Technical and Regulatory Strategies for Reducing the Carbon Footprint of Maritime Transport

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*Opinions are my own.

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Technical Criteria

- Follow the format:

$$\frac{CO_2\ Emissions}{Performed\ Transport}$$

- The attained metric should be smaller than or equal to the required metric:

$$Attained\ EEDI\ \leq Required\ EEDI = \left(1 - \frac{X}{100}\right) \cdot Reference\ line\ value$$

An Anatomy of the Energy Efficiency Design Index (EEDI) Equation for Ships

MAIN ENGINES EMISSIONS | AUXILIARY ENGINES EMISSIONS | SHAFT GENERATORS/MOTORS EMISSIONS | EFFICIENCY TECHNOLOGIES

$$\frac{\left(\prod_{j=1}^{M} f_j\right)\left(\sum_{i=1}^{nME} P_{ME(i)}\cdot C_{FME(i)}\cdot SFC_{ME(i)}\right) + \left(P_{AE}\cdot C_{FAE}\cdot SFC_{AE}^{*}\right) + \left(\left(\prod_{j=1}^{M} f_j\cdot\sum_{i=1}^{nPTI} P_{PTI(i)} - \sum_{i=1}^{neff} f_{eff(i)}\cdot P_{AEeff(i)}\right) C_{FAE}\cdot SFC_{AE}\right) - \left(\sum_{i=1}^{neff} f_{eff(i)}\cdot P_{eff(i)}\cdot C_{FME}\cdot SFC_{ME}\right)}{f_i\cdot Capacity\cdot V_{ref}\cdot f_w}$$

TRANSPORT WORK

ENGINE POWER (P)

Individual engine power at 75% of Maximum Continuous Rating

- $P_{eff(i)}$ Main engine power reduction due to individual technologies for mechanical energy efficiency
- $P_{AEeff(i)}$ Auxilliary engine power reduction due to individual technologies for electrical energy efficiency
- $P_{PTI(i)}$ Power of individual shaft motors divided by the efficiency of shaft generators
- P_{AE} Combined installed power of auxilliary engines
- $P_{ME(i)}$ Individual power of main engines

CO_2 EMISSIONS (C)

CO_2 emission factor based on type of fuel used by given engine

- C_{FME} Main engine composite fuel factor
- C_{FAE} Auxilliary engine fuel factor
- $C_{FME(i)}$ Main engine individual fuel factors

SPECIFIC FUEL CONSUMPTION (SFC)

Fuel use per unit of engine power, as certified by manufacturer

- SFC_{ME} Main engine (composite)
- SFC_{AE} Auxilliary engine
- SFC_{AE}^{*} Auxilliary engine (adjusted for shaft generators)
- $SFC_{ME(i)}$ Main engine (individual)

CORRECTION AND ADJUSTMENT FACTORS (f)

Non-dimensional factors that were added to the EEDI equation to account for specific existing or anticipated conditions that would otherwise skew individual ships' rating

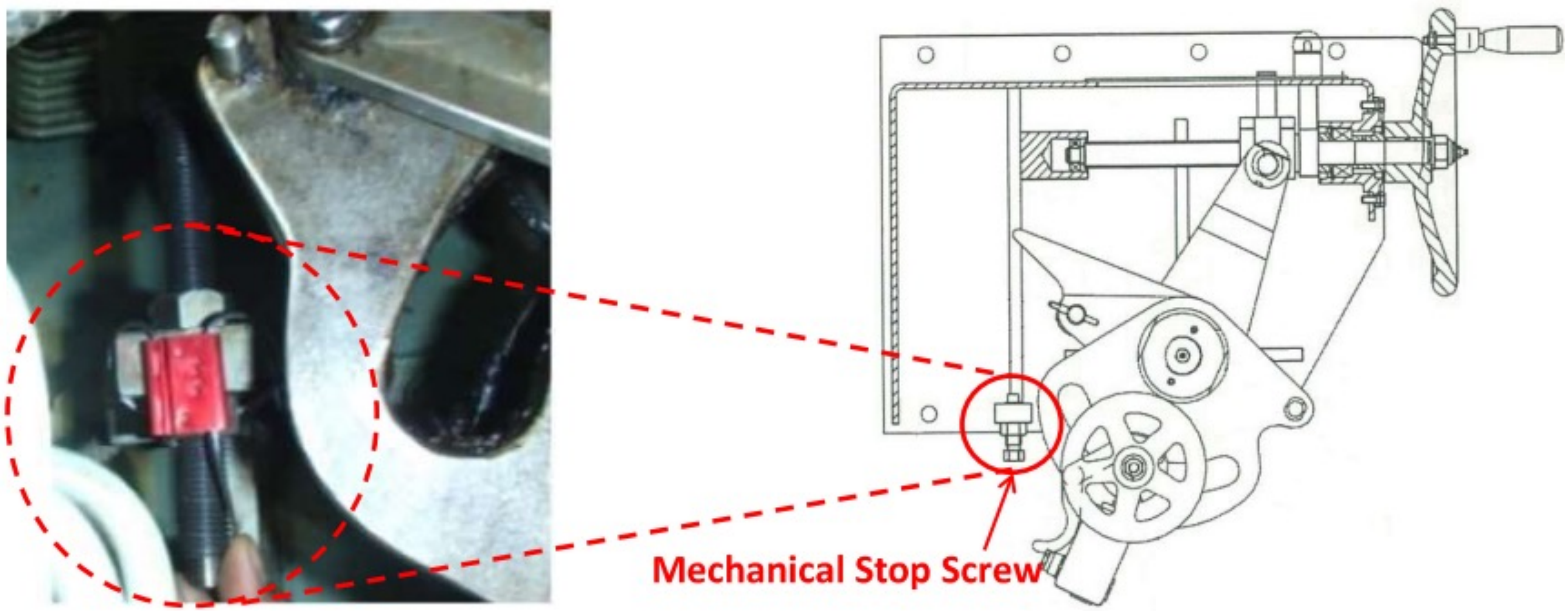
- $f_{eff(i)}$ Availability factor of individual energy efficiency technologies (=1.0 if readily available)
- f_j Correction factor for ship specific design elements. *E.g.* ice-classed ships which require extra weight for thicker hulls
- f_w Coefficient indicating the decrease in ship speed due to weather and environmental conditions
- f_i Capacity adjustment factor for any technical/regulatory limitation on capacity (=1.0 if none)

SHIP DESIGN PARAMETERS

- V_{ref} Ship speed at maximum design load condition
- *Capacity* Deadweight Tonnage (DWT) rating for bulk ships and tankers; a percentage of DWT for Containerships DWT indicates how much can be loaded onto a ship

icct
THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

Engine Power Limitation



Mechanical stop screw sealed by wire

Engine side control console in the governor

Figure 2: Sealing of mechanical stop screw

Source: 2021 Guidelines on the shaft / engine power limitation system to comply with the EEXI requirements and use of a power reserve. Link: https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/Air%20pollution/MEPC.335(76).pdf

Engine Power Limitation

.2 EPL:

.1 for the mechanically controlled engine, a sealing device which can physically lock the fuel index by using a mechanical stop screw sealed by wire or an equivalent device with governor limit setting so that the ship's crew cannot release the EPL without permission from the ship's master or OICNW, as shown in figure 2; or

- Engine power limitation can be deactivated in emergencies, e.g., necessity to overcome bad weather.

Source: 2021 Guidelines on the shaft / engine power limitation system to comply with the EEXI requirements and use of a power reserve. Link: https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/Air%20pollution/MEPC.335(76).pdf

Accounting of systemic improvements in vessel performance

Innovative Energy Efficiency Technologies				
Reduction of Main Engine Power			Reduction of Auxiliary Power	
Category A	*Category B-1*	*Category B-2*	*Category C-1*	*Category C-2*
Cannot be separated from overall performance of the vessel	Can be treated separately from the overall performance of the vessel		Effective at all time	Depending on ambient environment
	$f_{eff} = 1$	$f_{eff} < 1$	$f_{eff} = 1$	$f_{eff} < 1$
– low friction coating – bare optimization – rudder resistance – propeller design	– hull air lubrication system (air cavity via air injection to reduce ship resistance) (can be switched off)	– wind assistance (sails, Flettner-Rotors, kites)	– waste heat recovery system (exhaust gas heat recovery and conversion to electric power)	– photovoltaic cells

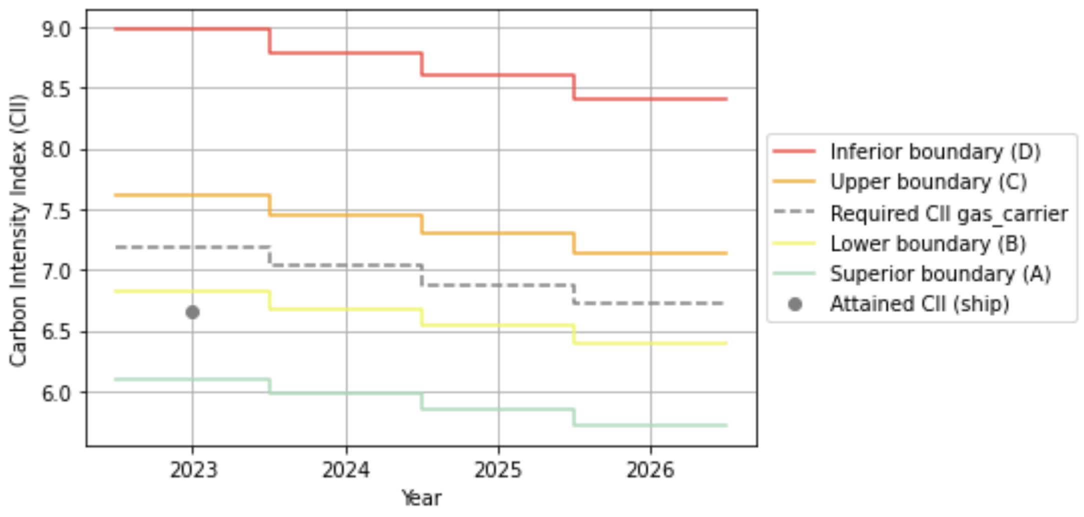
4.2 Category (A) technology

4.2.1 Innovative energy efficiency technologies in category (A) affect P_P and/or V_{ref} and their effects cannot be measured in isolation. Therefore, these effects should not be calculated nor certified in isolation in this guidance but should be treated as a part of vessel in EEDI Calculation Guidelines and EEDI Survey Guidelines.

Source: 2021 Guidance on Treatment of Innovative Energy Efficiency Technologies for Calculation and Verification of the Attained EEDI and EEXI.
Link: https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/Air%20pollution/MEPC.1-Circ.896.pdf

Differences among EEXI, EEDI and CII

- Scope:
  - EEXI and EEDI are valid for vessels over 400 GT.
  - CII is valid for ships over 5000 GT.
- Calculation:
  - EEXI and EEDI are design / specification criteria.
  - CII is an operational criteria.
- Application over the years:
  - EEDI and CII become more restrictive over the roll out of different phases.
  - EEXI is applied as a stable criterion.

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Assuming this vessel attains the same CII, it will end 2026 with a satisfactory rating.
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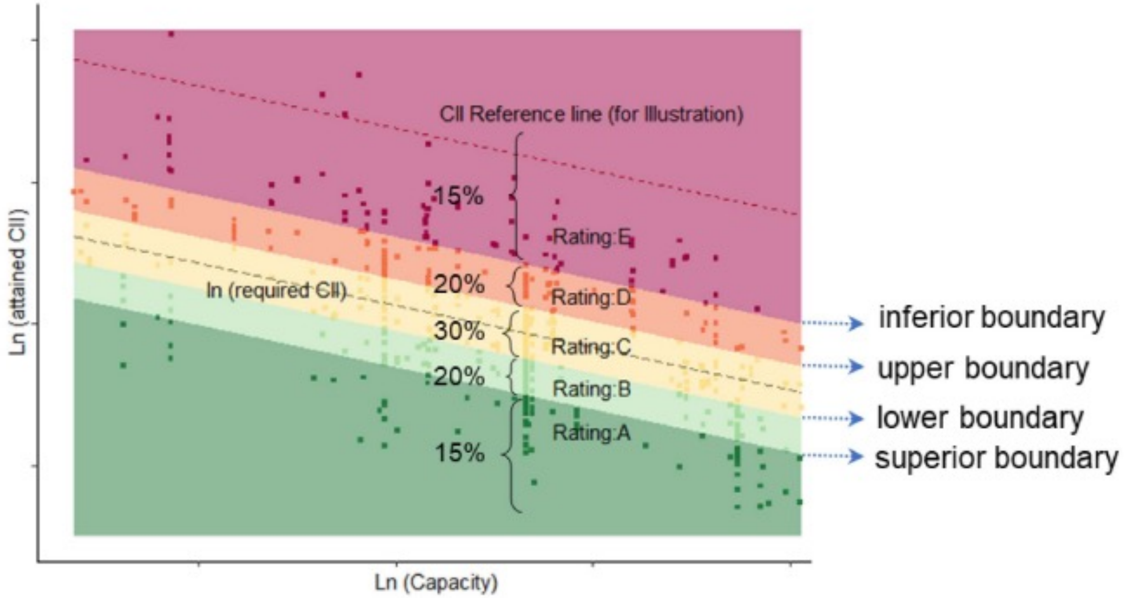
CII

Calculation of annual CII:

$$\text{CII} = \frac{\text{Annual fuel consumption} \bullet CO_2 \text{ factor}}{\text{Annual distance travelled} \bullet \text{Capacity}} \bullet \text{Correction factors}$$

To be developed

Figure's source: DNV.



Source: 2022 Guidelines on the Operational Carbon Intensity Rating of Ships (CII Rating Guidelines, G4). Link: https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/Air%20pollution/MEPC.354(78).pdf

Implementation

- Data is submitted by class to IMO's Data Collection System (DCS).

- Collected data includes CO2 emissions and travelled distance.

- Fuel consumption can be calculated through:
  - Measurements of fuel remaining on board (ROB).
  - Flowmeters.
  - Direct measurements of exhaust gases.

Penalties

Corrective actions and incentives

7 A ship rated as D for three consecutive years or rated as E shall develop a plan of corrective actions to achieve the required annual operational CII.

8 The SEEMP shall be reviewed to include the plan of corrective actions accordingly, taking into account the guidelines to be developed by the Organization. The revised SEEMP shall be submitted to the Administration or any organization duly authorized by it for verification, preferably together with, but in no case later than 1 month after reporting the attained annual operational CII in accordance with paragraph 2 of this regulation.

9 A ship rated as D for three consecutive years or rated as E shall duly undertake the planned corrective actions in accordance with the revised SEEMP.

10 Administrations, port authorities and other stakeholders as appropriate, are encouraged to provide incentives to ships rated as A or B.

Source: Resolution MEPC.328(76) Amendments to the Annex of the Protocol of 1997 to Amend the International Convention for the Prevention of Pollution from Ships, 1973, as Modified by the Protocol of 1978 Relating Thereto 2021 Revised MARPOL Annex VI. Link: https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/Air%20pollution/MEPC.328(76).pdf

Deficiencies and Conformity

- CII calculation considers vessel capacity, and not transported cargo.
- May lead to It may lead to attempts to circumvent the rule by traveling longer distances in ballast condition.
- Some stakeholders allege it would be desirable for the attained CII to correct for waiting time in port and the climatic conditions of the region of operation.
- Among the implemented compliance measures is the reduction of operational speed (or, “slow steaming”).
- However, this recommendation is sometimes based on simplistic propulsion models, e.g.:

$$fuel\ consumption\ rate = cte \cdot speed^3$$

Slow Steaming

$$\text{CII} = \frac{\text{emissions}}{\text{capacity} \cdot \text{distance}} = \frac{\text{conversion factor} \cdot \text{fuel consumption}}{\text{capacity} \cdot \text{distance}}$$

constant

$$= \frac{\text{constant} \cdot \text{fuel consumption}}{\text{distance}} = \frac{\text{constant} \cdot \text{fuel cons rate} \cdot \text{time}}{\text{distance}}$$

$$= \frac{\text{constant} \cdot \text{fuel cons rate} \cdot \frac{\cancel{\text{distance}}}{\text{speed}}}{\cancel{\text{distance}}} = \frac{\text{const} \cdot \text{fuel cons rate}}{\text{speed}}$$

EU ETS: Design and Implementation

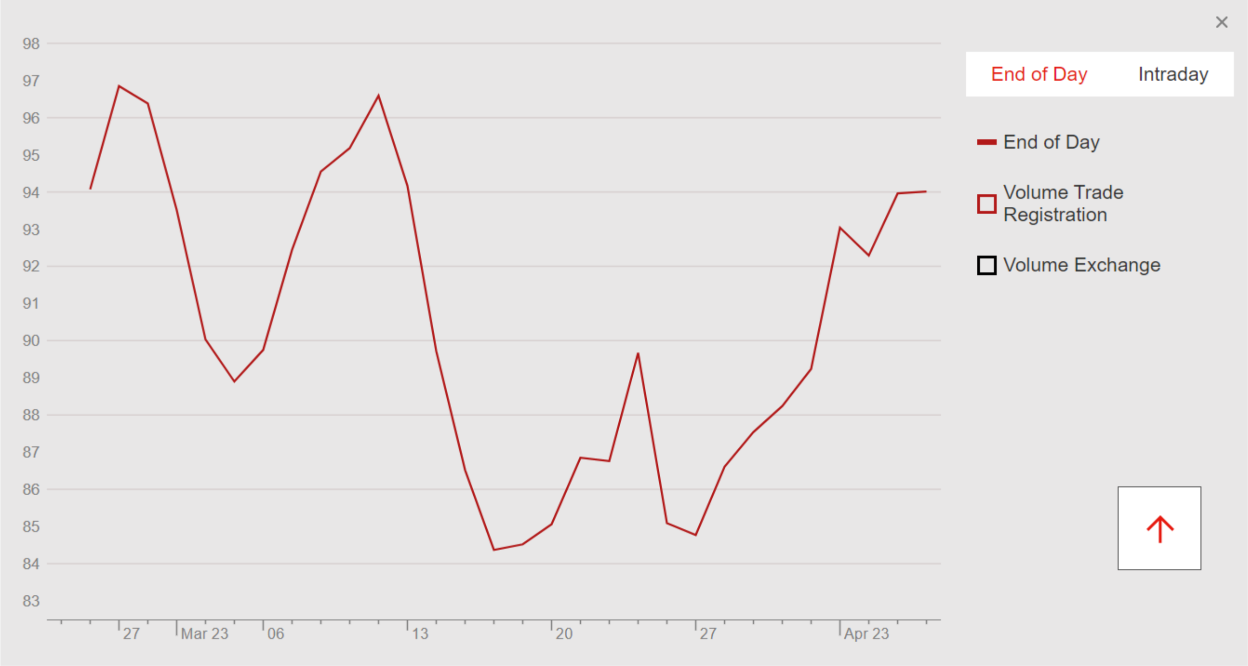
- "Cap and trade" system that charges permissions for companies to emit CO2 within the European Union.
- The system has been in operation since 2005 but should be expanded to maritime transport in 2024.
- Based on public data collected by the EU: THETIS-MRV (europa.eu).
- The regulation proposal includes:
  - 100% taxation of emissions on voyages and stays in ports within the EU.
  - 50% taxation of emissions on voyages entering or leaving the EU.
  - Gradual phase-in period between 2024 and 2026, ranging from 40% to 100% emissions coverage.

Source: The Inclusion of Shipping in the EU ETS. Link: https://www.hecla-em.co/post/the-inclusion-of-shipping-in-the-eu-ets.

EU ETS: Implementation

- Shipping companies will have to acquire allowances, such as in auctions or on the spot market, and deliver them to the EU to cover their emissions.

Spot	Last Price	Last Volume	End of Day Index	Volume Exchange	Volume Trade Registration
2021-2030	-	-	94.26	-	-



Source: EEX EUA Spot. Link: https://www.eex.com/en/market-data/environmentals/spot#%7B%22snippetpicker%22%3A%2252%22%7D

EU ETS: Penalties

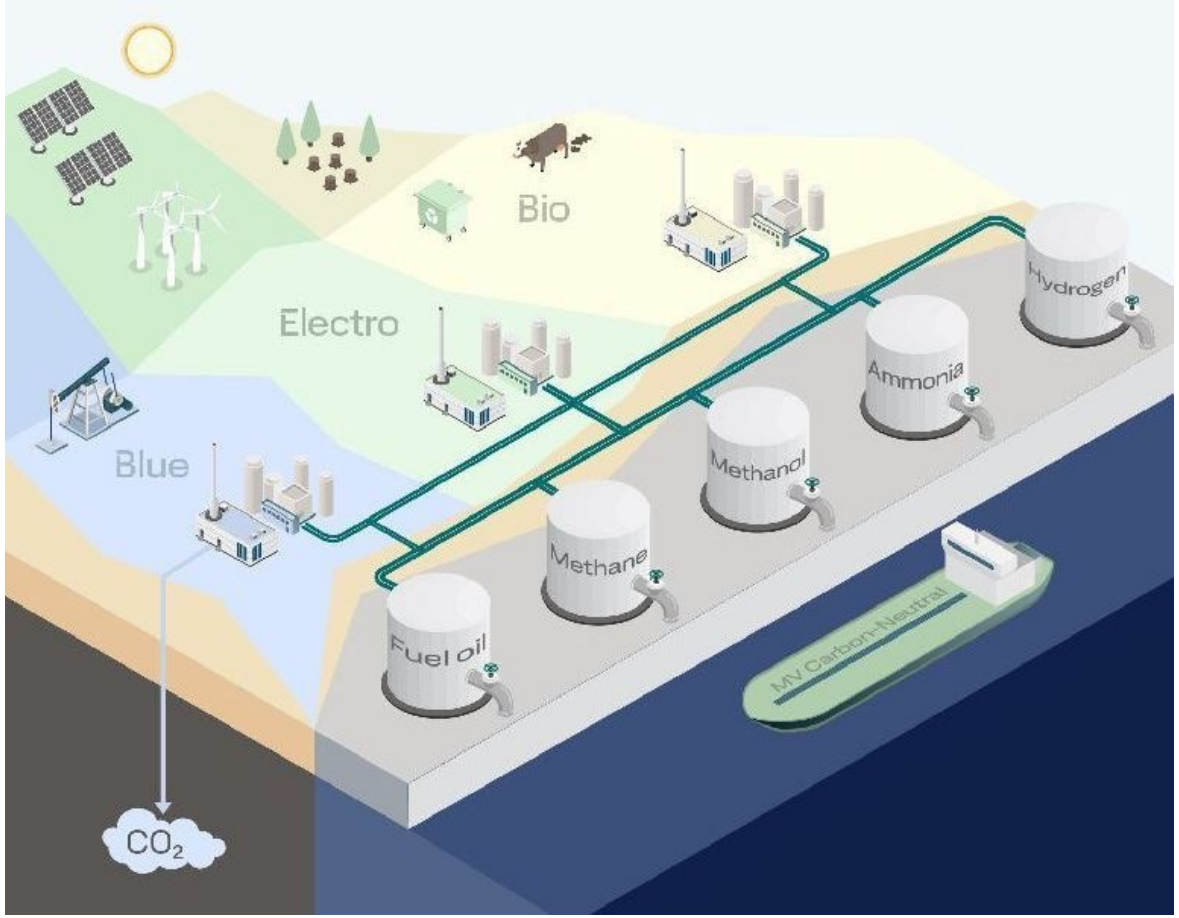
- Emissions that have not been covered by the company in question must be regularized in the following year with payment of an additional penalty.

- If the transport company does not comply with the norm for two years in a row, it may be subject to an expulsion order from the member countries until it regularizes its situation.

Source: The Inclusion of Shipping in the EU ETS. Link: https://www.hecla-em.co/post/the-inclusion-of-shipping-in-the-eu-ets.

Alternative Energy Sources

- There are several types of fuel that are candidates for adoption as clean energy sources.
- Each fuel's GHG footprint must also be analysed in relation to its manufacturing process (i.e., "well-to-wake").
- Each candidate source has its scaling peculiarities and challenges.



Figure's source: Future Fuels, DNV. Link: https://www.dnv.com/maritime/hub/decarbonize-shipping/fuels/future-fuels.html.

Adoption and Availability Uncertainties

- Public policies:
  - How to avoid the adoption of clean sources stagnates due to lack of competitiveness in relation to carbon-based alternatives?
  - To what extent should these sources be subsidized to become competitive?
  - Example: Marginal abatement cost curves (MACCs) for assessing the role of market-based measures (MBMs) in enhancing the adoption of alternative marine fuels | Research Square.*

- Interaction between supply and demand:
  - How to resolve the impasse between supply and demand for new energy sources?
  - Example: The Next Wave: Green Corridors (energy-transitions.org).*

- Design and specification of new vessels:
  - How to select the energy source to be included in new vessels?
  - How to address clean energy sources during design phase?
  - How to make vessels more flexible to allow for future renovations with cleaner fuels?
  - Example: Optimal ship lifetime fuel and power system selection – ScienceDirect.

*Not peer-reviewed.

Conclusion

- Strategies to reduce greenhouse gases translates into a series of short and medium term regulations coming from global (IMO) and regional (EU) venues.

- Regulations should continue to undergo changes and adjustments as climate and political scenarios develop over the coming years and decades.

- Despite this, the long-term path to full decarbonization still faces a series of uncertainties.