FROM COMPLIANCE TO PERFORMANCE:

A Practical **Low-Emission Framework for Large Yachts**

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1 Objective

The yachting sector is entering a period of accelerating environmental change, driven by regulation, owner expectations, technology and public scrutiny, which are collectively reshaping how large yachts are designed, operated, maintained and managed. While commercial shipping has already established structured pathways towards lower-emission solutions, the large yacht sector remains considerably more heterogeneous. Differences in operational profiles, ownership models, vessel sizes, regulatory applicability and technical constraints mean that solutions developed for merchant shipping cannot simply be transferred to yachts. As a result, owners, managers, shipyards, designers and technical service providers are left with a practical question: Where should lower-emission efforts begin?

This publication proposes that a successful transition to low-carbon operations should not begin with selecting technologies or alternative fuels. Instead, it should begin with understanding the yacht's energy profile, whether measured in service or predicted at the design stage. For most yachts, the greatest opportunities for emission reduction follow a structured sequence of actions, as shown in Figure 1. The sequence reflects a fundamental engineering principle: energy that is not consumed does not need to be replaced with lower-emission alternatives.

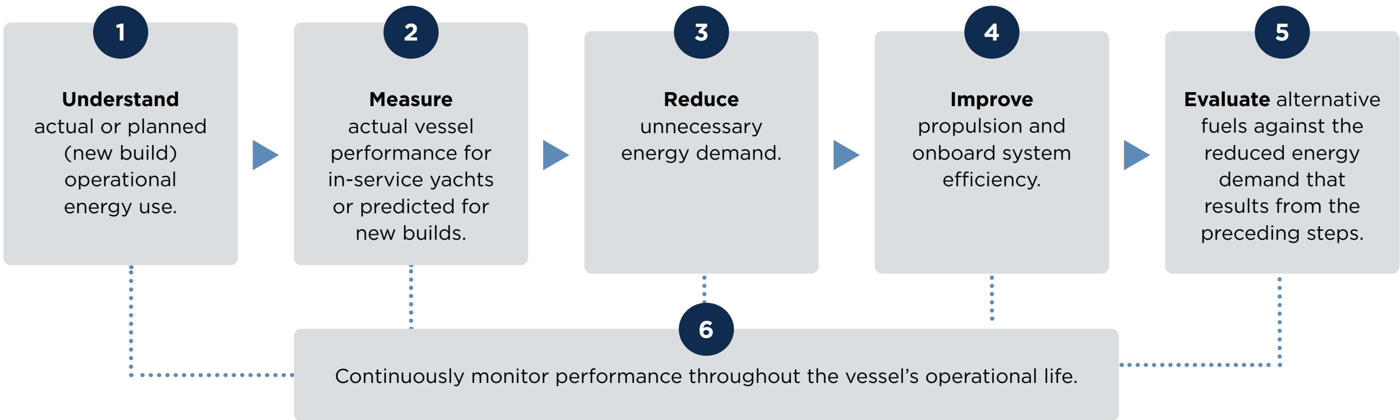


Figure 1: Recommended sequence of emission reduction actions.

A further challenge this publication addresses is the widespread misunderstanding of regulatory applicability. Industry discussions often combine International Maritime Organization (IMO) regulations, European Union (EU) legislation, class requirements, flag State obligations and voluntary initiatives without distinguishing their respective legal status or applicability to different categories of yachts. This can result in uncertainty regarding current obligations and future preparedness. The publication discusses each within the appropriate context and identifies practical actions that remain beneficial regardless of future regulatory developments.

This publication recognizes that no single technology or fuel provides a universal solution for all yachts and that fuel and technology selections should always follow a vessel-specific assessment. One recurring finding is that a yacht's operating profile (stationary for most of the year) often favors alternative energy carriers sized to hotel load rather than propulsion, a pattern that differs materially from how fuel transition is typically framed for commercial shipping. It presents a staged roadmap that treats emission reduction as a continuous engineering and decision-making process rather than a single technology purchase. Such an approach enables owners and operators to reduce emissions while maintaining operational flexibility and preparing for an evolving regulatory and commercial landscape.

2 Introduction

2.1 Scope and Sector Context

There is no single universally agreed definition of a large yacht or superyacht. For this publication, the terms large yacht and superyacht generally denote motor and sailing yachts 24 meters (m) and above in length used for sport or pleasure, in private or commercial operation, with the majority of the analysis focused on the fleet above 30 m, for which more consistent market data[1] and environmental performance methodologies are available[2]. This publication covers private and charter motor yachts, sailing yachts, explorer yachts and their support vessels. The primary focus is greenhouse gas emissions from operations, with a secondary treatment of life-cycle emissions. Other environmental impacts, including underwater radiated noise, wastewater, antifouling, anchoring and biodiversity, fall outside the scope of this document.

As of 2025, more than 6,000 yachts above 30 m were reported to be in operation, and 588 yachts over 30 m were reported to be in build. Motor yachts account for most of the fleet in operation and the yachts in build, as shown in Figure 2. Over the last five years, approximately 184 new yachts in this size range have been completed annually, representing an estimated €4.5 billion in newbuild value per year, and more than 2,000 were reportedly available for charter[1]. These figures indicate both the scale of the existing fleet and the continued addition of long-lived assets whose energy performance may remain relevant for several decades.

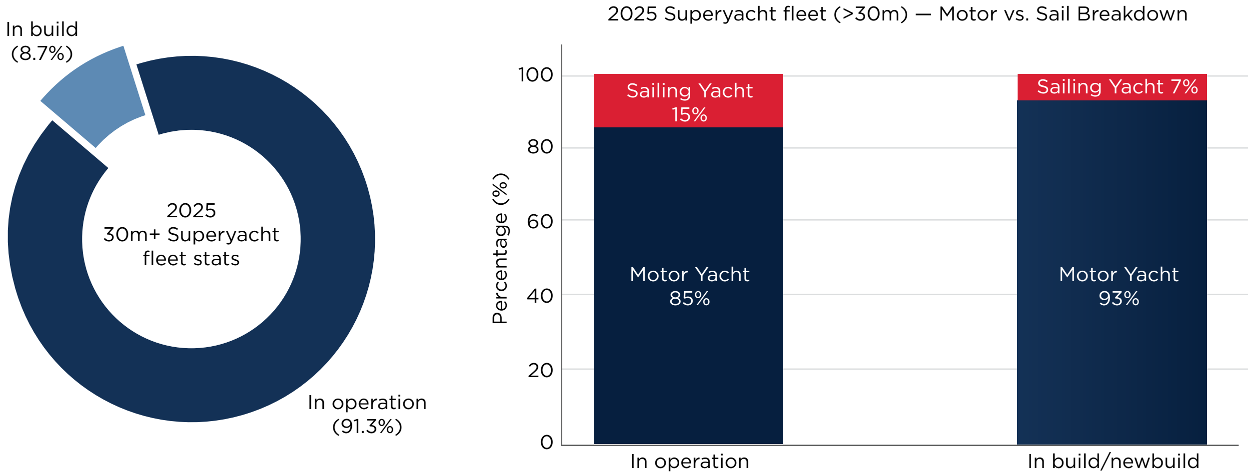


Figure 2: Yachts in build and in operation over 30 m, 2025[1].

2.2 Measurement as the Starting Point

The yacht sector's emission challenge is not only a question of total emissions. It is also a question of energy-use structure, data quality and measurement.

A yacht uses energy in a pattern shaped by onboard comfort rather than by transport work, and the tools the wider industry uses to assess ships are not built to describe that pattern. Emissions estimates are scattered and not comparable. A sector that cannot measure its performance consistently cannot reliably manage it, compare improvement options, substantiate environmental claims or prepare for possible future reporting requirements. For this reason, the framework presented treats measurement as the first lever rather than a preliminary to the real work. Section 3 examines the structure and the resulting measurement gap.

2.3 Strategic Readiness

Design and refit decisions remain in effect for decades, while the conditions that shape them change within a few years. Concept design, machinery selection and major refit can influence energy demand, fuel compatibility and emissions beyond the immediate ownership period. A yacht delivered today will operate under regulations, fuel supply conditions and reporting expectations that are not yet settled. Readiness therefore describes the ability to make decisions that hold as those conditions change, rather than a commitment to a particular technology or fuel. Figure 3 lays out the two pillars of readiness.

This mismatch needs to be addressed through a structured sequence. That sequence begins with the distinctive energy and emissions profile of large yachts, moves to regulatory applicability, then to reducing avoidable energy demand, and finally to the role of alternative fuels. A closing roadmap turns this into a project: what to establish at each stage and how to verify the result. The aim throughout is to support vessel-specific decisions (technically credible, measurable and adaptable) as operating requirements, regulation and energy markets evolve.

Design and refit decisions hold for decades. Regulation, fuel markets and reporting rules do not.
Readiness means making decisions that hold as conditions change, not committing to one technology or fuel.

PILLAR ONE
Regulatory Readiness

- No single test determines applicability. Criteria combine gross tonnage (gt), statutory ship type, voyage pattern, commercial carriage, and port calls.
- A yacht may fall inside one measure and outside another, and its position can change when the operating pattern changes.
- Readiness is establishing the vessel's actual position, not assuming universal inclusion or permanent exemption.

PILLAR TWO
Fuel Supply Readiness

- Fuel availability differs between regions and between ports within a region. Supply is not uniform.
- Engine, tank, and fuel-system design are fixed at newbuild or major refit, committed against a supply picture that may shift within the vessel's service life.
- Readiness means understanding what a design leaves possible, including the space, structural, and electrical provision for later conversion, not the fuel selected today.

Figure 3: Strategic readiness for design and refit decisions under evolving dimensions, including regulatory requirements and fuel conditions.

3 Understanding Energy Profile of Large Yachts

3.1 How Yachts Differ from Commercial Shipping

A yacht's emission problem does not resemble that of a cargo ship. In commercial shipping, emissions are evaluated by transport work, meaning cargo moved over distance, and the efficiency measures governing the sector express carbon intensity as emissions per unit of cargo carried over distance[3]. A yacht produces no transport work in that sense, so design-efficiency metrics built around cargo carried per mile map poorly onto it.

Utilization differs as sharply as function. In the Fourth IMO Greenhouse Gas (GHG) Study's 2018 fleet analysis, covering ships of 100 gt and above, the largest bulk carriers averaged 252 to 258 days at sea per year and large containerships up to 261 days, roughly 70 percent of the year underway[4]. The same analysis puts the average yacht (100 gt and above) at 78 days at sea per year, approximately 21 percent. A second and narrower measure, the operational profile underpinning ISO/TS 23099, counts cruising only rather than days at sea and fixes 10 percent of the year underway for large yachts specifically[2]. Figure 4 compares these values.

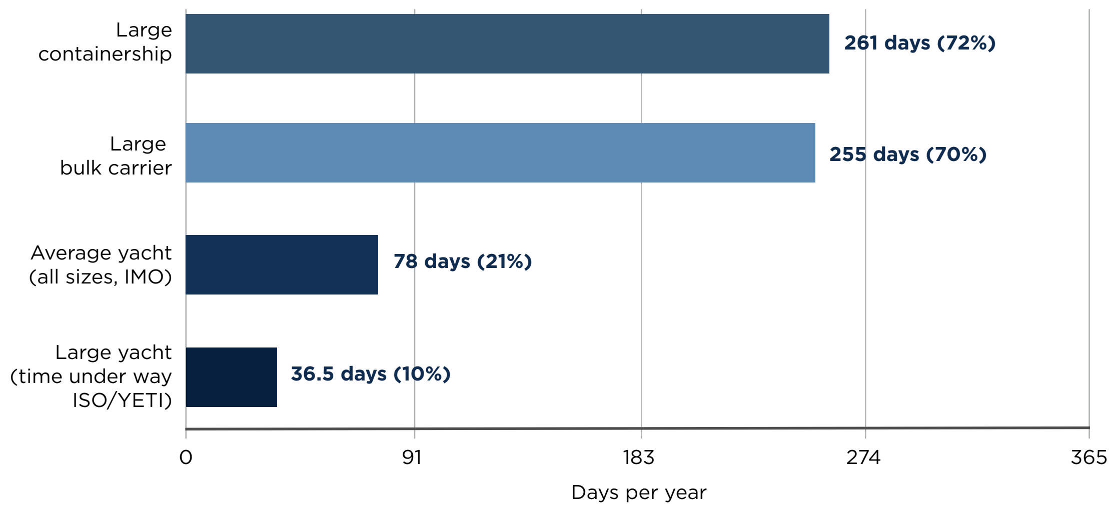


Figure 4: Annual utilization comparison[2, 4].

The consequence is structural. A yacht is under engine power for a small fraction of the year yet may consume energy continuously, so auxiliary and hotel demand can represent a material share of annual energy use. The ISO/TS 23099 states that propulsion typically accounts for approximately half of a yacht's annual energy use and hotel power for the other half, while noting in the same document that hotel power calculations are highly subjective and traditionally inaccurate[2]. A merchant ship presents the opposite profile, with main-engine propulsion representing the overwhelming share of fuel consumption and auxiliary demand a minor fraction[4].

3.2 The Operational Profile of a Yacht

Conventional efficiency instruments take the voyage as the unit of analysis. The Yacht Environmental Transparency Index (YETI) joint industry project was established on the position that this does not capture the operational characteristics of large yachts, and a standardized operational profile was developed so that yachts could be assessed against how they are used[5]. The ISO/TS 23099 adopts that profile, noting that the Energy Efficiency Design Index (EEDI) methodology presumes continuous movement while a yacht spends approximately 90 percent of its operational time at anchor or in harbor, and that the energy consumed during those stationary periods cannot be neglected[2].

The underlying study analyzed Automatic Identification System (AIS) data from 130 yachts of varying type, make and age. After excluding incomplete and unrepresentative datasets, a refined set of 109 yachts over 35 m covering 297 yacht-years between 2015 and 2020 produced the profile, which is published by the Water Revolution Foundation and referenced in ISO/TS 23099[2, 5]. It reports that a large yacht is underway 10 percent of the year and stationary for 90 percent, of which 56 percent is in port and 34 percent at anchor, as shown in Figure 5.

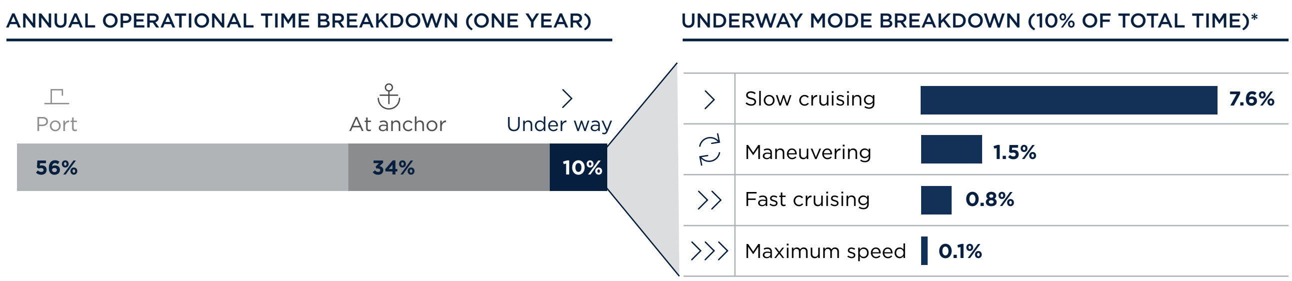


Figure 5: Annual operational profile of a large yacht[5].

Reported variation: under way 10% ± 5, in port 56% ± 18. Time at anchor is derived as the remainder, not measured directly.

**Shares of the full year. The four modes sum to the 10% under way.*

The profile covers time rather than energy. It reports the split between moving and stationary time and the speeds while moving, drawn from AIS records, which show where a yacht is but not what it consumes on board. It is also a fleet average rather than the behavior of an individual yacht, since itinerary, climate, charter activity, speed, shore-power access and owner use vary materially. What it establishes is that stationary systems run for most of the year, which is why stationary energy demand cannot be treated as secondary.

Reported variance is wide. Time underway averages 10 percent with a standard deviation of 5 percent, and time in port averages 56 percent with a standard deviation of 18 percent. Time at anchor is derived as the remainder rather than measured directly, and a single profile was applied across all yacht types[5].

3.3 The Measurement Gap

Unlike commercial vessels, a yacht may spend most of the year without producing transport work while continuing to supply accommodation, ventilation, cooling, lighting, refrigeration, entertainment, water production and other onboard services. Consequently, annual fuel consumption alone is insufficient to describe yacht performance. A low annual total may reflect limited use rather than an efficient vessel, while a frequently operated yacht may consume more fuel despite having comparatively efficient systems. Propulsion intensity expressed only per nautical mile also provides an incomplete picture because it does not capture the energy consumed at berth or anchor. The relevant assessment boundary might therefore include propulsion, hotel and auxiliary demand, operating mode, shore electricity and the efficiency with which energy is produced and distributed on board.

Commercial shipping's measurement architecture has been built out progressively since 2013 through the EEDI for new ships, the IMO Data Collection System (DCS) for fuel oil consumption reporting and, from January 1, 2023, the Energy Efficiency Existing Ship Index (EEXI) and the Carbon Intensity Indicator (CII)[6, 7]. Most large yachts sit outside the design and operational indices for the reason set out in Section 4.2, namely that those instruments are keyed to a list of ship types that does not include yachts.

The data that architecture generates for the commercial fleet therefore has no yacht equivalent, and the sector has little comparable information to work from. The industry's benchmarking work shows how thin the record is, since electrical load balances are typically theoretical rather than measured, with very little monitoring data available from real hotel loads. A yacht passes through almost none of the standard measurement points that generate comparable data for the commercial fleet, so even its largest energy demands rest more on assumption than on record[2].

Voluntary frameworks have begun to close this gap by giving the sector a common way to measure and compare. Section 4.5 goes more in depth on these frameworks.

4 Regulatory Applicability and Emerging Requirements

4.1 Why Regulatory Applicability is Often Misunderstood

Large yachts sit between two regulatory worlds. They may be privately used or commercially chartered, certified for no more than 12 passengers or built as passenger yachts, and range from less than 400 gt to well above 5,000 gt. The instruments affecting them are equally heterogeneous, and each carries its own thresholds, ship-type filters and activity tests. None of the individual thresholds or categories described in this section is new; flag Administrations, classification societies and other stakeholders already work with them daily. What is less consistently available is a single, vessel-category-specific statement of how they combine and where they are most often misapplied to yachts specifically. Figure 6 sets out three shortcuts that account for most errors.

Why regulatory applicability is often misunderstood
Three shortcuts account for most errors

THE SHORTCUT *"400 gt is a universal climate threshold."*	**THE SHORTCUT** *"Private or commercial use decides every instrument."*	**THE SHORTCUT** *"Passenger count settles statutory ship type."*
WHAT APPLIES It governs Annex VI survey and certification, and the broad application of chapter 4. Individual obligations within that chapter carry narrower thresholds and ship-type conditions.	**WHAT APPLIES** It is central to the EU measures, meaning monitoring, reporting and verification (MRV), Emissions Trading System (ETS) and FuelEU Maritime, but private use does not generally remove a yacht from MARPOL Annex VI.	**WHAT APPLIES** More than 12 passengers makes a vessel a passenger ship under SOLAS, without resolving its category under MARPOL Annex VI.

Applicability is documented vessel by vessel, not inferred from sector labels such as superyacht, private yacht or commercial yacht.

Figure 6: Common misunderstanding of regulatory applicability and what applies[8, 9].

The result is that a yacht may be subject to Annex VI fuel and engine requirements, carry an International Air Pollution Prevention certificate and a Ship Energy Efficiency Management Plan (SEEMP), yet remain outside EEXI or CII because the vessel does not fall within one of the ship categories defined for the relevant MARPOL efficiency requirement. A very large commercially operated passenger yacht calling at European ports may enter the EU monitoring, carbon-pricing and fuel-intensity regimes. Applicability is therefore documented vessel by vessel.

4.2 The Four Applicability Tests

For practical screening, applicability can be assessed through the questions in Table 1 on the following page. The first three describe the vessel, the fourth describes the voyage. Instrument-specific exemptions and definitions are considered only after these facts are established.

1 STATUTORY SHIP TYPE

How is the vessel recorded on its statutory certificates and by its Administration?

Yacht is not itself a listed MARPOL efficiency category.

2 GROSS TONNAGE

Is the yacht below 400 gt, 400 to 4,999 gt, or 5,000 gt and above?

The principal breaks fall at 400 gt and 5,000 gt.

3 NATURE OF OPERATION

Is the yacht used privately, in commercial use, or engaged in commercial passenger transport?

Commercial registration alone does not settle the activity test.

4 GEOGRAPHIC SCOPE

Does the yacht operate internationally, solely in flag-State waters, in an ECA or EU ports?

The only test that describes the voyage, and it reaches every tonnage.

The four tests are applied together rather than in sequence, since each instrument sets its own combination of them and passes any condition it does not set. A yacht may satisfy one test and fail another, so the same four facts produce a different answer for each instrument.

Figure 7: Regulatory Applicability Screening Tests for Large Yachts.

Decision rule: Applicability should not be assessed by asking "Does this apply to yachts?" Instead, the assessment should begin with the yacht's certificates, gt, operating model and voyage pattern, and evaluate those characteristics against the criteria of each instrument. Final determinations should be confirmed with the flag Administration, recognized organization/class society and, for EU measures, the responsible verifier or administering authority. Table 1 sets out which conditions apply to each instrument.

4.3 Current Regulatory Position

The instruments below are separated because they regulate different things. The EU MRV measures emissions, the EU ETS prices covered emissions, FuelEU Maritime regulates energy GHG intensity and MARPOL Annex VI combines air-pollution controls with global ship efficiency requirements. Table 1 summarizes the tonnage, ship-type and activity conditions under which each applies.

Regulatory Applicability Summary for Large Yachts

High-level screening of key IMO and EU regulations for yachts ≥ 400 gt.

- ✅ Generally applicable
- ❗ Conditionally applicable
- ❌ Generally not applicable

Regulation/Instrument	What It Regulates	Thresholds and Key Determinants for Yachts	Applicability (≥ 400 gt)	Primary References
IMO INSTRUMENTS *Global application*				
MARPOL Annex VI Air Pollution	Limits on sulphur oxides, nitrogen oxides and particulate matter, with an IAPP Certificate required.	• All ships, with survey and certification from 400 gt • Engine power output • Operation in emission control areas	✅ IAPP Certificate carried	MARPOL Annex VI Reg. 13, 14; Reg. 5, 6
MARPOL Annex VI Chapter 4 – Energy Efficiency	Energy-efficiency framework covering EEDI, EEXI, SEEMP, DCS and CII.	• 400 gt and above • Excluded where the yacht operates solely in flag-state waters • Diesel-electric, turbine and hybrid propulsion excluded from Reg. 22–25	❗ Each measure tested separately	MARPOL Annex VI Reg. 19; Res. MEPC.328 (76)
EEDI and EEXI	Design and technical efficiency indices for newbuilds and existing ships.	• Listed ship types only, by capacity band • "Yacht" is not a listed ship type • Applies only where the yacht is classed as a listed type	❌ Ship type is the deciding test	MARPOL Annex VI Reg. 22–25; Res. MEPC.364 (79), MEPC.350 (78)
SEEMP	Ship Energy Efficiency Management Plan, in three parts.	• Part I from 400 gt • Part II from 5,000 gt • Part III only where CII applies, so not for yachts	❗ Part I applies from 400 gt	MARPOL Annex VI Reg. 26; Res. MEPC.346 (78)
IMO DCS	Annual collection and reporting of fuel oil consumption data.	• 5,000 gt and above • No ship-type restriction, so yachts are in scope on tonnage alone	❗ Yes at 5,000 gt and above	MARPOL Annex VI Reg. 27; Res. MEPC.348 (78)
CII	Annual operational carbon intensity rating on an A to E scale.	• 5,000 gt and above, listed ship types only • "Yacht" is not among the listed categories • No reference line is defined for yachts	❗ Ship type is the deciding test	MARPOL Annex VI Reg. 28.1; Res. MEPC.352 (78)
EU INSTRUMENTS *EU and EEA ports and voyages*				
EU MRV	Monitoring, reporting and verification of greenhouse gas emissions.	• 5,000 gt and above • Carrying cargo or passengers for commercial purposes • The 400–5,000 gt band opened in 2025 covers general cargo and offshore ships only	❗ Commercial activity is the deciding test	Reg. (EU) 2015/757, Art. 2, as amended by Reg. (EU) 2023/957
EU ETS	Emissions trading covering CO_2, CH_4 and N_2O.	• 5,000 gt and above, cargo and passenger ships • All intra-EU emissions and half of extra-EU emissions • Inclusion of 400–5,000 gt ships under review to 31 December 2026	❗ Commercial activity is the deciding test	Directive 2003/87/EC Annex I and Art. 3gg (5), as amended by Directive (EU) 2023/959
FuelEU Maritime	Greenhouse gas intensity standard for energy used on board.	• Above 5,000 gt • Serving the purpose of transporting passengers or cargo for commercial purposes • Covers energy used at berth in EU ports	❗ Commercial activity is the deciding test	Reg. (EU) 2023/1805, Art. 2

Note: This table provides a high-level screening only. Applicability depends on vessel-specific facts, classification society requirements and flag State interpretation.

Table 1: Scope and applicability criteria of key IMO and EU emissions regulations for large yachts.

4.4 Emerging Regulatory Developments

The 2023 IMO GHG Strategy sets sector-wide ambitions rather than yacht-level obligations, indicating the direction of future regulation without requiring an individual yacht to meet any of its levels[10]. The pending IMO Net-Zero Framework (NZF) combines a GHG-intensity standard with an emissions-pricing mechanism and is directed at oceangoing ships greater than 5,000 gt. Its progress, and the EU review of the 400 to 4,999 gt band, are presented in Figure 8[11, 12, 13].

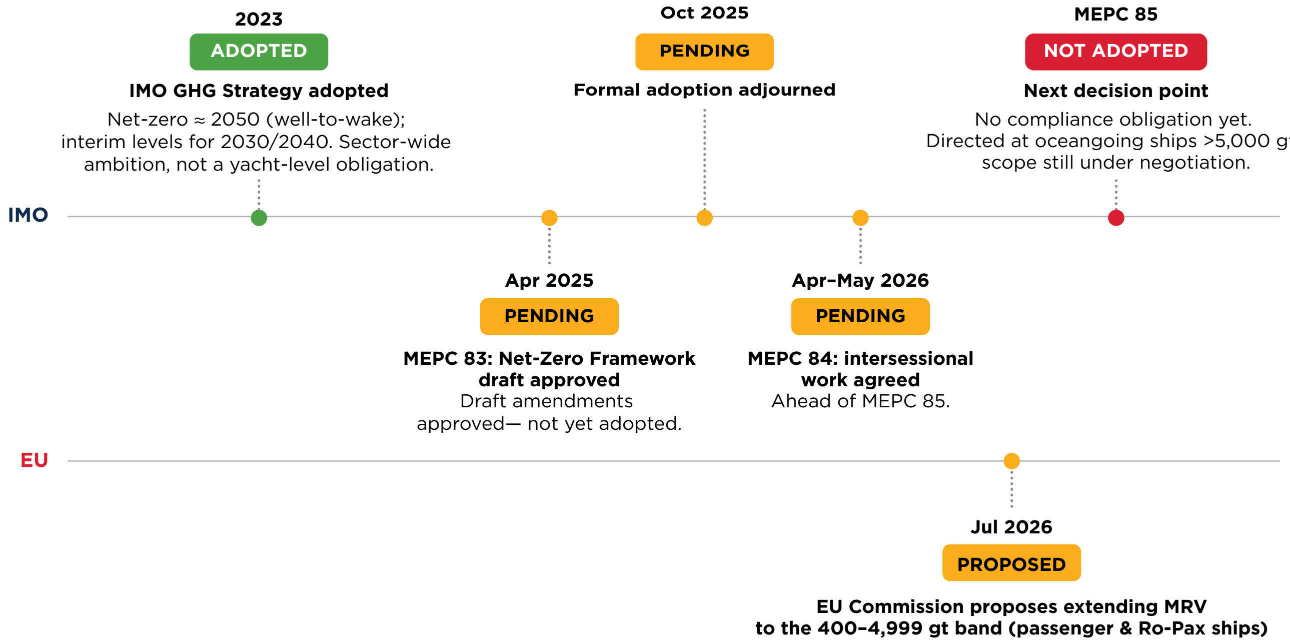


Figure 8: Status of the IMO NZF and of the EU review of the 400 to 4,999 gt band.

Emission Control Areas (ECAs) are expanding independently of carbon regulation, as shown in Figure 9, so for yachts operating in Europe and the North Atlantic, fuel-system flexibility, bunker planning and engine-certification records have immediate value before any new carbon measure applies[14, 15].

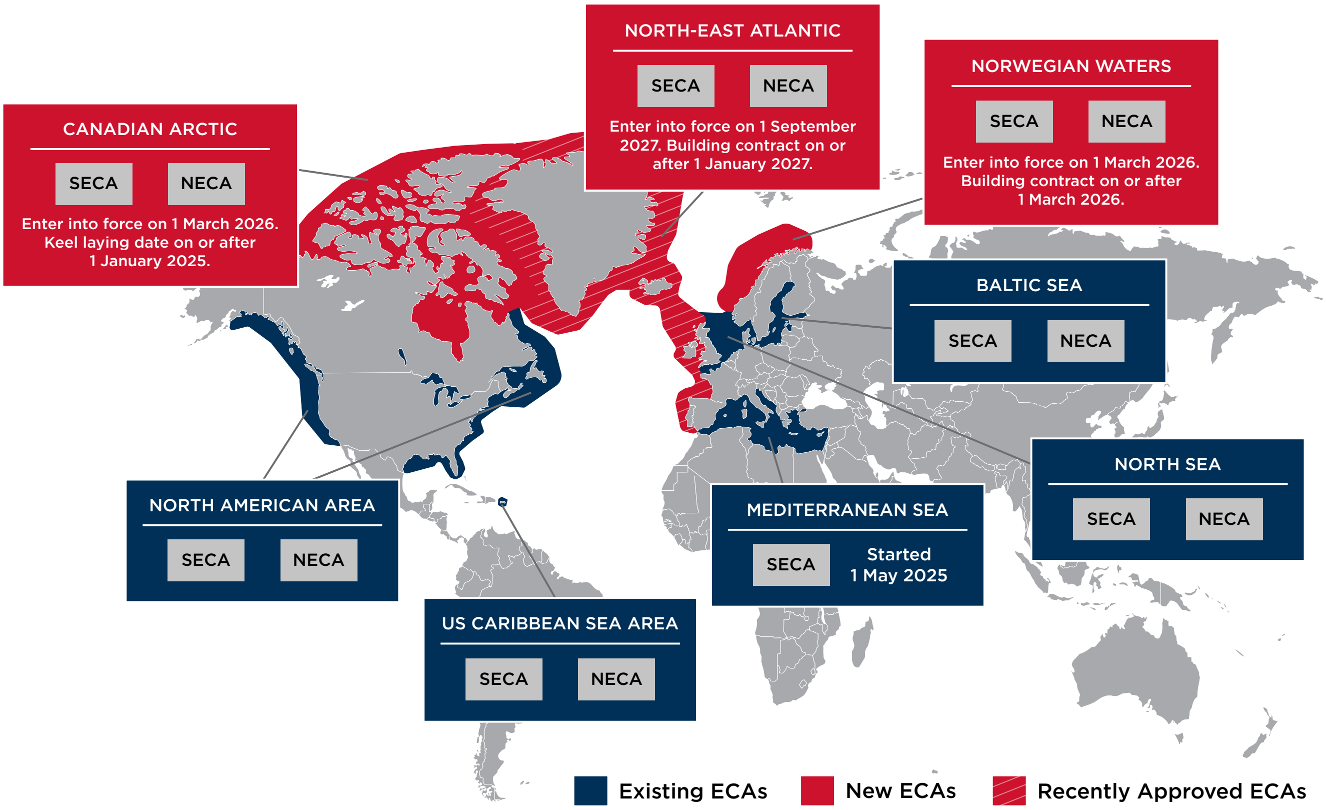


Figure 9: ECAs under MARPOL Annex VI[16].

4.5 Voluntary Frameworks

Voluntary frameworks fill the gap described in Section 3.3. They can provide a consistent baseline, but they must be presented accurately as assessment tools rather than legal compliance certificates.

The ISO/TS 23099, published in March 2026, is a technical specification rather than a full standard. It establishes a methodology for assessing the environmental impact of operational energy use for large yachts over 30 m and for comparing performance against a defined baseline fleet. Its scope covers upstream and downstream emissions associated with operational energy, while excluding individual behavioral variation, materials and production, maintenance processes and end-of-life impacts. That makes it well suited to technical benchmarking, but not a full yacht life-cycle assessment[2]. The YETI is the industry initiative that helped develop this methodology[17, 18].

The Superyacht Eco Association Index provides an independent yacht-focused carbon dioxide assessment adapted from IMO EEDI/EEXI principles, rating a yacht against defined emission thresholds. Its carbon certification has since been joined by an air quality certification covering nitrogen oxides and particulate matter. It is a voluntary certification and does not determine MARPOL or EU applicability[19].

5 Lower-Emission Pathways

Two categories of measures are available. The first reduces the energy that a yacht demands and converts what remains more efficiently. The second changes the fuel or energy carrier that supplies it. The order matters as much as the measures themselves, meaning lowering demand reduces annual fuel volume, tank capacity, battery capacity, generator rating, cooling requirements and shore-power demand, and therefore determines the size of every fuel decision that follows.

5.1 Energy Management: Reducing Demand

5.1.1 Establish the Load Profile Before Selecting Measures

Efficiency gains on a yacht sit in the interaction between systems rather than in equipment datasheets, so the measure worth installing on one yacht may not be worth installing on another. The first objective is therefore to convert fuel and electricity records into an operational energy map. The starting point is a system-level assessment of machinery, electrical, and heating ventilation and air conditioning (HVAC) systems against the operating profile rather than a design-point assumption, followed by continuous monitoring. For a yacht in service, that profile is measured, and the baseline covers enough time to capture seasonal and operational variation, since a short snapshot taken during a single charter or yard period is rarely representative. For a newbuild, it is predicted from the intended operating pattern and from comparable vessels, with the wider uncertainty stated alongside it, and replaced by measured values after sea trials and the first year of operation. The management process follows a continuous improvement cycle of planning, implementation, monitoring and self-evaluation. This is consistent with the IMO SEEMP framework, which requires applicable ships of 400 gt and above on international voyages to maintain a SEEMP under MARPOL Annex VI, thereby placing part of the yacht fleet within a statutory planning structure[20, 21].

5.1.2 Reducing Propulsion and Hotel/ Auxiliary Demand

Because a large yacht is stationary for roughly 90 percent of the year, stationary demand must be included in any energy assessment.

The highest-value early measures are those that reduce demand and convert energy more efficiently before any fuel switch is considered. Efficiency reduces cost and emissions together, applies to the legacy fleet as readily as to newbuilds, and is largely free of the storage-density and availability constraints that complicate alternative fuels. It also changes the size of every measure that follows, since each kilowatt-hour removed from demand is one that does not have to be stored, and every fuel in Section 5.2 carries a volume penalty against conventional diesel. The measures available, and when each can be carried out, are set out in Figure 10.

Hotel load reduction

Existing fleet

A significant efficiency opportunity in many large yachts, particularly HVAC in warm climates. Air conditioning is the principal consumer.

- Demand-controlled ventilation
- Zoning of unoccupied spaces
- Higher-efficiency chillers
- Improved insulation and glazing
- Waste-heat recovery
- LED lighting
- Variable-speed pumps and fans
- Efficient auxiliaries

Individually modest, but they compound on a vessel energized most of the year.

Hull and propulsion condition

Condition, any vessel

Condition is available to every vessel. Hull form optimization is largely not.

- Fouling
- Coating degradation
- Surface damage
- Propeller roughness

All increase resistance or reduce propulsive efficiency. The IMO biofouling guidelines note, drawing on ISO 19030-2, that a speed loss of 1–3% or a fuel consumption increase of 3–9% may indicate biofouling.

Generator efficiency

Existing fleet

Redundancy carried for comfort and reliability means generators often run at a low fraction of their rating, where fuel per unit of electricity is higher than at the design point.

- Correctly sized generator sets
- Power management that keeps running machines near their efficient load

Recovers the loss without changing the yacht's capability.

Shore power readiness

Newbuild or major refit

Shore power replaces generator running in port and at anchor with a grid connection.

- Mature and inexpensive if installed during design
- Expensive and disruptive to add afterwards
- Readiness worth specifying regardless of what the quay currently offers

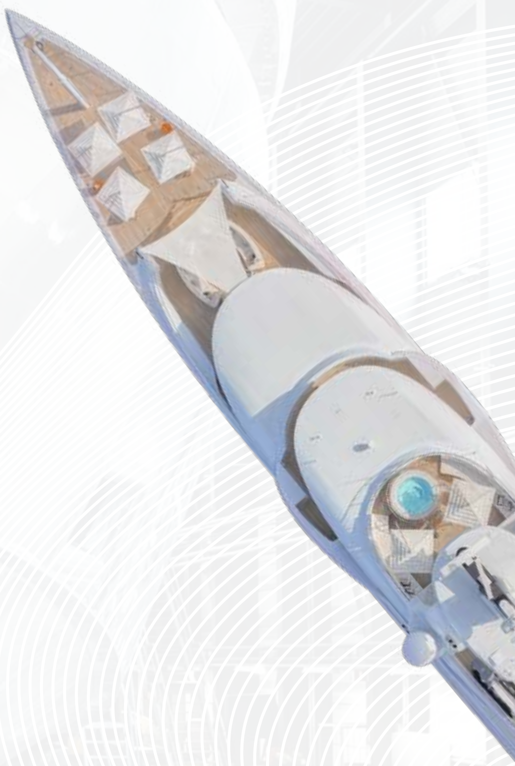
It removes emissions from the yacht rather than eliminating them, so a comparison uses delivered kilowatt-hours, connection losses and a local emission factor.

Power architecture

Newbuild or major refit

In a diesel-electric or hybrid arrangement the engines produce electricity rather than driving the propellers, feeding one system with a battery bank.

- Engines run where they burn the least fuel
- Batteries absorb short peaks
- The yacht lies at anchor, or maneuvers at low speed, with the engines off and no noise
- Shore power and a later fuel cell connect to the same system



None of these measures depend on knowing which fuel will prevail.

Figure 10: Measures for reducing propulsion and hotel demand, grouped by when each can be carried out.

5.2 Energy Transition: Alternative Fuels and Energy Carriers

Alternative fuels usually impose a penalty on tank volume, system complexity, weight, cost or bunkering flexibility. Every pathway considered carries less energy per liter than marine gasoil (Figure 11), and on a yacht, that penalty is paid in accommodation, crew or tender space rather than in cargo. The volume question therefore precedes the machinery question.

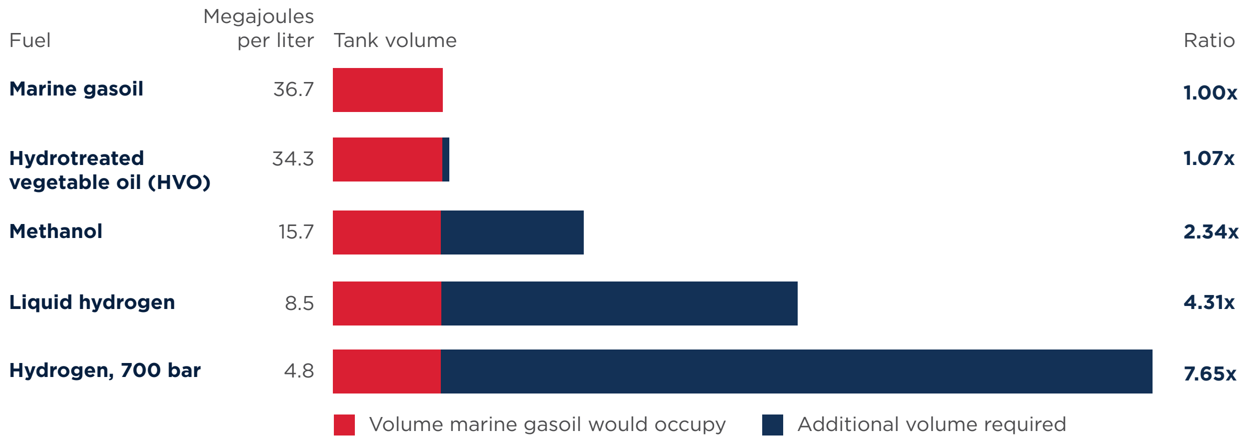


Figure 11: Energy per liter and the resulting tank volume required for equivalent energy.

The clearest fit between a yacht's energy profile and an alternative energy carrier is not in propulsion. Because propulsion drives approximately 10 percent of a yacht's annual operating time, while hotel and auxiliary load run continuously, the pathway most likely to deliver a genuine emissions benefit is one that supplies electrical power at anchor rather than one that replaces marine gasoil underway. Section 5.3 develops this point through methanol and hydrogen fuel cells specifically, but the underlying logic applies across candidate pathways: a yacht's operating profile rewards solutions sized to hotel load, not to propulsion range.

There is no universal best fuel. What matters is the lowest-risk pathway for a defined yacht, operating profile and time horizon. An existing 50 m yacht with limited machinery-space access, a new 100 m yacht intended for global cruising and a yacht spending most of the year connected to low-carbon shore power will rationally reach different conclusions. Fuel choice is therefore a vessel-integration decision rather than a market-ranking exercise[24].

Marine fuel emissions are assessed on a well-to-wake basis. The IMO life-cycle framework separates upstream well-to-tank emissions from onboard tank-to-wake emissions and covers carbon dioxide, methane and nitrous oxide, so different production pathways for the same chemical fuel produce materially different results[25].

Hydrogen contains no carbon and produces no carbon dioxide at the point of use, yet its total climate impact depends on production and supply chain. Biofuels depend on feedstock, land-use effects, energy processing, transport, allocation methodology and certification. Electricity depends on the generation mix and the time and place of charging[25, 23]. For decision-making, a fuel proposal must state many details such as the physical fuel, production pathway, feedstock or electricity source, well-to-tank factor, certification scheme and chain-of-custody method. A generic statement such as "green methanol ready" or "HVO-capable" is not an emissions result.

5.3 Candidate Pathways for Large Yachts

5.3.1 Hydrotreated Vegetable Oil

HVO, also called renewable diesel, is a paraffinic diesel produced by hydrotreating waste oils and fats, including residue feedstocks. It uses existing liquid-fuel storage and diesel machinery, which makes it the least disruptive route for many existing yachts, and it blends with conventional marine gasoil[26].

Drop-in status does not remove the need for verification. Compatibility depends on the product, the approvals held by the installed engines and the fuel-treatment arrangement. The 2024 edition of ISO 8217 covers fuels from petroleum, synthetic and renewable sources[27], and the grade specified at the point of order determines which limits apply.

The unified interpretation of regulation 18.3 of MARPOL Annex VI lists HVOs among the products defined as biofuel (UI 795/Rev.9)[28]. Unblended HVO falls in the band above 30 percent biofuel content. The engine manufacturer confirms that the installed engines are suitable and states any conditions and the fuel specification under which the engines intend to run. A risk assessment showing that risk control measures are in place for engine failure or fuel-related issues is submitted to the vessel's classification society[28].

Under the revised IMO interim guidance, applying from January 1, 2027, HVO that is not certified as sustainable, or that does not meet the well-to-wake criteria, is assigned the conversion factor of the equivalent fossil fuel[29]. A claimed reduction therefore rests on certification by a recognized scheme, evidenced by a Proof of Sustainability provided with the bunker delivery note[29].

5.3.2 Methanol

Methanol is liquid at ambient temperature and pressure, avoiding the very low temperatures or very high pressures that hydrogen requires. Its quality as a marine fuel is defined in ISO 6583:2024[30], and it requires approximately 2.4 times the tank volume of conventional fuel for equivalent energy, before safety spaces are counted[31]. With a flash point of about 11 °C and a toxicity hazard, methanol falls within the SOLAS framework for low-flashpoint fuels; IMO's detailed interim safety provisions for methyl/ethyl alcohol are contained in the Maritime Safety Committee's (MSC) circular, MSC.1/Circ.1621[32, 33, 34]. The applicable guidelines call for segregation and double barriers, restrictions on tank location, leak detection with automatic isolation, double-walled piping in machinery spaces and crew training[33, 34]. Methanol therefore changes the layout of the yacht rather than only its machinery. The HVO can be bunkered through existing fuel infrastructure while methanol requires new infrastructure or modification.

Methanol can be used in dual-fuel combustion engines or in fuel cells via onboard reforming to hydrogen. Many current compression-ignition dual-fuel methanol engines use pilot fuel and therefore carry a methanol system in addition to the diesel system rather than instead of it. Because stationary demand may represent a large share of a yacht's annual energy, the application that best matches how a yacht consumes energy is electrical power at anchor rather than propulsion. A fuel cell can supply that load without combustion, and without storing hydrogen on board, and the methanol is converted to hydrogen by a reformer as it is used. Several prominent yacht applications to date have focused on methanol-reformed fuel cell systems rather than the combustion route.

The benefit depends primarily on the production pathway and associated upstream emissions. Methanol from natural gas offers little or no life-cycle advantage; bio- and e-methanol carry the reduction, and their certified supply is scarce and geographically concentrated.

5.3.3 Hydrogen

Hydrogen may be converted in a fuel cell or combustion engine. Hydrogen used in a fuel cell yields electricity and water vapor at the point of electrochemical conversion, with no onboard carbon dioxide, nitrogen oxides or particulates, and very low noise, which is a close match for the hotel load and for operation in sensitive marine areas. Although hydrogen releases no carbon dioxide at the point of use, this does not make it a zero-carbon fuel on a life-cycle basis.

The life cycle GHG performance of hydrogen depends on its production pathway. Renewable electrolysis can deliver substantial reductions, while unabated fossil-derived hydrogen generally does not. Its certified supply is smaller and more concentrated than that of renewable methanol. Bunkering availability in yachting regions is in the early stages.

The space claim reaches its extreme here. Per unit of energy delivered, liquid hydrogen requires 4.3 times the volume of marine gasoil, while 700-bar compressed hydrogen requires approximately 7.6 times the volume, before accounting for the insulation and structural arrangements that increase it further[35].

Interim guidelines for the safety of ships using hydrogen as fuel were approved at MSC 111 in May 2026[36]. Fuel cell installations are addressed separately in MSC.1/Circ.1647[37]. In the absence of a mandatory code, projects proceed through risk-based alternative-design approval, in which the safety case is built for the vessel and demonstrated as equivalent to conventional standards.

The fuel cell is not tied to a single fuel. It can use hydrogen bunkered directly or hydrogen reformed on board from a carrier such as methanol. The complete electrical system should be evaluated as an integrated arrangement, including reforming where another hydrogen carrier provides the feedstock, as well as battery buffering, cooling ventilation, redundancy and emergency operation. Because reforming carries an energy penalty and produces direct emissions, the zero-emission result belongs to the pure-hydrogen supply rather than to the fuel cell itself[35]. Figure 12 shows where the fuel cell sits within that system.

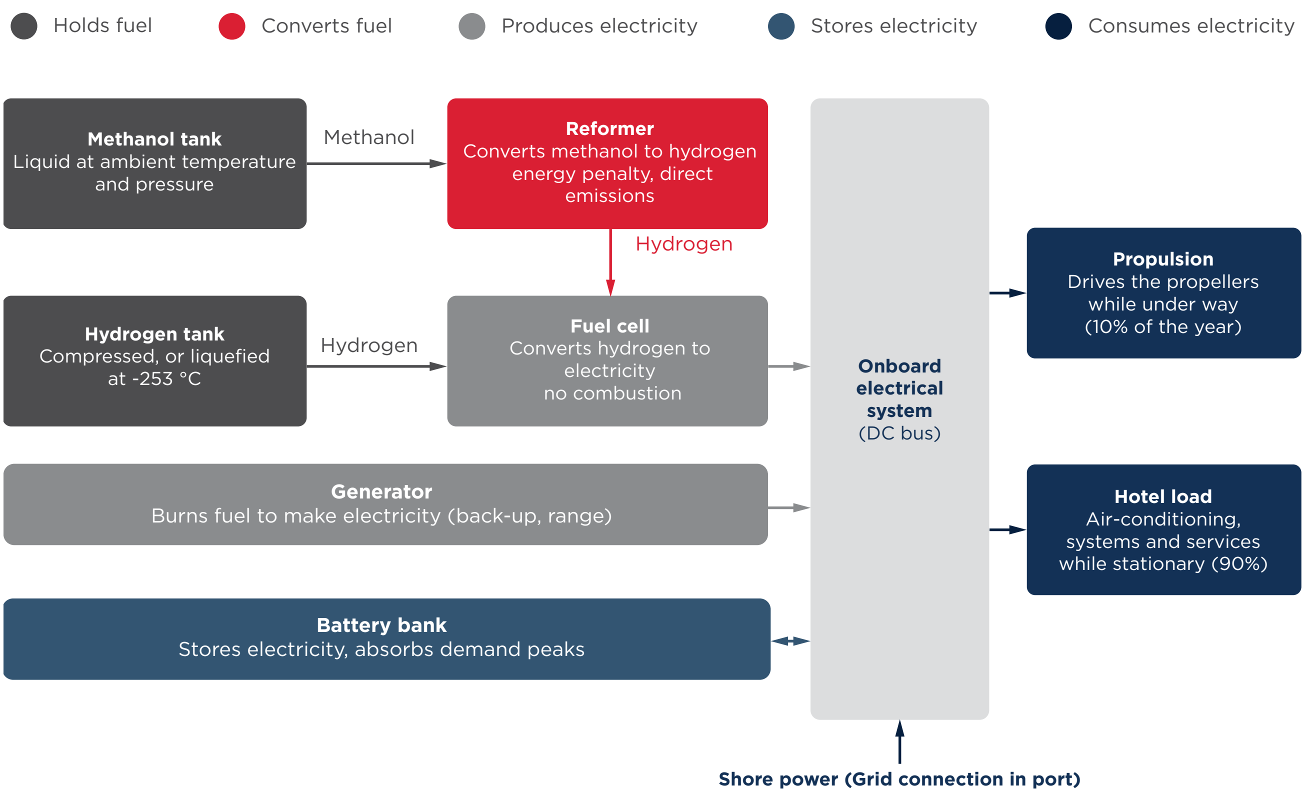


Figure 12: How a fuel cell sits in a yacht's energy system.

5.3.4 Battery-Electric and Hybrid Systems

Battery systems do not provide a primary energy source in the same way as a liquid fuel; they store electricity generated on board or supplied from shore. In hybrid arrangements, batteries can absorb short-duration load peaks, support generator load optimization and allow engines to be shut down during selected low-power operating periods. Plug-in systems can also charge from shore power, enabling stored electricity to support hotel loads, maneuvering or other short-duration duties without local exhaust emissions while operating on battery power. These functions can reduce engine running hours and improve the efficiency of the overall power system[38].

For large yachts, however, battery mass and volume increase rapidly with the amount of energy that must be stored. Batteries are therefore generally better suited to hybridization, peak shaving and limited-duration operation than to replacing liquid fuels for long-range propulsion. Their environmental benefit also depends on how the electricity used to charge them is generated. Integration must be assessed as part of the complete electrical architecture, including the battery-management, power-management and energy-management systems, charging arrangement, and applicable class and safety requirements[39]. Table 2 compares candidate alternative fuels and energy carriers for yachts.

Fuel, Energy Carrier or Storage System Comparison	Containment	Conversion on Board	On Yachts to Date	Principal Constraint
HVO renewable diesel	Ambient liquid, conventional flashpoint	Existing diesel engines	In service today as a drop-in, subject to engine-maker acceptance	Certified sustainable feedstock, price premium, availability outside Europe
Methanol low flashpoint	Ambient liquid, flashpoint about 11°C, toxic	Dual-fuel engine with pilot fuel, or fuel cell via on-board reformer	Delivered applications follow the fuel-cell route, at newbuild. Combustion propulsion under development	Tank volume and surrounding safety spaces. Certified supply scarce and concentrated
Hydrogen cryogenic or compressed	Compressed at 700 bar, or liquefied at about -253°C	Fuel cell, or combustion engine	Fuel-cell installations delivered, serving hotel load and coastal navigation, with smaller systems in build	Largest volume penalty, no mandatory code, very limited bunkering
Battery electric energy carrier	Electrochemical storage	Direct to the onboard electrical system	Established for peak shaving, shore-power support and silent operation at anchor	Current battery energy density limits practical application for long-range propulsion on large yachts

Table 2: Candidate alternative fuels and energy carriers for large yachts.

6 Practical Roadmap Architecture

The recommended architecture has six stages. They are sequential for governance, but not rigid in calendar time. Low-cost actions may begin while improving the baseline, and newbuild projects may assess future fuels earlier because space and safety decisions must be fixed during concept design. Nevertheless, each stage should end with a defined output and approval decision.

1 FRAME

PURPOSE

Set boundary, ownership and objectives.

CORE WORK

- Statutory facts
- Operating horizon
- Carbon boundary
- Decision authority
- Risk appetite

REQUIRED OUTPUT

Approved statement of scope, horizon and decision authority, with a named accountable owner.

2 MEASURE

PURPOSE

Establish the technical and operational baseline.

CORE WORK

- Mode-based energy profile
- Measured in-service or predicted from comparable vessels for a newbuild
- Data-quality review
- Regulatory applicability

REQUIRED OUTPUT

Verified baseline, uncertainty statement and priority-load map.

3 REDUCE

PURPOSE

Remove avoidable energy demand before resizing the supply.

CORE WORK

- Operational measures
- Hull/propeller condition
- HVAC and auxiliary optimization
- Shore-power use
- Maintenance controls

REQUIRED OUTPUT

Action plan of measures that pay back regardless of future fuel choice, with measured savings.

4 OPTIMIZE

PURPOSE

Develop integrated technical packages for the actual duty cycle.

CORE WORK

- Hybridization
- Propulsion and electrical upgrades
- Heat recovery
- Controls
- Hydrodynamic retrofits
- Refit integration

REQUIRED OUTPUT

Class and flag-feasible concept, lifecycle cost and verification plan.

5 TRANSITION

PURPOSE

Select the lowest-risk energy pathway.

CORE WORK

- Well-to-wake fuel comparison
- Tank and machinery integration
- Supply and certification
- Fuel-ready provisions
- More applicability for new builds

REQUIRED OUTPUT

Approved fuel/power strategy with fallback and conversion conditions.

6 VERIFY AND RENEW

PURPOSE

Demonstrate performance and update the pathway.

CORE WORK

- Reconciliation of meter and fuel records
- Post-implementation trials
- Annual review
- Corrective actions
- Next-refit trigger

REQUIRED OUTPUT

Verified results, revised baseline and rolling three-year plan.

VERIFY | LEARN | UPDATE | REPEAT

Figure 13: The six roadmap stages.

As shown in Figure 13, the framing stage fixes the ownership and investment horizon over which decisions are assessed; a defined scope keeps later comparisons free of shifting assumptions. At the measurement stage, a newbuild has no operational data, so its baseline is a predicted mode profile with a wider uncertainty range stated alongside it, which sea trials and the first year of operation then replace with measured values. Reduction comes first among the physical measures because those actions are faster to implement, lower risk and capable of immediate savings, and each carries a cost, an expected benefit and a verification method. At the optimization stage, technology packages are evaluated against the yacht's actual operating profile rather than supplier headline savings. The transition stage is governed by remaining service life and retrofit complexity for the existing yacht, and by fuel-ready design for a newbuild, aiming for a credible pathway for the yacht's operating area and ownership horizon.

Verification runs through this sequence rather than closing it. The verification plan is written before purchase, defining the baseline, the relevant operating conditions, data-quality thresholds, test periods and external variables. Commissioning confirms that equipment works as designed, operational verification proves actual in-service savings and underperformance triggers corrective action. The rolling three-year plan is updated annually, or whenever the yacht changes its flag, operation, ownership, major machinery or fuel, with each updated baseline becoming the starting point for the next cycle.

The six stages apply to an existing yacht and to a newbuild alike. What differs is the input available at each stage and the freedom to act on it. An existing yacht works within a fixed arrangement, a newbuild works before the arrangement is set. Figure 14 sets out the two tracks within the same architecture.

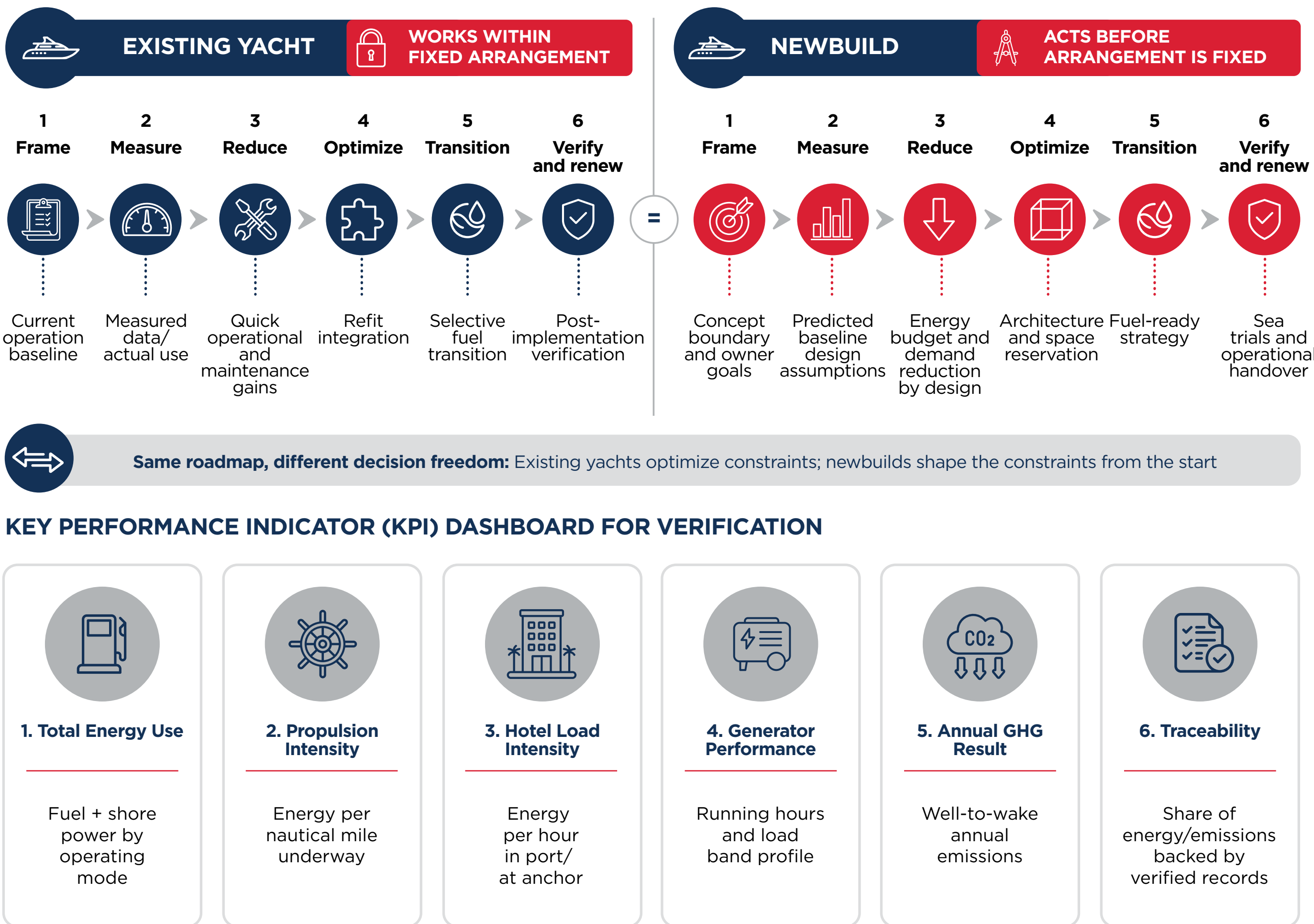
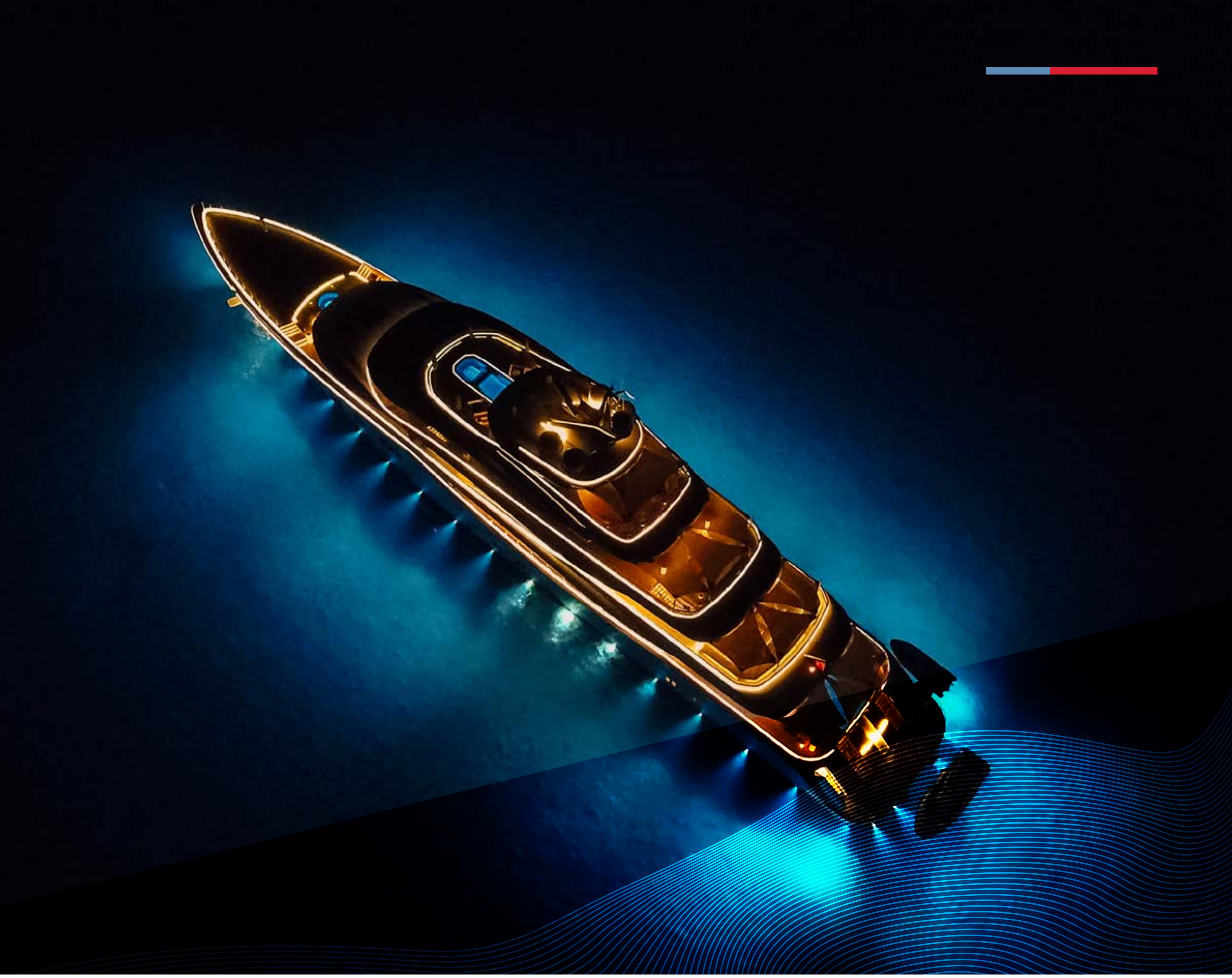


Figure 14: Existing yacht and newbuild tracks within the six roadmap stages.

The KPIs in Figure 14 are deliberately few. A small set of indicators, each tied to a verified source, is more useful than a large dashboard, built on unverified data, and each of the six KPIs follows from a characteristic of yacht operation identified earlier.

Four measures remain useful regardless of which fuel pathway develops. These are a verified energy baseline, reduction of demand before any fuel switch, physical and electrical provision for later conversion and governance of what is measured and claimed. None of them requires knowing which fuel prevails, and each narrows the eventual choice and improves the evidence supporting it.



7 Conclusion

Three factors limit the conclusions in this document:

- No authoritative, regularly updated emissions inventory exists for the global yacht fleet, so the scale of the sector's total footprint remains an estimate rather than a measured figure.
- No harmonized life-cycle methodology exists to settle whether refit or replacement produces the lower total impact over a vessel's remaining service life.
- No measured split between propulsion and hotel energy has been established for the fleet. The approximate halves cited from ISO/TS 23099 rest on theoretical load balances rather than monitored data.

Each is recorded here as an open question rather than resolved by assumption.

A roadmap is judged by what it produces in service rather than by what it proposes. Yachts that establish their energy profile, reduce demand before expanding supply, evaluate investments against vessel-specific evidence and verify outcomes against an agreed baseline are better positioned to credibly reduce emissions while preserving safety, comfort, reliability and operational capability.

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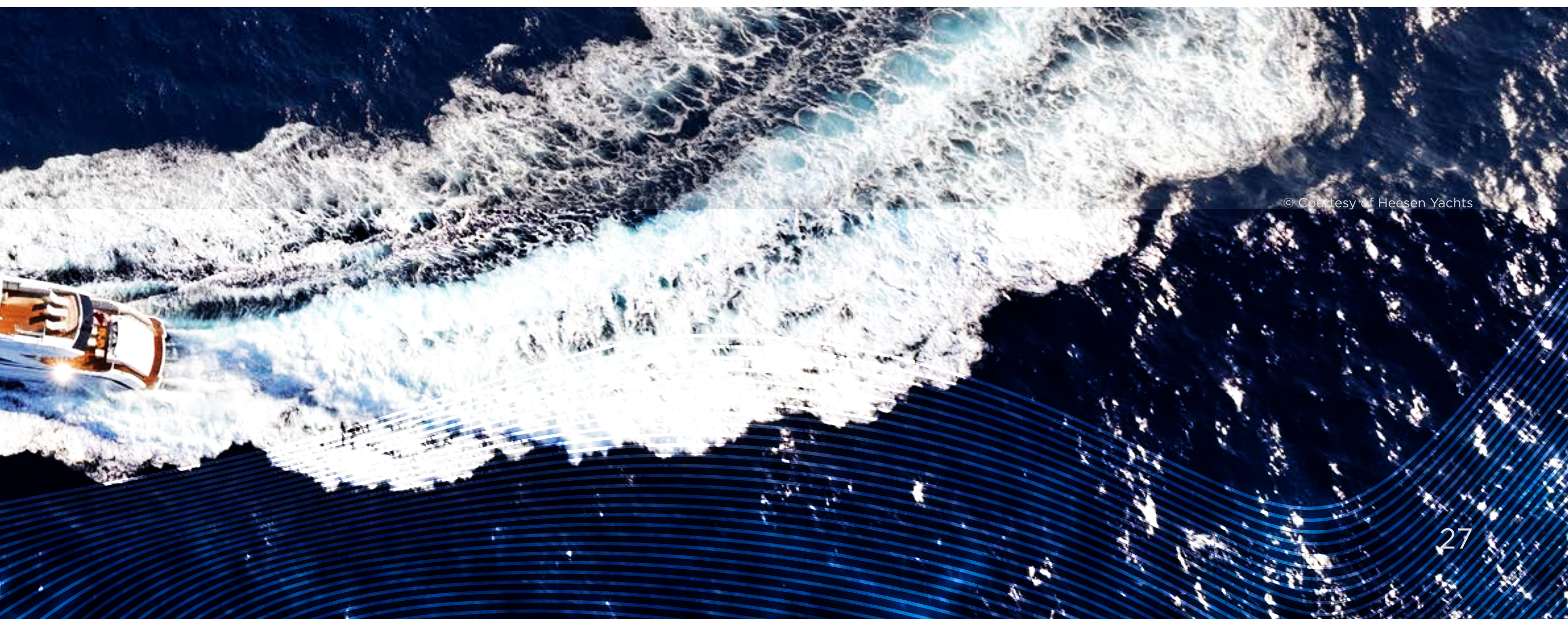

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