The Net-Zero Challenge

Converting the Burden into Opportunity

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Executive Summary

The decarbonization of shipping is no longer optional—it is mandated, monitored, and monetized under international (MEPC 83) and regional (EU ETS) regulatory frameworks. These new rules introduce steep penalties for non-compliance and create a **carbon cost** that directly affects vessel profitability. IMO MEPC 83 enforces fuel lifecycle emissions targets that tighten progressively through 2050, while the EU ETS imposes carbon pricing for voyages involving EU ports. Technology and alternative fuels —though critical for long-term change— are not yet mature, scalable, or cost-effective enough to close the compliance gap under real-world operating conditions.

In this transitioning regulatory and financial landscape, carbon markets have emerged as both a liability and an opportunity. Strategic use of allowances and credits can mitigate exposure and unlock profits, but requires dynamic planning and active risk management. Static compliance strategies or late action will expose shipowners to financial deterioration and operational constraints.

HHX.blue, in partnership with KarbonX, provides an integrated Net-Zero solution, combining a dynamic emissions and investment modeling, based on timely procurement of allowances, and effective carbon credit hedging. This transforms regulatory pressure into a structured and budgeted competitive advantage supporting compliance, enabling strategic fleet planning, and improving negotiation positions across the value chain. Embracing this proactive approach positions shipping companies for sustainable growth in a carbon-constrained future.

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At the global level, the International Maritime Organization (IMO) introduced the MEPC 83 Net-Zero Framework, setting progressive targets and clear mechanisms designed to drive international shipping toward net-zero greenhouse gas emissions by 2050 (see Figure 1). Simultaneously, the European Union (EU) has incorporated maritime transport into its Emissions Trading System (EU ETS), making ships directly accountable for their CO_2 emissions within European waters starting in 2024. These regimes overlap in scope and impact, creating a complex compliance landscape for ship owners and operators. This section provides a clear, business-oriented breakdown of how each regulation is applied in practice, covering their scope, key metrics, reporting requirements and annual com-pliance procedures. We also illustrate examples of compliance scenarios and examine the interplay between the two systems to help stakeholders understand how they converge and differ.

1 What are the implications of MEPC 83 regulations?

The IMO's Net-Zero Framework introduces a GHG Fuel Intensity (GFI) mechanism applicable to virtually all large ships engaged in international trade. Specifically, it will cover all ships above 5,000 gross tonnage (GT), consistent with the scope of IMO's data collection. Smaller vessels below 5,000 GT are not directly included in this scheme, for the moment, yet national initiatives are reasonably expected. This global measure applies irrespective of flag State or voyage route of every covered ship worldwide must comply once the framework enters into force (see Table 1); entrance into force is expected in 2026.

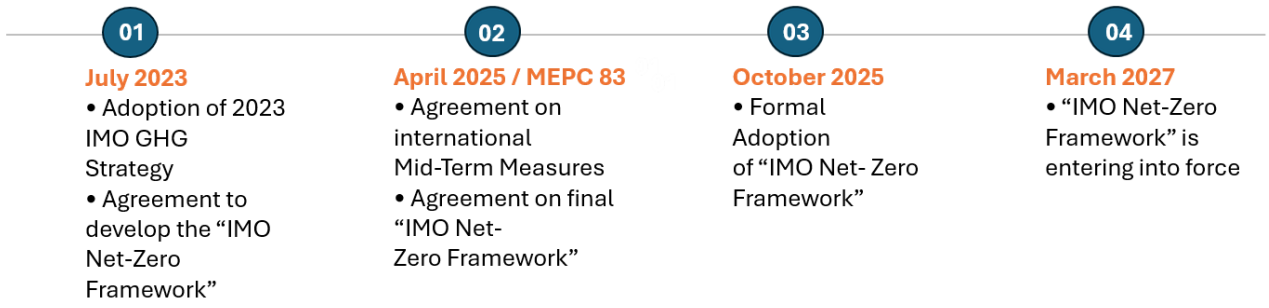

Figure 1: The expected evolution of the Net-Zero Regulation

The approach of the IMO is based on the carbon intensity of the ship's fuel (energy) use, measured in grams of carbon dioxide equivalent CO_{2eq} per MJ of energy ($\frac{gCO_{2eq}}{MJ}$). This is a well-to-wake (WtW) metric capturing full lifecycle GHG emissions. **In other words, it accounts not only for CO_2 emitted from the ship's funnel (tank-to-wake) but also emissions from fuel production and transport.** Each year, a ship will calculate its attained GFI for the year by dividing total GHG emissions (CO_2, and later potentially CH_4 and N_2O, converted to CO_{2eq}) by the total energy consumed (in MJ). The IMO has defined target intensity levels that become progressively stricter over time, expressed as a percentage reduction from a 2008 reference value of $\sim 93.9\frac{gCO_{2eq}}{MJ}$.

Ships already report fuel and CO_2 data annually to their flag State but with added requirements to determine WtW emissions; this suggest the reporting of data on fuel type and source, and the application of standard well-to-tank emission factors. Each ship's attained GFI is calculated and reported to a centralized IMO GFI Registry, a new platform that will manage compliance data and credit/unit transactions. Ships will be required to register an account by 1 October 2027 in this IMO GHG Registry to facilitate trading and compliance actions. Each year, the IMO sets two separate GHG GFI targets per ship type:

Year	GFI Target ($\frac{gCO_{2eq}}{MJ}$)	Reduction vs 2008 (%)
2008	93.9	-
2028	77.0	17%
2030	74.0	21%
2035	53.5	43%

Table 1: IMO MEPC 83 GFI Targets and Required Reductions (Baseline: 2008)

- Direct Compliance Target: The mandatory intensity level each ship must meet through operational and technical measures.
- Base Target: A secondary, less stringent reference level used to calculate penalties when the Direct Compliance Target is exceeded.

The regulation results in the following compliance scenarios (see Figure 1):

- **Compliant - Case A**: If the Attained GFI is equal to or lower than the Direct Compliance Target, the ship is fully compliant without any penalties.
- **Non-compliant (Tier 1 Penalty) - Case B**: If the Attained GFI exceeds the Direct Compliance Target but remains below the Base Target, the ship must buy Tier 1 Remedial Units at approximately \$100 per tonne CO_{2eq} to cover the excess emissions.
- **Non-compliant (Tier 2 Penalty) - Case C**: If the Attained GFI exceeds even the Base Target, the ship must buy:
  1. Tier 1 Remedial Units for emissions up to the Base Target (at \$100 per tonne CO_{2eq})
  2. Tier 2 Remedial Units for the additional excess beyond the Base Target (at \$380 per tonne CO_{2eq})

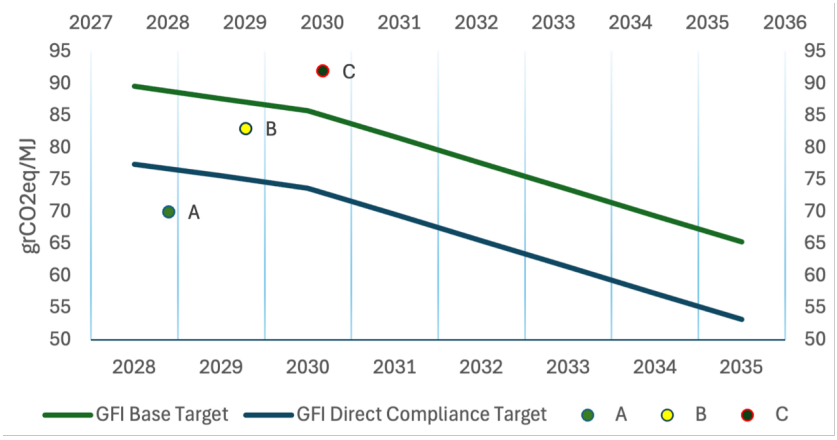

Figure 2: IMO GFI Targets (Base & Direct Compliance) and Compliance Scenarios for Three Vessels (A, B, C)

For the above three cases, Table 1 summarizes the estimated penalty for given cargo-ships. Apparently, the penalty depends on the operational plan of the vessel, yet it demonstrates the need to reassess current technology and operational options.

Ship	Year	Attained GFI ($\frac{gCO_{2eq}}{MJ}$)	Direct ($\frac{gCO_{2eq}}{MJ}$)	Base ($\frac{gCO_{2eq}}{MJ}$)	Compliance	Penalty ($)
Vessel A	2029	72	75.6	87.7	Compliant	-
Vessel B	2030	85	75.6	87.7	Tier 1 Penalty	$94,000
Vessel C	2031	88	65.5	77.0	Tier 2 Penalty	$340,000

Table 2: MEPC 83 GFI Compliance Examples and Penalty Calculations for Different Vessels

Key Takeaways:

- **Compliance measured annually using attained GFI versus IMO-set targets.** Each year, ships calculate their actual GFI and compare it against the mandatory IMO targets to ensure regulatory compliance.
- **Two compliance thresholds (Direct Compliance Target and Base Target).** IMO sets a strict 'Direct Compliance Target' for mandatory compliance, and a looser 'Base Target' to determine penalty severity.
- **Non-compliance incurs financial penalties calculated based on the gap between attained GFI and targets.** Penalties are proportional to the ship's GFI exceeding set targets, incentivizing proactive measures.
- **Tier 1 penalty applies moderate costs ($100 per tonne CO_{2eq}) for moderate shortfalls.** Moderate non-compliance results in Tier 1 penalties, aimed at correcting minor deviations.
- **Tier 2 penalty imposes significantly higher costs ($380 per tonne CO_{2eq}) for severe shortfalls.** Severe non-compliance attracts substantially higher Tier 2 penalties, encouraging significant corrective action
- **Ships exceeding compliance targets generate tradable Flexible Compliance Units (FCUs).** Over-performing ships earn credits (FCUs), providing a financial incentive for reducing emissions beyond targets
- **Annual compliance reporting through the IMO GFI Registry.** Ships must annually report their GFI data into a centralized IMO platform, ensuring transparency and accountability.
- **Penalties fund IMO's global maritime decarbonization initiatives.** Funds collected through penalties support global projects aimed at decarbonizing the maritime industry, fostering long-term sustainability.

As a result, the MEPC 83 regulation fundamentally alters the operational and financial landscape of the shipping industry. By enforcing annual GHG Fuel Intensity (GFI) targets and introducing severe financial penalties—ranging from $100 to $480 per tonne CO_{2eq} for non compliance, it directly links emissions performance to a ship's profit-and-loss statement. **This requires shipowners to shift from simply monitoring emissions to actively managing and hedging their carbon exposure.** Daily operations, including routing, speed, and fuel selection, are now subject to emissions scrutiny. Financial planning must integrate projected carbon liabilities into chartering decisions, cost estimations, and long-term capital investments. Importantly, compliance cannot be achieved through operational and technical adjustments alone under normal conditions. Ships like Vessel A (compliant) must compensate for underperformers like Vessel C (Tier 2 penalty), either internally or through pooled asset strategies—favoring larger fleets or consortiums with deep capital reserves. The new interna-

tional regulation mandates the consideration of following in the decision-making:

High penalty risk : Up to \$480/t CO_{2eq} for MEPC 83 violations, plus €100/t CO_{2eq} for EU ETS

Insufficient technical means : Operational efficiency and current technology alone cannot ensure compliance across a full fleet.

Cross-subsidization required : Efficient ships must compensate for less efficient ones benefiting owners with larger fleets.

Strategic pooling : Smaller fleet owners may need to join consortiums or engage in internal carbon credit exchanges.

Alignment with EU legislation : MEPC 83 is streamlined with FuelEU Maritime and the Fit for 55 package, which also demand lifecycle GHG reduction and incentivize carbon pooling strategies across Europe[1].

2 Why can't technology and fuels alone address MEPC 83 challenges?

Despite advancements in alternative fuels and energy-efficiency devices (EEDs), these solutions cannot, alone, close the compliance gap in the short to medium term. Fuels like ammonia and hydrogen are still in the pilot stage, with unresolved safety, supply, and infrastructure concerns. Technologies such as rotor sails or air lubrication deliver at most 16% efficiency gains, far below the 43% GFI reduction required by 2035. Even biofuels, the most mature low-carbon fuel, face storage stability, microbial growth, and global availability issues. Retrofitting or ordering new builds that rely on these immature technologies poses high financial and operational risks. As a result, full compliance through technology is currently not viable for most shipowners.

[1] see EU Fit for 55 overview

Technology	**Pros**	**Cons**
Ammonia (NH_3)	zero CO_2 emissions	highly toxic and corrosive
	potential long-term solution	immature technology
	no carbon content	no bunkering available
Hydrogen (H_2)	zero emissions	high explosion risks
	potential for zero-carbon lifecycle with green production	very low energy density
		requires cryogenic storage
		no bunkering available
Methanol (CH_3OH)	lower emissions than oil	corrosive and toxic
	existing dual-fuel engines proven operational safety	higher cost than conventional fuel
		limited global supply and availability
Biofuels (FAME/HVO)	drop-in compatibility with existing engines high lifecycle GHG savings (up to 84%); established handling infrastructure	storage stability issues (FAME)
		microbial growth risk
		higher fuel cost
Liquefied Natural Gas (LNG)	extensive global infrastructure	still fossil
	widely adopted, mature technology significantly reduced SO_x, NO_x, and particulate emissions	based with methane slip issues
	moderate CO_2 savings ($\sim$ 20% vs HFO)	cryogenic storage complexity
		long-term regulatory risks due to methane emissions
Energy-Efficiency Devices (EEDs)	immediate fuel/emission savings (4-16%)	variable and condition-dependent efficiency
	universally applicable	integration and operational complexity
	retrofittable	uncertain real-world performance
	no new fuel infrastructure needed	limited standalone compliance potential
Nuclear Propulsion (SMRs)	zero operational emissions	extremely long refueling intervals high energy density
	potential for near-zero fuel cost	immense safety and regulatory hurdles complex operational requirements
		no existing maritime nuclear infrastructure
		significant public acceptance and liability concerns
		distant commercial readiness (decades)

So, one should remember:

Immature technology : Ammonia and hydrogen engines not commercially ready before 2026–27.

Insufficient reductions : Even combined EEDs deliver only 4–16% efficiency gains—far be-

low regulatory targets.

Fuel supply and infrastructure : Global bunkering and supply chains for green fuels are not yet in place.

Fuel prices : The fuel price of the new fuel alternatives is expected to be a multiple of current oil prices, even after 2035.

High risk of stranded assets : Premature investment may result in non-compliant, obsolete, or fuel-incompatible vessels.

Economic viability : High fuel and retrofitting costs not justified under current market and chartering conditions.

Conclusion: Current technology is not sufficient. New fuels are not market-ready and their cost per energy unit is currently unknown but definitely higher than oil. **The higher cost of investment for the new technology assets and the higher cost of fuel is expected to be higher than that of a conventional ship that offsets the regulation with market-based instruments.**

3 How do carbon markets work?

Carbon markets allow emitters to buy and sell emissions allowances or credits. New regulations have introduced a market-oriented vocabulary in maritime shipping, with two distinct carbon markets emerging. Cap-and-trade systems like the EU-ETS issue a limited number of allowances (EUAs), which decrease annually by $\sim 4.3 - 5\%$, raising scarcity and prices over time. Companies must surrender allowances equal to their emissions or face financial penalties. Allowances can be traded on spot or futures markets. Remedial Units (RUs) under MEPC 83 work differently—they're fixed-price credits (USD100–380/t CO_{2eq}) issued to compensate for GFI shortfalls, not tradable in open markets. The combination of market-based (EUAs) and semi-fixed (RUs) compliance tools forces strategic planning.

These developments position carbon compliance as a strategic consideration, directly influencing chartering decisions, fuel sourcing, financial planning, and creditworthiness. By 2030, regulatory frameworks (IMO MEPC 83 and EU ETS/FuelEU) may align, standardizing MRV processes, accounting methods, and credit systems. Unified reporting and interchangeable credits could simplify compliance, reducing administrative burdens and creating a more integrated global carbon market for shipping. Ultimately, carbon compliance is becoming unavoidable in global shipping, transforming regulatory burdens into integral drivers of long-term competitiveness. In few words, the vocabulary of the market includes the following:

Cap-and-trade model : Emitters must buy allowances equal to emissions; prices set by market supply and demand.

EU ETS reduction factor : Annual cap decreases by $\sim 4.3 - 5\%$, tightening supply[2].

Penalties for non-compliance : €100/t CO_{2eq} plus purchase of missing EUAs.

MEPC 83 units (RUs) : Not traded but purchased at fixed prices to cover shortfalls: Tier 1 ($100), Tier 2 ($380).

Global markets : Japan, Korea, Shanghai, Brazil emerging; future links could allow arbitrage and global strategies.

[2] see, e.g., EU ETS emissions cap

Important Development: Carbon allowance are the new assets of liquidity. **Should one fail to comply or practively meet the targets, then the penalty will drain profits, liquidity, and possibly solvency.** Should one succeed, extraordinary profits can be harnessed besides achieving compliance and reaching net-zero targets.

4 Why is dynamic carbon strategy essential?

Carbon markets are volatile and increasingly influential in shipping economics. As supply of allowances tightens—like the EU-ETS's confirmed 4.3% annual linear reduction factor[3], prices will rise and fluctuate. When shipping fully integrates into global and regional carbon schemes (e.g., Brazil, Shanghai, Japan, South Korea), arbitrage opportunities will emerge. Dynamic, rather than static, strategies in acquiring and trading carbon rights enable shipowners to hedge cost effectively and gain time for technological maturation. Static, *buy-and-hold* approaches risk overpaying or under-hedging during volatile market phases. **Like equity markets, successful carbon exposure management requires continuous rebalancing and targeted not opportunistic trading.**

Price volatility : Carbon prices are expected to rise sharply with growing demand from shipping, aviation, and heavy industries.

Regulatory divergence and links : Emerging regional schemes will create arbitrage opportunities, requiring active engagement.

Dynamic trading beats static hedging : Adapting to daily and cyclical changes can optimize cost and compliance.

Market analogy : Similar to stock trading, success lies in portfolio timing and flexibility, not passive holding.

Lessons learned from other markets: A dynamic strategy is necessary when prices are volatile. It is not possible to keep on ignoring the fluctuations of compliance cost and penlaties (i.e., of RUs). The understanding and management of the risk (fluctuation) of compliance (RUs) implies successful financial results, as in the case of the fluctuating charter rates and assets values. **Sophisticated carbon risk management is required, as it impacts all parameters of decision-making**.

5 Strategic Advice from HHX and its Partners

HHX, in collaboration with KarbonX, offers a comprehensive Net-Zero strategy that combines technical expertise with financial innovation. Through DSC and MRV-based carbon exposure modeling, early EUA procurement, and access to high-quality carbon credits at USD25–30/t CO_2, HHX helps shipowners ensure compliance while protecting against cost volatility. **Our approach transforms carbon compliance from a cost center into a competitive asset.** By stabilizing carbon budgets, HHX enables shipowners to negotiate better charter terms and investment financing. HHX also supports fleet renewal, retrofits, and access to capital, ensuring flexibility in a dynamic regulatory environment.

In a nutshell:

Carbon exposure modeling : Forecasts liabilities to 2030-40-50 for strategic planning

[3] source

Dynamic hedging : Carbon credits secured at lower levels of USD/tCO_2 versus spot and penalty prices of USD100 and 380/t CO_2

KarbonX partnership : Access to competitive carbon credits across global markets.

Fleet renewal support : HHX advises on retrofits and technology investments tied to future regulations.

Capital access : HHX facilitates funding for large-scale decarbonization projects.

Negotiation leverage : Carbon strategy becomes a financial asset when dealing with charterers and stakeholders.

What is the first step?

⇒ **Audit Your Fleet's Energy and Carbon Profile:** Conduct technical assessments (EEXI/CII, fuel readiness) and prepare for disclosure obligations under SFDR and CSRD[4].

⇒ **Review Your Finance Strategy:** Check whether your existing facilities allow transition-linked incentives or could be restructured under green terms.

⇒ **Engage Proactively:** Most regulatory pressure is front-loaded in Europe, but global alignment (e.g., IMO MEPC 83 on energy efficiency) is tightening the net.

⇒ **Play the Market:** Develop a carbon-strategy that enables compliance at a lower than the market cost of allowance and harness profits with timely budgeted solutions.

Final Word: At HHX, we see too many stakeholders underestimating how fast finance is changing. This is not only a compliance matter; **it is a competitive issue**. Sustainable and carbon-linked finance is becoming the gatekeeper to growth, liquidity, and reputation. **Oil-fueled marine operations must be financially offset to meet regulatory demands, but offer unmatched flexibility and a strong resale market advantages for the ships that vessels using emerging fuels and technologies currently lack.** HHX can support this option too.

[4]This is an important requirement for EU-sourced finance; SFDR, Regulation (EU) 2019/2088 and Directive (EU) 2022/2464 - CSRD

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