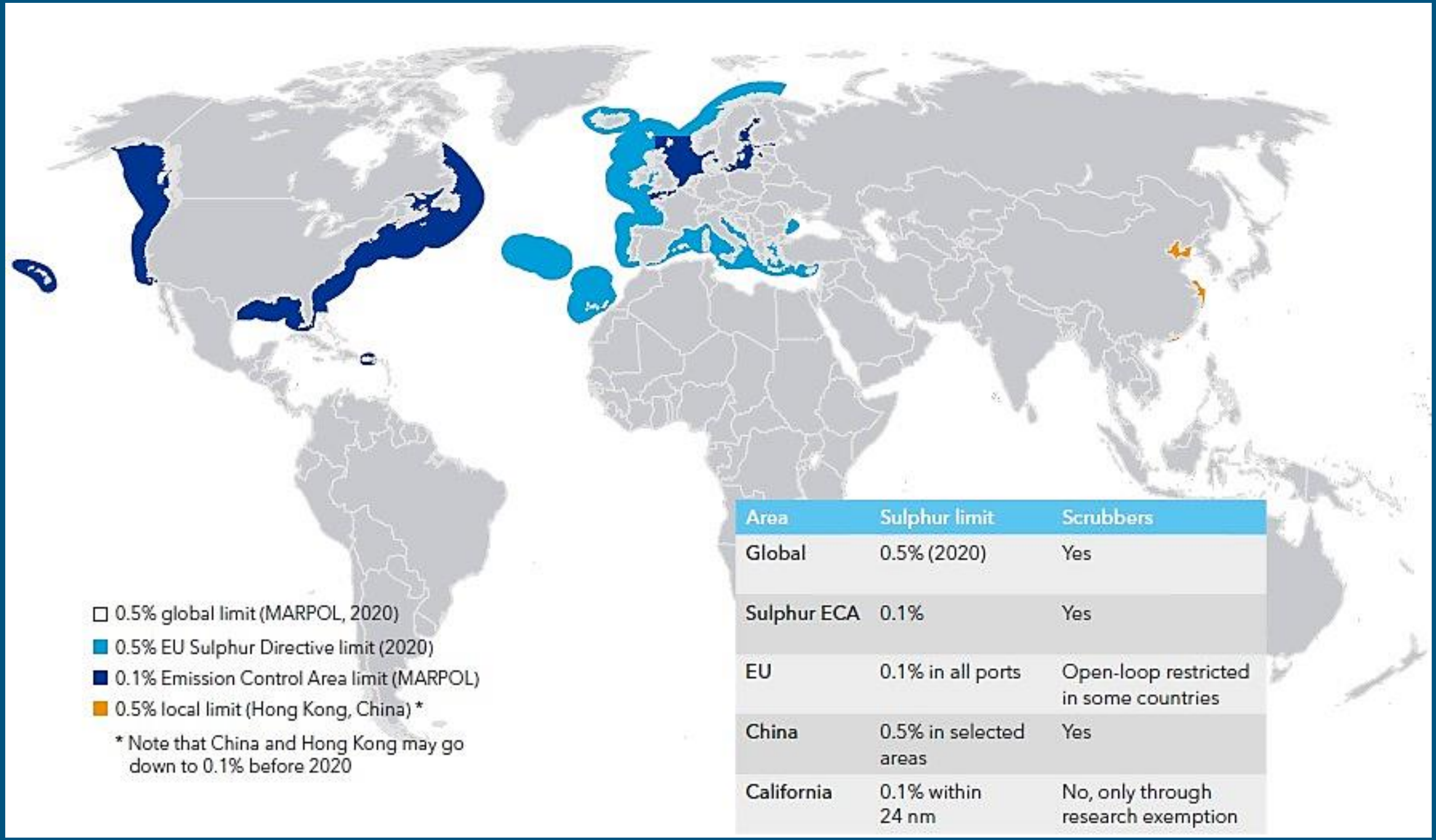
North America NECA + US Caribbean NECA for ships constructed on or after **1 January 2016**

North Sea and Baltic Sea NECA for to ships constructed on or after **1 January 2021**



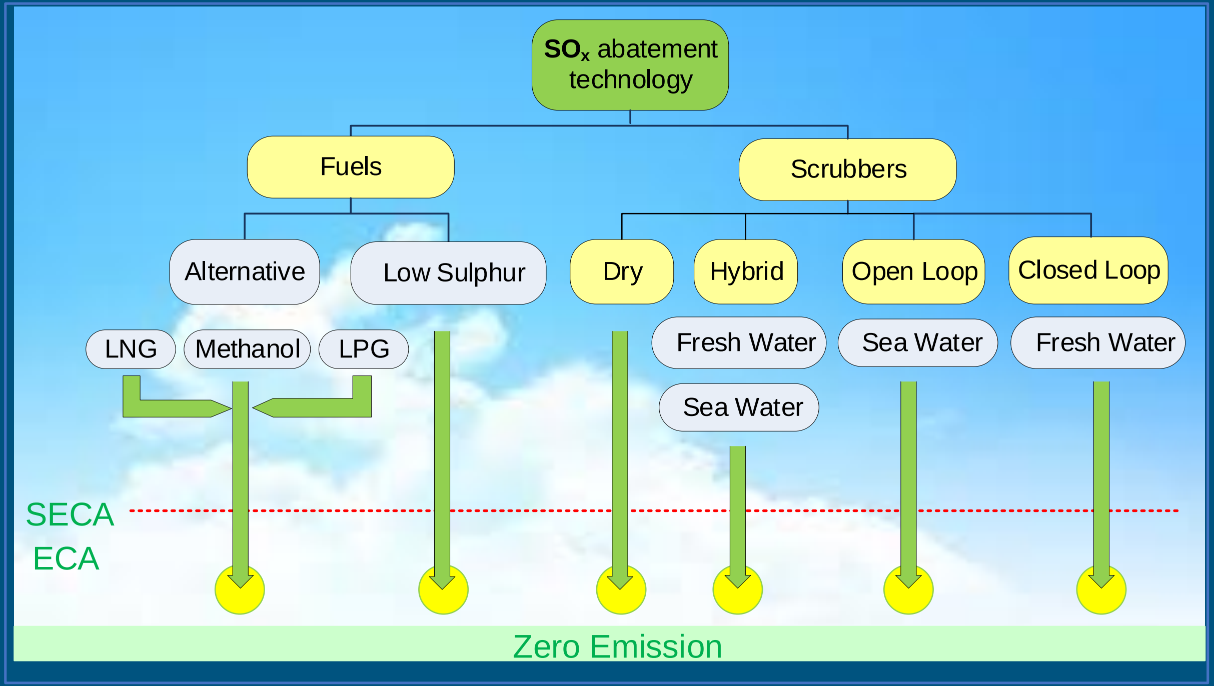
Maritime regulations on exhaust emissions in force

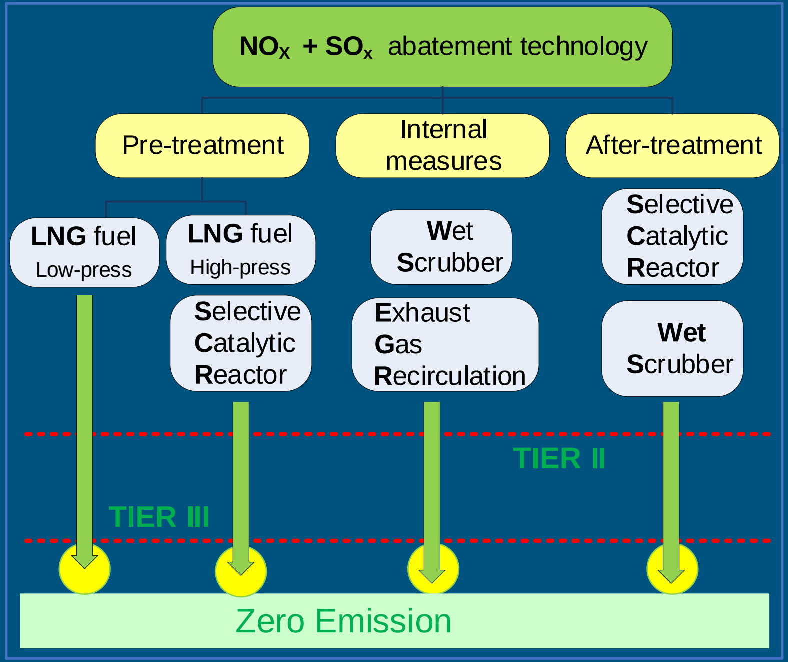
IMO global and SECA, EU and China SO_x control regions



Area	Sulphur limit	Scrubbers
Global	0.5% (2020)	Yes
Sulphur ECA	0.1%	Yes
EU	0.1% in all ports	Open-loop restricted in some countries
China	0.5% in selected areas	Yes
California	0.1% within 24 nm	No, only through research exemption

Ship emissions and reduction technology outlook





SECA

SO_x emission control :

- **Primary** - formation of the pollutant is avoided (low sulphur fuels)
- **Secondary -** pollutant is formed but removed, prior to discharge to the atmosphere (wet or dry scrubbers).

NECA

NO_x reduction :

- **pre-treatment** - lowering the combustion temperatures by external treatment or use of alternative fuels,
- **internal measures -** altering the engine configuration to modify the combustion process
- **after-treatment** - systems fitted externally to the engine and are applied directly to the exhaust gases.

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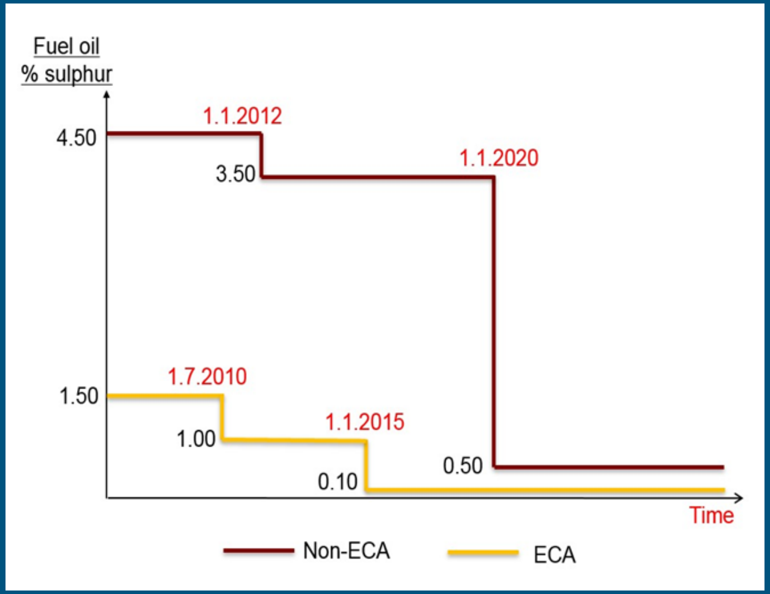
The SO_x emission compliance options

1. **Multi-fuel options**: two or more separate fuels on-board, i.e. **VLSFO** and **ULSFO** fuel oils.
2. **LNG** as marine fuel or other alternative fuels: Specific regulations applies.
3. **SO_x scrubber systems**: Specific regulations applies (equivalent method: 2015 Guidelines for exhaust gas cleaning, resolution MEPC.259(68))

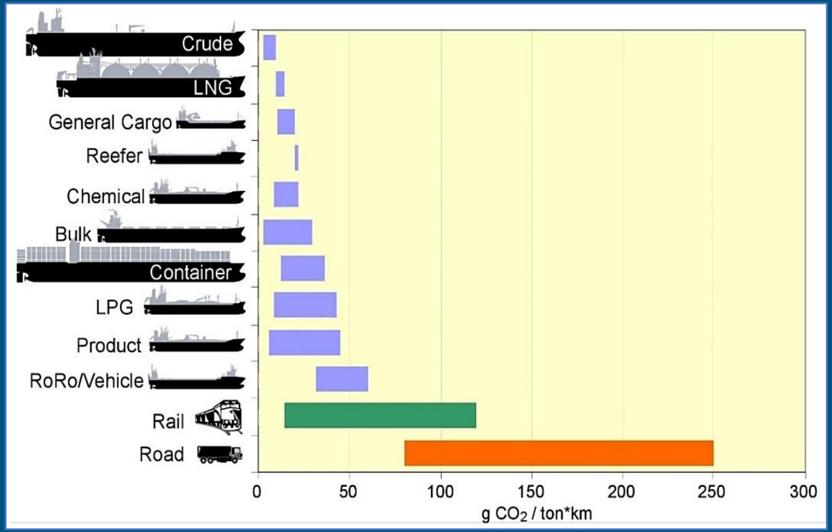


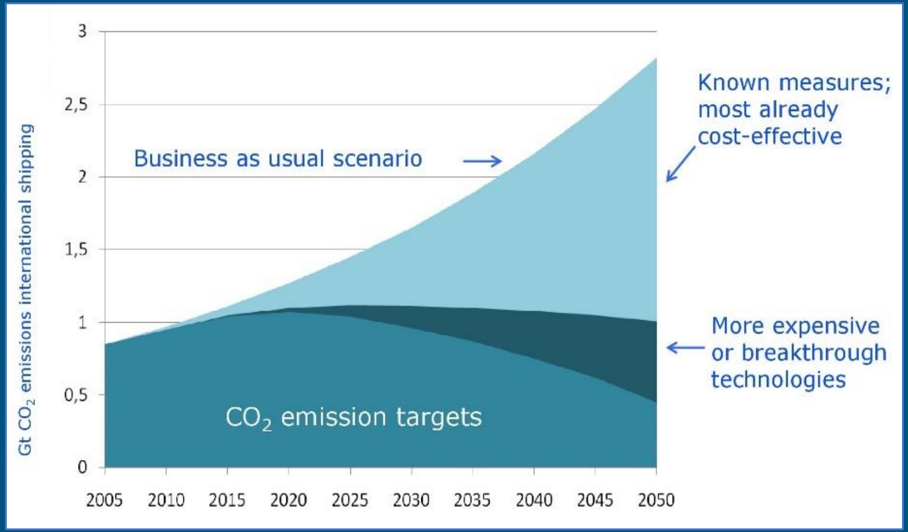
The following definitions of fuel oils are used, as applicable:

1. Distillate marine fuels (**DM**) are as specified in ISO 8217:20171 (e.g. **DMA, DMB, DMX, DMZ**);
2. Residual marine fuels (**RM**) are as specified in ISO 8217:20171 (e.g. **RMD 80, RMG 380**);
3. Ultra-low sulphur fuel oil (**ULSFO**) are as specified in ISO 8217:20171 (e.g. maximum 0.10% S **ULSFO-DM**, maximum 0.10% S **ULSFO-RM**);
4. Very low sulphur fuel oil (**VLSFO**) (e.g. maximum 0.50% S **VLSFO-DM**, maximum 0.50% S **VLSFO-RM**);
5. High sulphur heavy fuel oil (**HSHFO**) exceeding 0.50% S.

Energy efficiency of ships - legal approach and legislation

Current greenhouse gas emissions (GHG) from maritime transport represent around 3% of global anthropogenic GHG emissions (Third and Fourth IMO GHG study).





Among the mandatory regulations related to energy efficiency of the marine ships, which are already implemented and are being enforced, following regulations can be highlighted:

MARPOL Annex VI, chapter 4 – Regulations on energy efficiency for ships

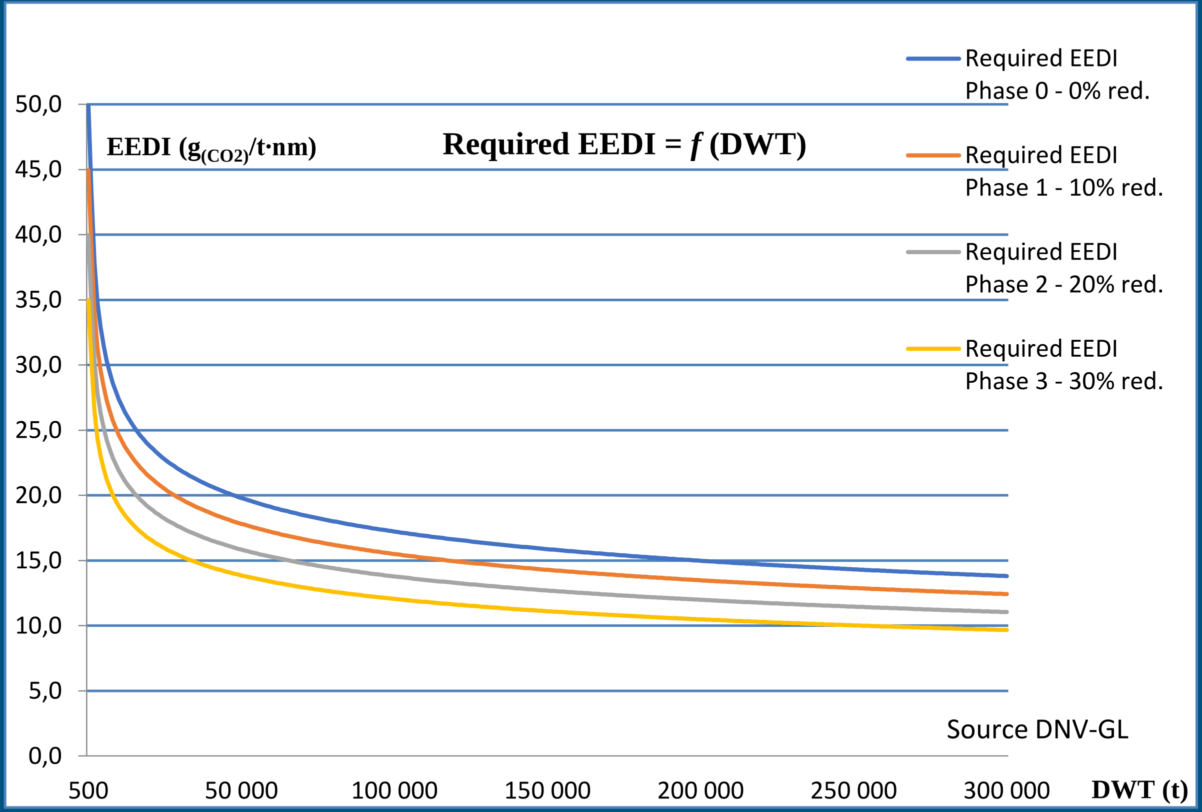
As a direct and practical way of implementation of above regulations into practice, following procedures have been specified:

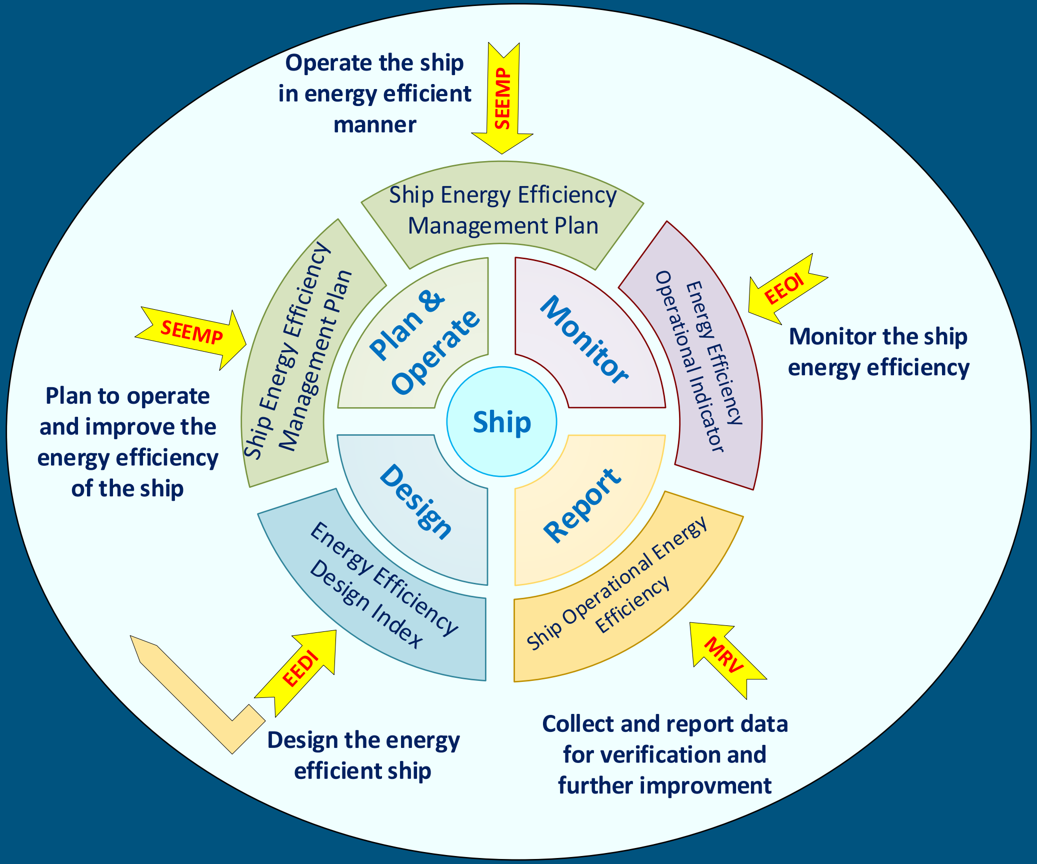
- **attained EEDI** – attained Energy Efficiency Design Index (regulation 20 of MEPC.203(62)),
- **required EEDI** – required Energy Efficiency Design Index (regulation 21 of MEPC.203(62)),
- **SEEMP** – Ship Energy Efficiency Management Plan (regulation 22 of MEPC.203(62)),
- **IEE** – International Energy Efficiency certificate and supplement (appendix VIII of MEPC.203(62)).

Ship energy efficiency legislation and functional loop

$$EEDI = \frac{total\ power \cdot total\ fuel\ consumption \cdot CO_2\ coversion\ factor}{capacity \cdot ship's\ speed}$$

$$EEDI = \frac{CO_2\ EMISSIONS}{BENEFIT\ CARGO} = \frac{\sum P \times C_F \times SFC}{CAPACITY \times SPEED}$$





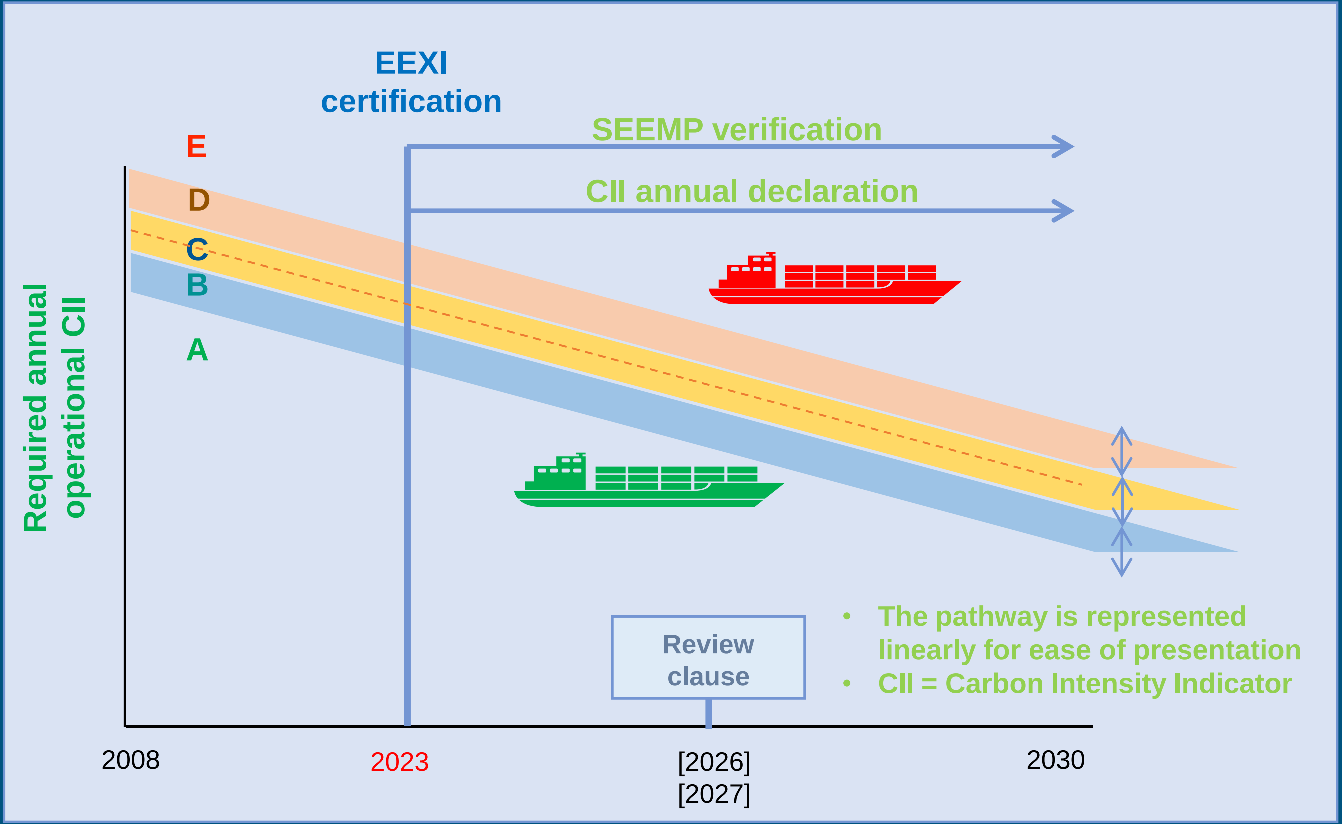
Source **DNV-GL**

IMO Identifying and regulating new Energy Efficiency Measures

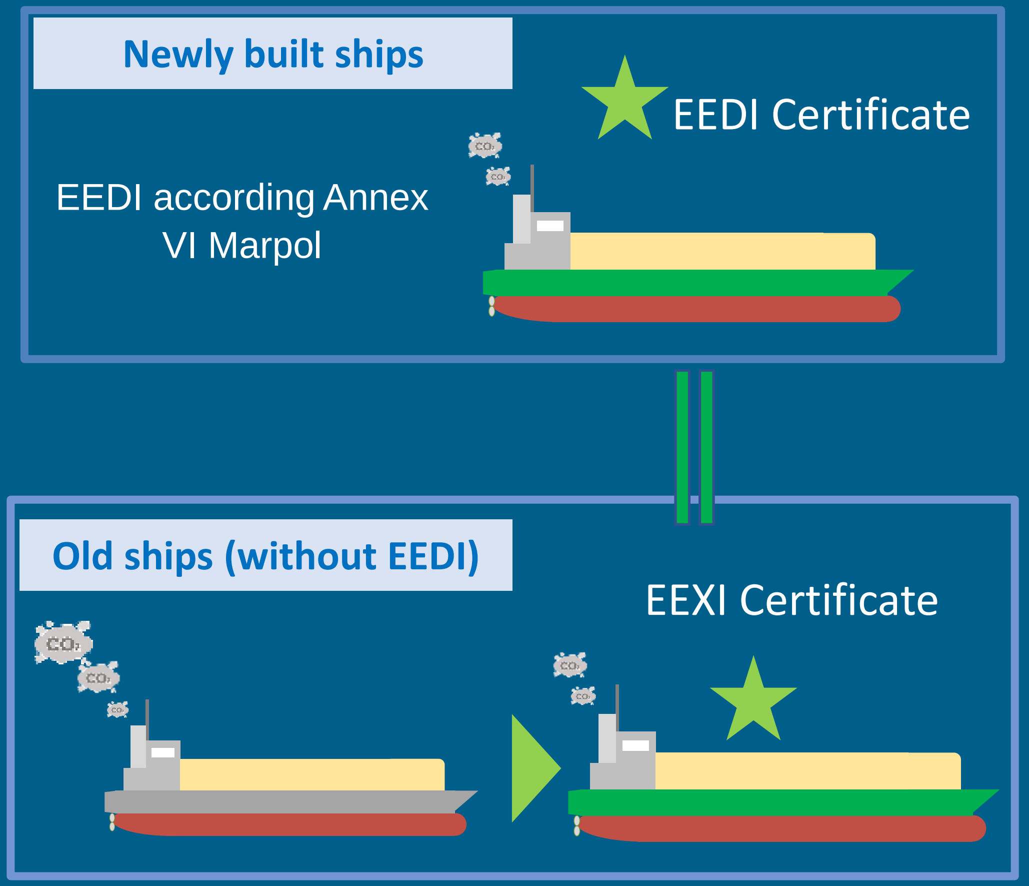
- Reduce the ships total annual emissions by at least 50% by 2050 as compared to 2008.
- Energy efficiency of shipping (tonne CO_2/tonne cargo·mile cargo) to reduce by an average of at least 40% by 2030, with main aim of reaching 70% by 2050, as compared to 2008.

Initial IMO GHG Strategy advocates the energy efficiency activities as below:

- **Short term measures:** Are those that can be defined and finalised between 2018 and 2023.
- **Mid-term measures** are those that will be those beyond short term and for discussion by the IMO between 2023 and 2030.
- **Long-term measures** are those measures that are going to be finalized, regulated and agreed by the IMO beyond 2030.

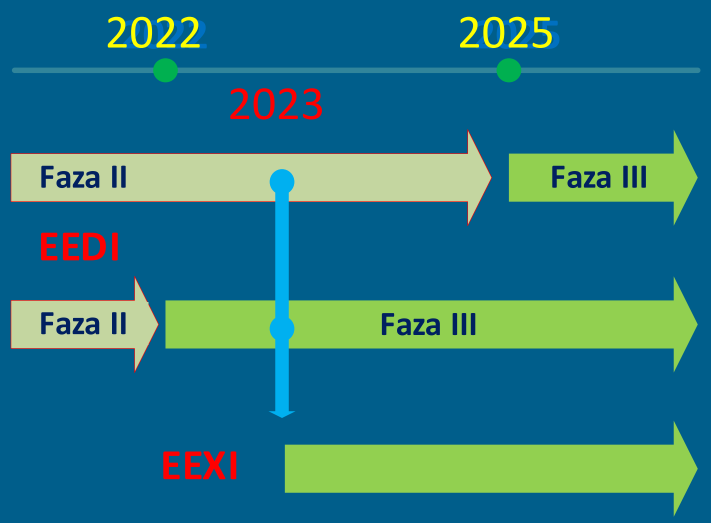


The main assumptions of further reducing CO_2 emissions for ships



MEPC has already debated some **short term measures** and the following has moved forward:

1. **EEXI**: A similar scheme as EEDI but for existing ships.
2. **CII** (Carbon Intensity Indicator): An operational efficiency indicator for measurement of energy efficiency of ships.
3. **EEDI**: Further increase in Reduction Factors (X) and bringing forward dates for Phase 3.

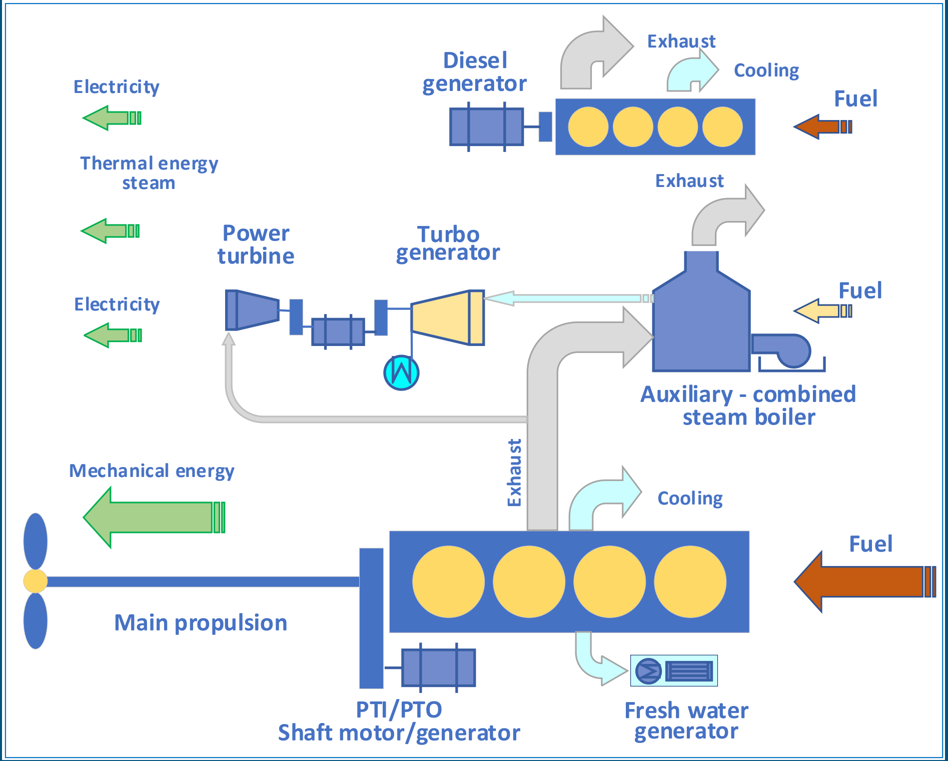


Ship propulsions efficiency - simplified consideration

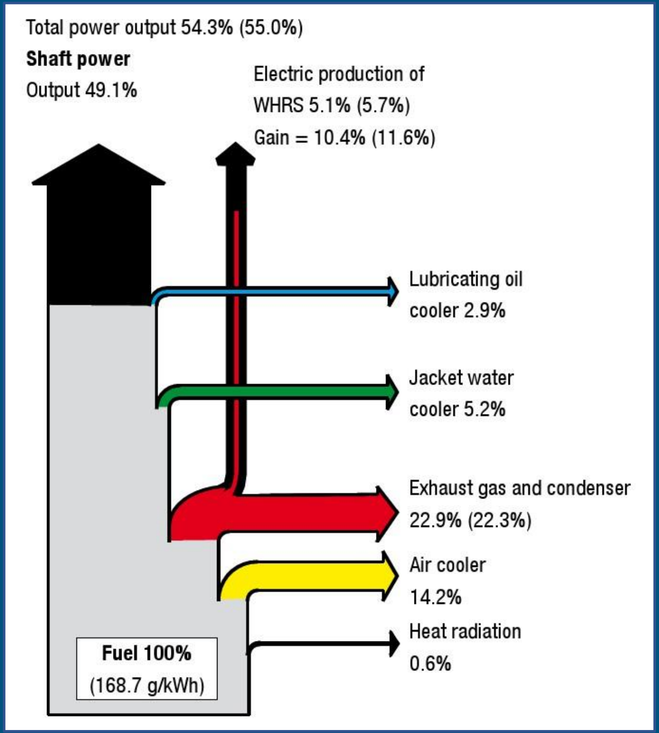
Modern ship power plant layout with WHRS

Waste Heat Recovery Systems

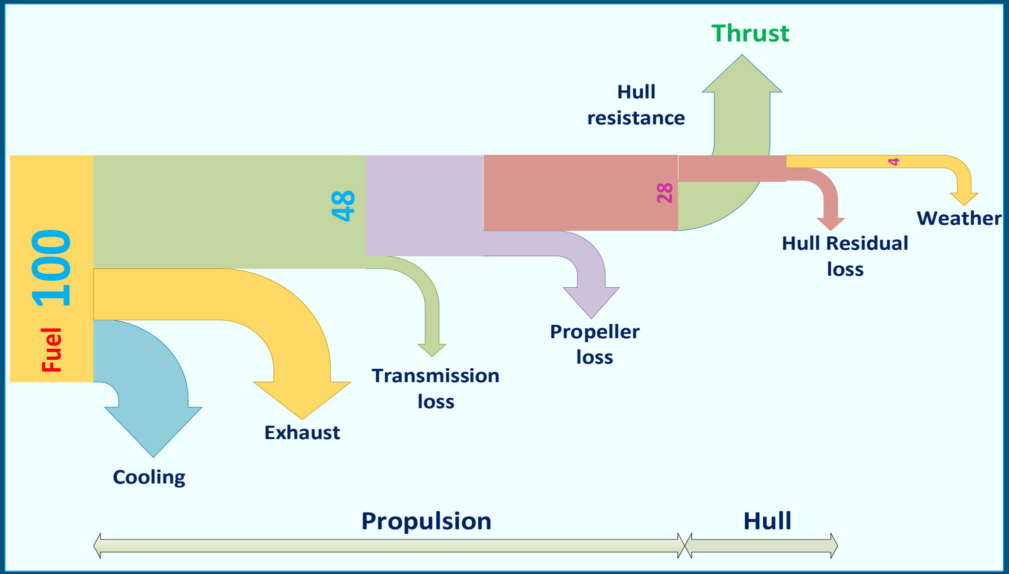
	Max. electrical recovery %
TCS – PTG:	3 to 5
STG – Single pressure system:	4 to 7
STG – Dual pressure system:	5 to 8
Full WHRS (ST - PT):	8 to 11



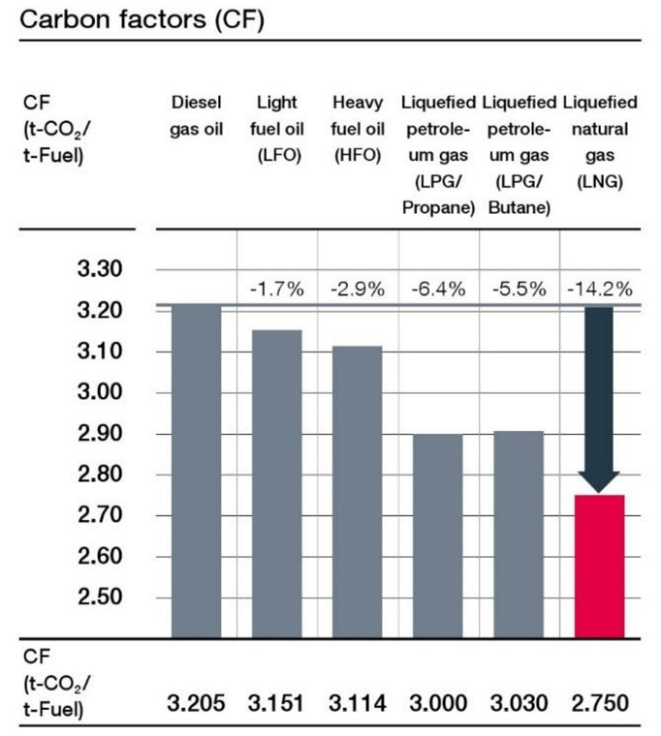
Ship main engine energy balance



Ship main propulsion energy balance



Ship energy efficiency technical measures



1. Type of fuel oil

If engines are operate on fuel that results less CO_2, the ship will have lower EEDI factor.

Becker twisted fins

Source: **Becker Marine Systems**

2. Innovative mechanical energy efficient technology

Source: **MAN Energy Solutions**

Alterantive Fuels

The carbon intensity measured in gram GHG/ton·nm has been reduced by around 18 -20% from 2008 to 2018 for the global fleet of bulk, tank and container vessels which in 2018 consumed around 60% of the fuel. This implies that we now are roughly halfway to the required 40% reduction in carbon intensity in 2030 compared to 2008.

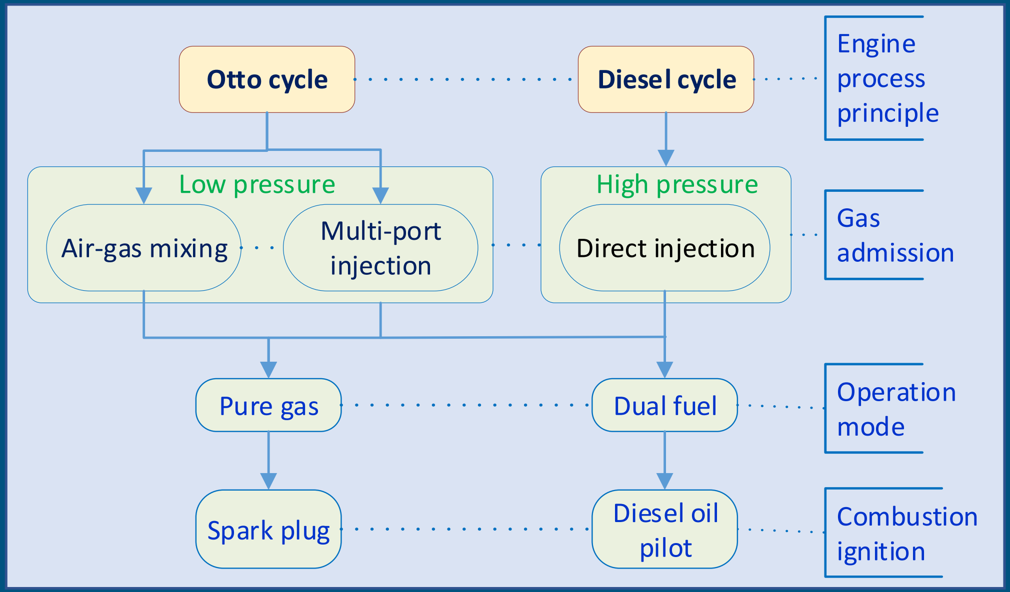
Basically there are three options for reducing the carbon intensity:

1. Design and other technical improvement of ships
2. Operational Improvement of maritime transport including operational speeds and size
3. Switching to fuels with zero or lower GHG footprint:
    - Blended conventional fossil and biofuels
    - LNG, LPG
    - Biofuels (ethanol, methanol, bio-diesel, bio-gas)
    - Hydrogen and ammonia
    - E-fuels

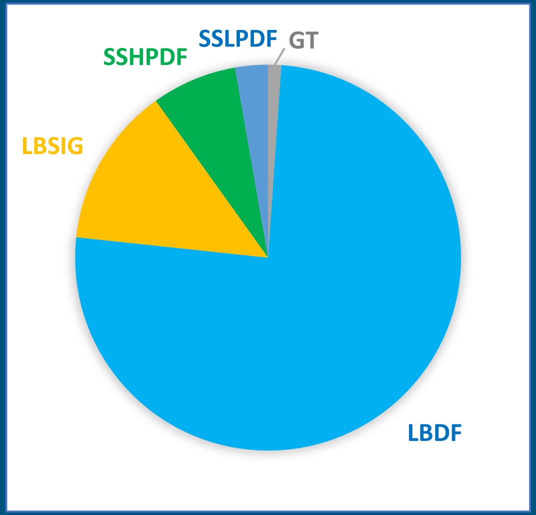
Alterantive Fuels - LNG

1. LNG as an alternative way to meet future **SO_X** and NO_X emission limits, is very promising. Also, CO_2 emission is lower.
2. However, this is a very complex technology if two aspects are taken into account:
   - bunkering and storage of **LNG** on the ship
   - new **LNG** generation of engines is significantly different from conventional - diesel engines.
3. In addition, unburned gas emission – methane slip (CH_4) is still very serious problem.

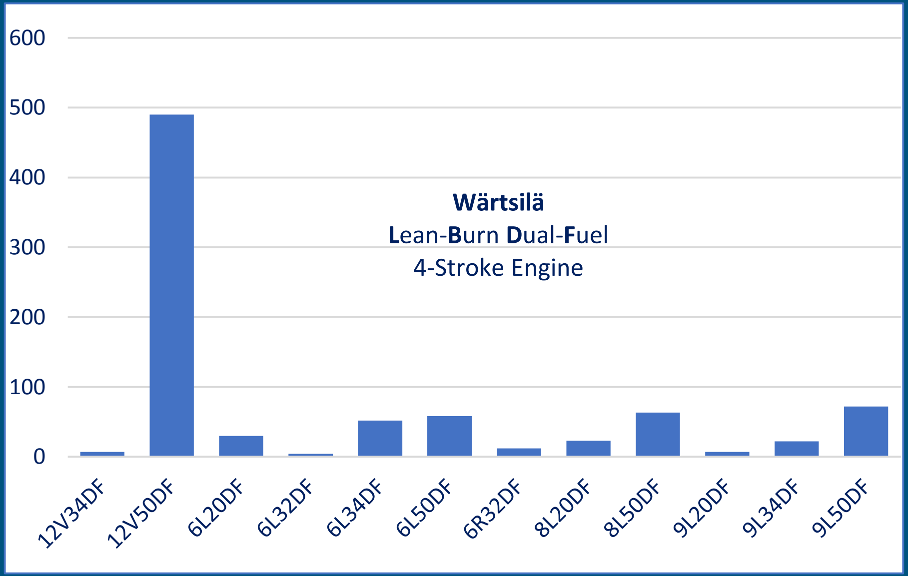
Engine concepts for LNG fuelled ships



Quantitative relations of different types of LNG engines and Wärtsilä dual-fuel engine family

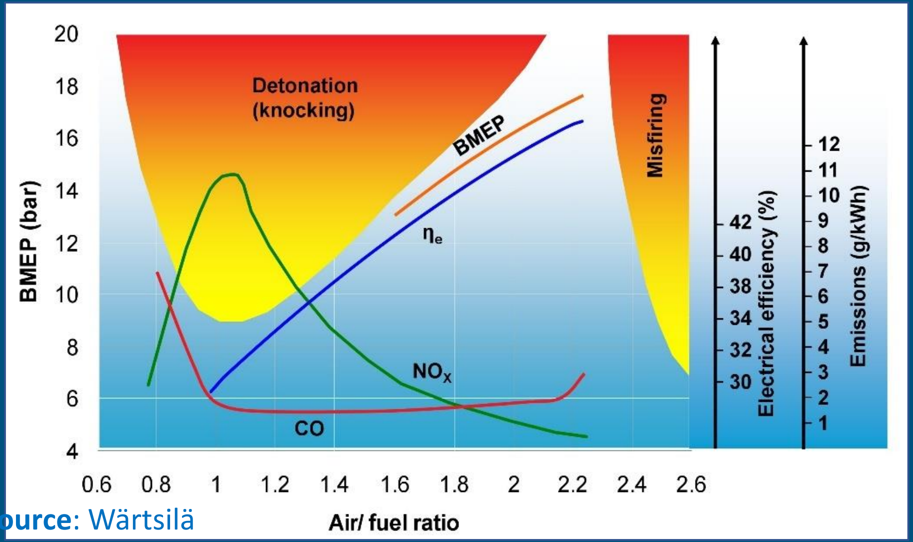


LBSIG – (Lean Burn Spark Ignited Gas),
LBDF – (Lean Burn Dual-Fuel),
SSHPDFD – Slow Speed High Pressure Dual-Fuel),
SSLPDF – (Slow Speed Low Pressure Dual-Fuel),
GT – (Gas Turbine)



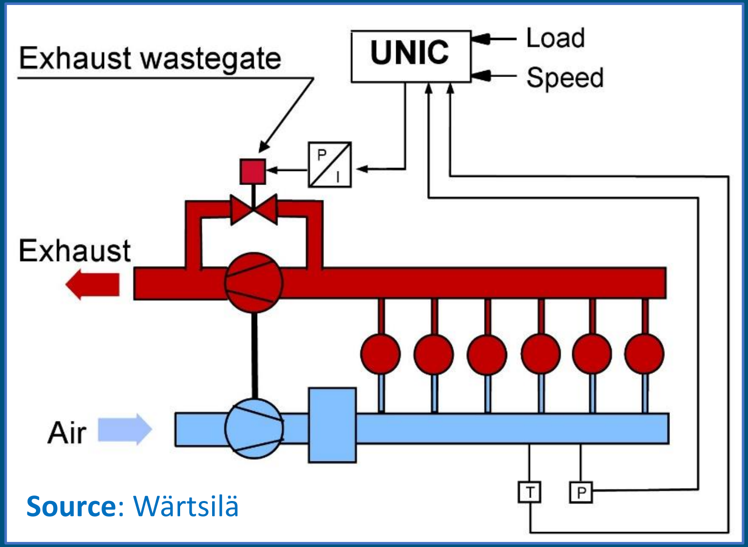
Engine concepts for LNG fuelled ships

Lean Burn Dual-Fuel engine operational process



Source: Wärtsilä

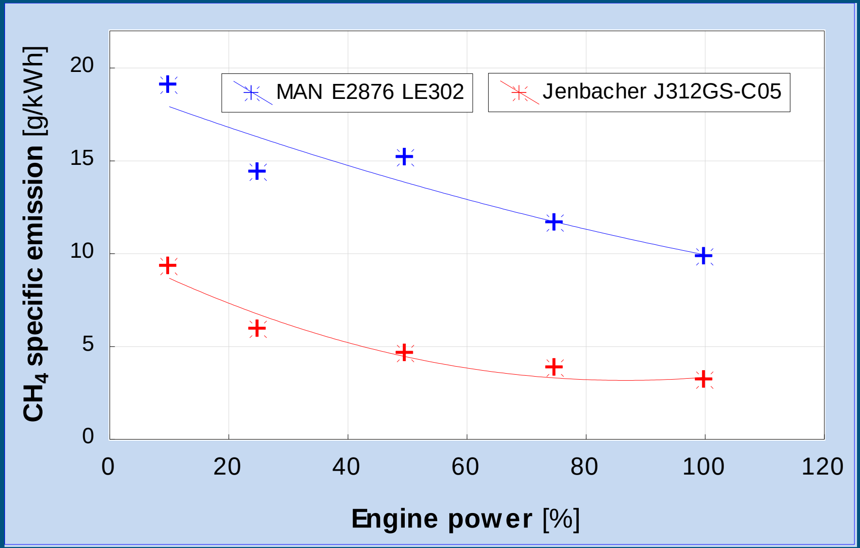
Lambda control

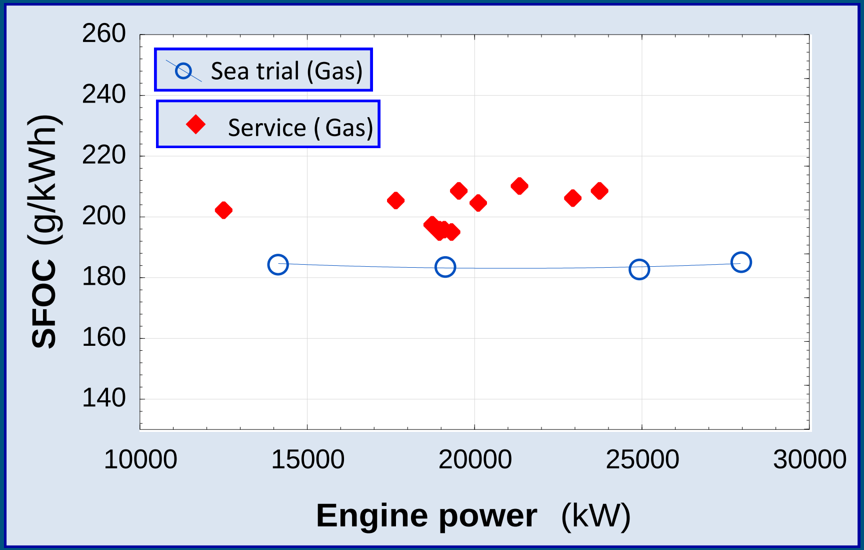


Source: Wärtsilä

Knock sensor

Lean Burn Spark Ignited Gas engine **methane slip** and gas consumption

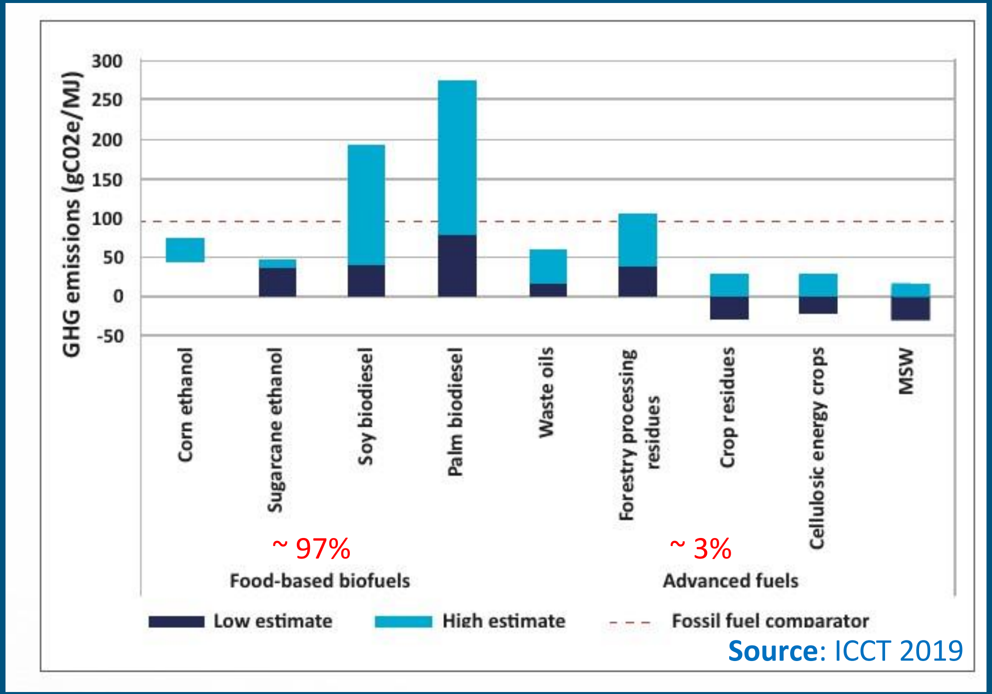


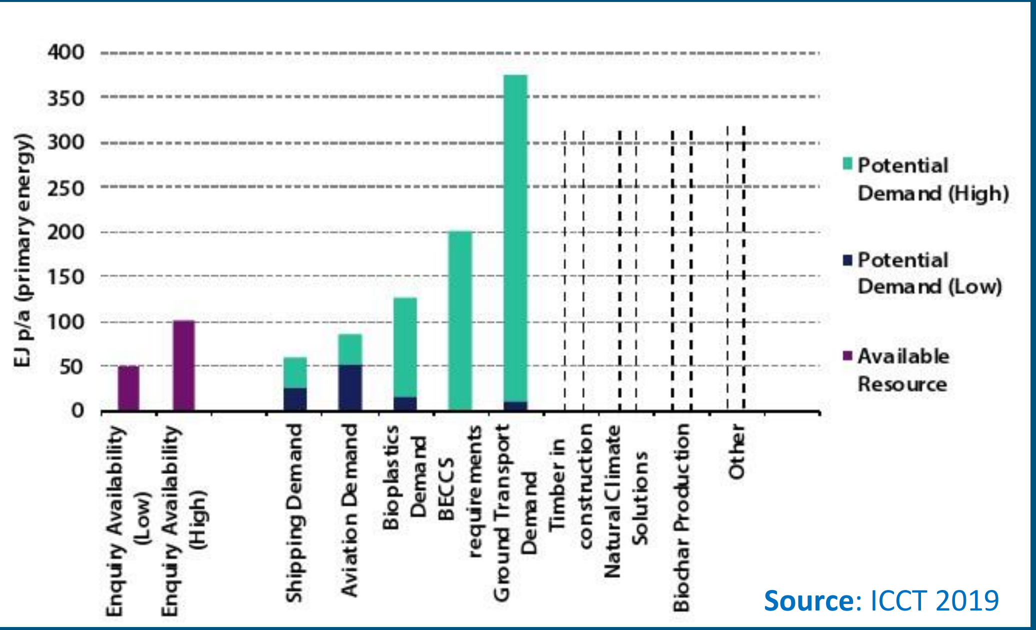


Alterantive Fuels - Biofuels

- Fuels derived from biomass, referred to as biofuels, may be an attractive option for the shipping sector.
- Biomass can be used as a feedstock to produce alcohol fuels such as: ethanol and methano or liquified bio-gas (LBG) or bio-diesel.
- Such fuels could be used as drop-in or blends with minor modifications to existing engines, machinery and storage systems, which simplifies the transition from existing fossil fuels.
- However, biofuels have also proven to be highly controversial, with questions about adverse sustainability impacts, but also whether they will be available in sufficient quantities to meet the needs of different sectors.

Comparison of lifecycyle GHG emissions associated with different biofuels





Projected avalaibility of biofuels (by mid-century) comapred to potential demand form differenty sectors

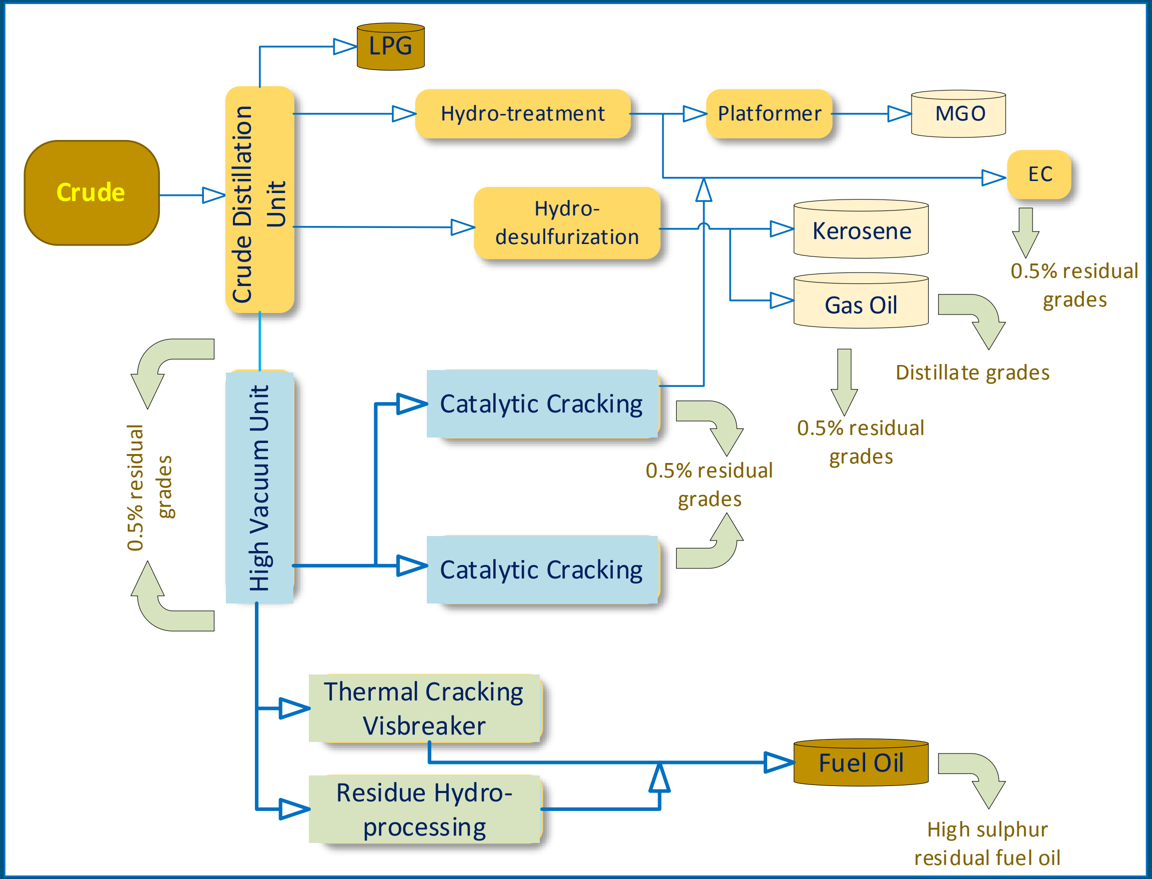
ICCT International Council on Clean Transportation's

Alterantive Fuels - Hybrids

Hybrid fuels are produced as a mixture of residual and distillate fuels to meet the maximum sulphur content of 0.1% required in the SECA. At present, there are many marine fuels of this grade available on the market.

- Increased demand for Distillate fuels may result in more land based products supply for marine purpose, some of these fuels (e.g. biodiesel) may contain Fatty Acid Methyl Ester (FAME).
- There are various technical challenges associated with use of fuel having FAME content with adverse implications (limitations in storage life).
- The ISO 8217 standard includes a maximum FAME content of 7.0% by volume for DFA/DFZ/DFB fuel oil grades. Some ports may offer automotive diesel fuel as the only fuel available, which contains FAME and could violate the fuel flashpoint requirements addressed in SOLAS.
- It is recommended to avoid using such biodiesel blend fuels for lifeboat engines, emergency generators, fire pumps, etc. where it is stored in isolated individual unit fuel tanks and subjected to conditions for accelerated degradation.

The complex process of blending 0.5% VLSFO



Alterantive Fuels – Ammonia

Generally, ammonia is produced via the Haber-Bosch synthesis process from hydrogen and nitrogen. While the nitrogen comes from air separation, a number of production routes can be used to produce hydrogen, most prominently from steam reforming of hydrocarbons or from electrolysis of water.

Ammonia engine designs are related to heating value and the corrosive nature of ammonia , lower calorific values (LCV) - 18.6 MJ/kg for ammonia

Two-stroke ammonia engine development schedule

2019	2020	2021	2022	2023	2024
Pre-study	**Project kick-off**	**1st engine test**	**Emission specification**	**Full scale engine test**	**1st engine delivery to yard**
✓ NH_3 combustibility investigation.	✓ 4T50ME-X test engine received as platform for the Ammonia engine development. ✓ HAZID workshop on engine concept.	– 1st engine confirmation at Research Centre Copenhagen (RCC). – Engine basic concept defined based on engine tests. – Ammonia supply & Auxiliary systems specified	– Specification of emission after-treatment done.	– Full scale engine test at RCC completed.	– Ammonia engine in engine programme. – 1st ammonia burning engine to be installed at yard.

Source: MAN

Alterantive Fuels - Methanol

Methanol, as a sulphur-free fuel presents lower CO_2 formation (up to 7% lower than HFO).

Methanol is characterised by a low cetane number and requiring a small amount of pilot fuel (95% methanol and just 5% diesel pilot fuel).

The MAN LGI and GI concept engines are based on the conventional, electronically controlled ME-C engine with dual-fuel injection

The MAN B&W ME-LGI W engine is dual-fuel solution with addition of water to methanol lowers the NO_x formation.

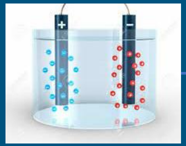
Alterantive fuels properties

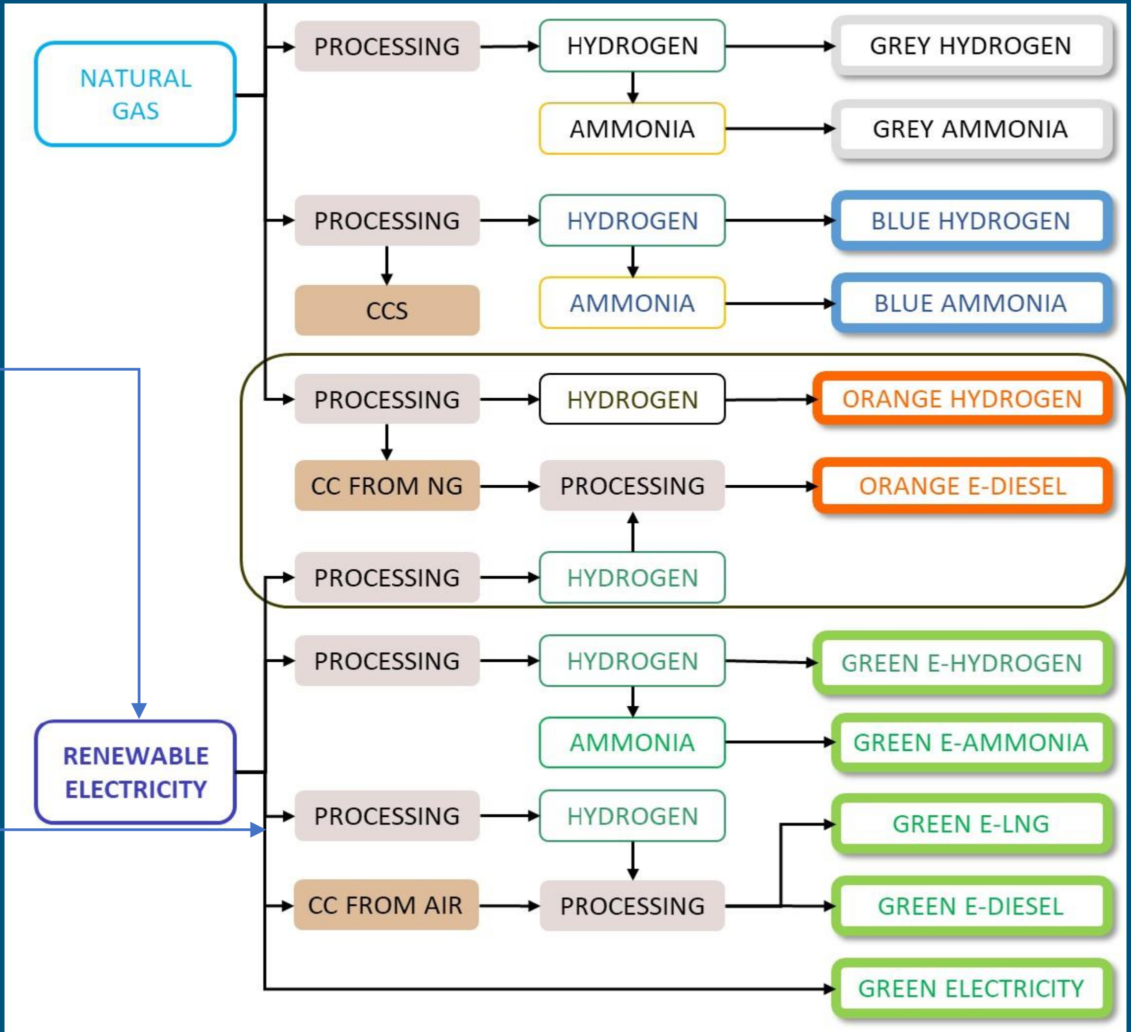
Energy storage type/chemical structure	Energy content, LHV [MJ/kg]	Energy density, [MJ/L]	Fuel tank size relative to MGO	Supply pressure [bar]	Flash-point [°C]	Vapour pressure at 20°C [bar]	Auto-ignition temperature [°C]	Emission reduction compared to HFO Tier II [%]			
								SO_x	NO_x	CO_2	PM
Ammonia (NH_3) (liquid, -33°C)	18.6	12.7(-33°C) / 10.6 (45°C)	2.8 (-33°C) / 3.4 (45°C)	80	132	0.13 / 0.13	630 / 470	100	Compliant with regulation	~90	~90
Methanol (CH_3OH) (65°C)	19.9	14.9	2.4	10	9	2.2-8.5		90-97	30-50	11	90
LPG (liquid, -42°C)	46.0	26.7	1.3*1	50	-104		410-580 (depending on the composition)	90-100	10-15	13-18	90
LNG (liquid, -162°C)	50.0	21.2	1.7*1	300				90-99	20-30	24	90
LEG (liquid, -89°C)	47.5	25.8	1.4*1	380				90-97	30-50	15	90
MGO	42.7	35.7	1.0	7-8							
Hydrogen (H_2) (liquid, - 253°C)	120.0	8.5	4.2		Not defined		500				

Source: MAN

As of November 2020, methanol has been approved and will bec incorporated in the International Code of Safety for Ships using gas or other low-flashpoint fuels (IGF code).

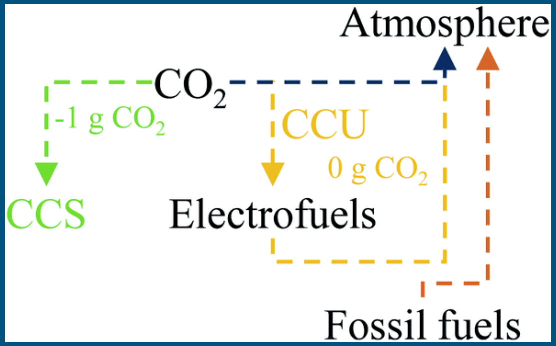
Alterantive Fuels – eFuels





Grey = Fossil,
Blue = Fossil with carbon capture,
Orange = Combining fossil & Green; fossil & Blue; or Bio & fossil
Green = Fully renewable

eFuels are produced with the help of electricity from renewable energy sources, water and CO_2 from the air. In contrast to conventional fuels, they do not release additional CO_2 but are climate-neutral.



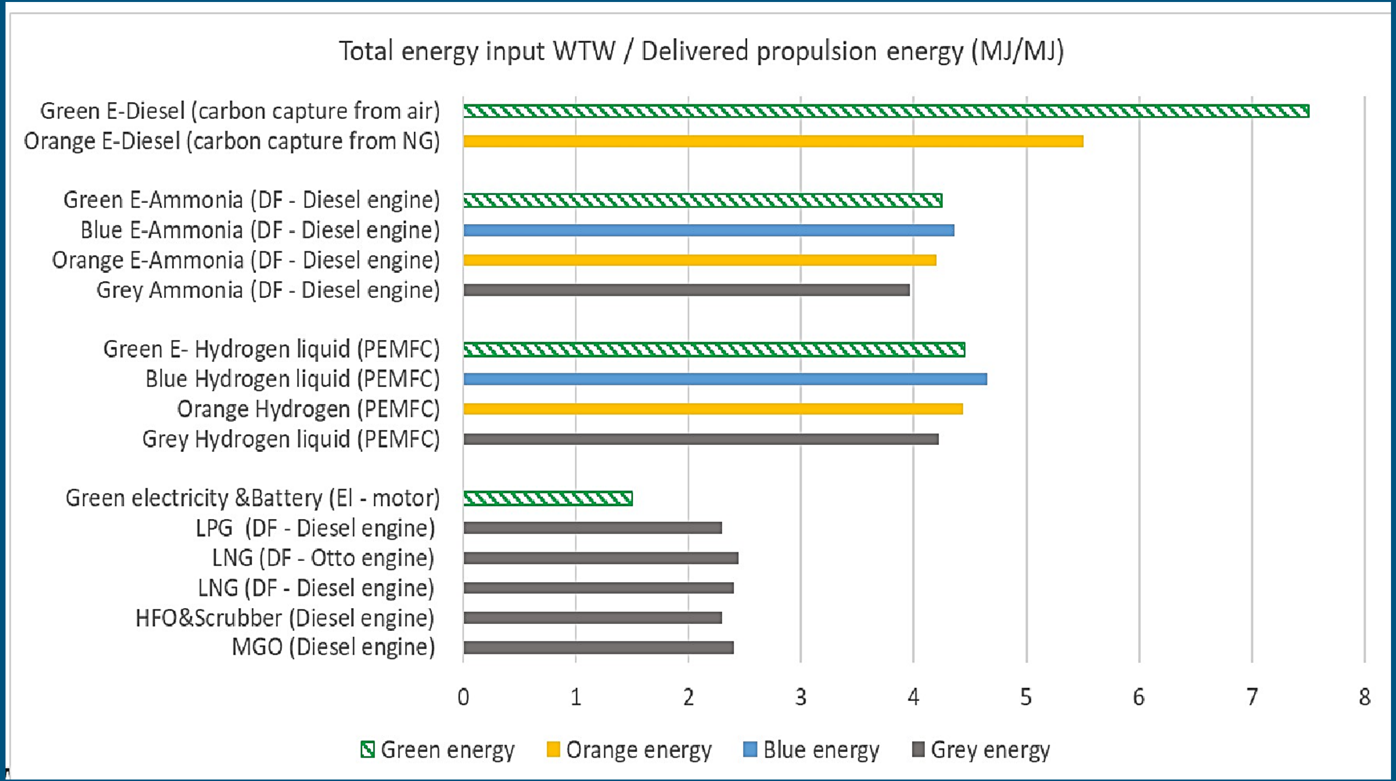
For the life-cycle analysis of the CO2 inputs, two reference systems are assessed

CCS - Carbon Capture and Storage

Conclusions

1. The shipping future will see cleaner fuels, and the two-stroke engine technology will likely remain the prime propulsion.
2. Current marine engine portfolio shows that the two-stroke engines combust various fuel types and future-proof technology with dual-fuels: LNG, LPG, ethane and methanol are in use.
3. The development of an engine type for ammonia supplements (dual-fuel) will meet future market demands for CO_2-neutral propulsion including retrofits.

Energy input per kW delivered for propulsionas a functionof fuel and its origin



Source: E. Lindstad, SINTEF Ocean AS, 2020

4. For future marine engine, methanol as a drop-in fuel is readily achieved by blending increasing amounts of green or blue methanol with grey methanol and eventually, the lower-carbon methanol becomes the main fuel. This is a net carbon-neutral solution that may co-evolve with an increasing production of green or blue methanol.

Fuel cost based on present knowledge (relative to VLSFO costs)

Fuel	Lowest estimat based on input needed per kW delivered for propulsion (as given in slide 7 & 10)	Current estimate (their lowest) of 4th IMO GHG study and UMAS & Lloyds register (2020)
VLSFO – very low sulphur oil < 0.5% Sulphur	1	1
Hydrogen & Ammonia	2	4
Green E-diesel	3	10

Source: E. Lindstad, SINTEF Ocean AS, 2020

Annual cost increasesas a functionof fuel and its price estimate (draft calculation)

Supramax Dry bulker 63 000 dwt	VLSFO & Diesel engine & SCR	Green Ammonia& High pressure DF (Diesel-engine)	MGO & Diesel engine & SCR - 45% Green synthetic E-diesel	MGO & Diesel engine & SCR - 100% Green synthetic E-diesel	UNIT
Fuel type	VLSFO	Ammonia	Blended diesel	Green E-diesel	
New-built cost with Diesel-engine & SCR	30			30	MUSD
Dual fuel engine & fuel system including tanks		10			MUSD
Required modification for ammonia		5			MUSD
Total investment	30	45	30	30	MUSD
Annual Fuel consumption (TOE)	6000	6000	6000	6000	Ton
Change in GHG compared to MGO (GWP 100)	1 %	-100 %	45 %	-100 %	
Annual capex & opex (MUSD)	3.60	5.4	3.6	3.6	MUSD
Fuel price per TOE - Low estimate	375	750	713	1 125	USD/ton
Fuel price per TOE - Average estimate	375	1 500	1 894	3 750	USD/ton
Annual Fuel cost Low estimate (MUSD)	2.25	4.5	4.3	6.8	MUSD
Annual Fuel cost current estimate (MUSD)	2.25	9.0	11.4	22.5	MUSD
Annual cost low estimate (MUSD)	5.85	9.90	7.88	10.35	MUSD
Annual cost average estimate (MUSD)	5.85	14.40	14.96	26.10	MUSD

Thank you for your attention