State-of-the-art sustainable energy efficiency technologies roadmap for waterborne transport towards the fit-for-55 guidance compliance

Project 101192661— FLEETfor55

Deliverable D2.2 – EETs Market Analysis

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Acronyms and Abbreviations	Meaning
AC	Alternating Current
AFC	Alkaline Fuel Cell
AFIR	Alternative Fuels Infrastructure Regulation
ALS	Air Lubrication System
CAPEX	Capital Expenditure
CFD	Computational Fluid Dynamic
CII	Carbon Intensity Index
CRP	Contra Rotating Propeller
DC	Direct Current
EEA	European Economic Area
EEDI	Energy Efficiency Design Index
EET	Energy Efficiency Technologies
EEXI	Energy Efficiency Existing Index
EMS	Energy Management System
EMSA	European Maritime Safety Agency
EST	Energy saving Device
ETS	Emissions Trading System
EU	European Union
FAME	Fatty Acid Methyl Ester
GA	Grant Agreement
GHG	Green House Gas
GT	Gross Tonnage
HT-PEMFC	High-Temperature PEM Fuel Cell
HVDC	Hight-Voltage Direct Current
HVO	Hydrotreated Vegetable Oil
ICE	Internal Combustion Engine
IMO	International Maritime Organization
ISM	International Safety Management
IWT	Inland Waterway Transport
JIT	Just In Time
LNG	Liquified Natural Gas
LPG	Liquefied Petroleum Gas
LVDC	Low-Voltage Direct Current
MCFC	Montel Carbonate Fuel Cell
MEPC	Marine Environment Protection Committee
MRV	Monitoring, Reporting and Verification

Acronyms and Abbreviations	Meaning
MTPA	Million Tonnes Per Annual
NDA	Non-Disclosure Agreement
OCC	Onboard Carbon Capture
OG	Oceangoing vessels
OPS	Onshore Power Supply
PAFC	Phosphoric Acid Fuel Cell
PBCF	Propeller Boss Cap Fins
PCTC	Pure Car and Truck Carrier
PEM	Proton-Exchange Membrane
PID	Propulsion-Improving Device
PTI	Power Take-In
PTO	Power Take-Off
PV	Photovoltaic
RO	Recognized Organization
Ro-Ro	Roll-on/Roll-off
Rpm	Revolutions per minute
SEEMP	Ship Energy Efficient Management Plan
SIN	Shipping Intelligence Network
SOFC	Solid Oxide Fuel Cell
SSS	Short Sea Shipping
TEN-T	Trans-European Transport Network
TIN	Technologies Innovation Network
TRL	Technology Readiness Level
UNCTAD	United Nations Conference on Trade and Development
VFD	Variable Frequency Drive
WAPS	Wind-Assisted Propulsion Technologies
WED	Wake Equalizing Duct
WHR	Waste Heat Recovery
WP	Work Package

Table of Contents

Document Info **4**

Table of Contents **8**

List of Tables **11**

Executive Summary **12**

1 Introduction **13**

1.1 Background 13

1.2 Objective 13

2 Methodology **15**

2.1 Identified EETs – Categorization 15

2.2 Input Source 16

2.2.1 TIN Contribution 16

2.2.2 Partners' Contribution 16

2.2.3 Clarksons Research Database 17

2.3 Technology Readiness Level 17

2.4 Key Regulatory Drivers 18

2.4.1 EU ETS Compliance 19

2.4.2 Carbon Intensity Indicator 20

2.4.3 Energy Efficiency Design Index/ Energy Efficiency Existing Ship Index 21

2.4.4 FuelEU Maritime Regulation 22

2.4.5 Alternative Fuels Infrastructure Regulation 22

3 Energy Efficient Technologies **24**

3.1 Renewable Energy Integration 24

3.2 Sustainable, Climate-neutral, and Low-emission Fuels 27

3.3 Adoption Barriers of Alternative Fuels 33

3.3.1 Sustainability and Certification of Fuels 33

3.3.2 Availability of Alternative Fuels 34
3.3.3 Fuel Bunkering Infrastructure 34
3.3.4 Engine Technology 34
3.3.5 Price Differential 35
3.4 Hydrodynamic Efficiency Improvements 35
3.5 Propeller and Propulsion Optimization 38
3.6 Operations and Condition-based Monitoring 40
3.7 Optimized Engineering Approaches 41
3.8 Power Conversion, Electrification and Energy Devices 44
4 Market Uptake 51
4.1 Current Adoption Rates 51
4.2 Orderbook Statistics 53
4.3 Combination of EETs 55
4.4 IWT Database 62
5 Market Players 63
5.1 Shipping Companies 63
5.2 Shipyards 63
6 Conclusions 65
7 Bibliography 66
Annex A: TIN Questionnaire 71
Annex B: Matrix of EETs vs Segments – TRL (Partners' Input) 74
Annex C: TRL from Literature Review 77
Annex D: Top Shipping Companies per EET Category 80
Annex E: Top Shipyards per EET Category 83

List of Figures

Figure 1: Solar panels installation and order by vessel type, number of vessels ; Source : Clarksons Shipping Intelligence Network, 1 September 2025 25

Figure 2: WAPS installation and order by vessel type, number of vessels; Source : Clarksons Shipping Intelligence Network, 6 August 2025 26

Figure 3: Hydrogen-fuelled vessels; current fleet and orderbook by vessel type; Source: Clarksons Shipping Intelligence Network, 10 August 2025 28

Figure 4: Ammonia-fuelled vessels; current fleet and orderbook by vessel type; Source : Clarksons Shipping Intelligence Network, 10 August 2025 29

Figure 5: Methanol-fuelled vessels; current fleet and orderbook by vessel type; Source : Clarksons Shipping Intelligence Network, 10 August 2025 30

Figure 6: Biofuel-fuelled vessels; current fleet and orderbook by vessel type; Source : Clarksons Shipping Intelligence Network, 10 August 2025 32

Figure 7: Alternative fuels uptake in the world fleet in number of ships; Source: Clarksons Shipping Intelligence Network, 10 August 2025 33

Figure 8: Alternative fuels uptake in the orderbook in number of ships; Source: Clarksons Shipping Intelligence Network, 10 August 2025 33

Figure 9: Air lubrication systems installation and order by vessel type, number of vessels ; Source : Clarksons Shipping Intelligence Network, 10 August 2025 36

Figure 10: Fuel cells installation and order by vessel type, number of vessels ; Source : Clarksons Shipping Intelligence Network, 10 August 2025 45

Figure 11: Battery-fuelled vessels; current fleet and orderbook by vessel type; Source : Clarksons Shipping Intelligence Network, 10 August 2025 47

Figure 12: WHR systems installation and order by vessel type, number of vessels ; Source : Clarksons Shipping Intelligence Network, 6 August 2025 48

Figure 13: EETs uptake in hydrogen-fuelled vessels, number of vessels ; Source : Clarksons Shipping Intelligence Network, 11 September 2025 59

Figure 14: EETs uptake in methanol-fuelled vessels, number of vessels ; Source : Clarksons Shipping Intelligence Network, 11 September 2025 60

Figure 15: EETs uptake in ammonia-fuelled vessels, number of vessels ; Source : Clarksons Shipping Intelligence Network, 11 September 2025 60

Figure 16: EETs uptake in biofuel-fuelled vessels, number of vessels ; Source : Clarksons Shipping Intelligence Network, 11 September 2025 61

Figure 17: EETs uptake in hybrid and full electric vessels, number of vessels ; Source : Clarksons Shipping Intelligence Network, 11 September 2025 61

List of Tables

Table 1: TRL description 18

Table 2: WAPS installation and order by technology, number of Vessels; Source : Clarksons Shipping Intelligence Network, 6 August 2025 26

Table 3: Adoption rates of EETs in the world fleet ..... **Error! Bookmark not defined.**

Table 4: Adoption rates of EETs in the orderbook ..... **Error! Bookmark not defined.**

Table 5: Co-adoption patterns of EETs 56

Executive Summary

This deliverable provides a concise overview of the Energy Efficiency Technologies (EETs) identified in Task 2.1. For each technology, the main drivers and barriers to adoption are outlined. The maturity of the EETs has been assessed through an extensive literature review, complemented by feedback from consortium experts, using the Technology Readiness Level (TRL) framework.

Drawing on data from Clarksons Shipping Intelligence Network (SIN), the analysis also captures current adoption rates and provides insights into short-term future uptake based on the orderbook. Adoption patterns are examined across vessel types (e.g., containerships, general cargo, bulk carriers). In addition to adoption rates, the main shipyards involved in EET integration and the leading shipping companies (based exclusively on Clarksons database identified.

This task, together with the forthcoming analyses of preliminary economic feasibility (Task 2.3) and technical applicability and feasibility (Task 2.4), will provide essential inputs for the decision support tool to be developed in Task 2.5. This integrated approach will enable a holistic assessment of the sustainability of each EET, ensuring that the outputs of Work Package (WP) 2 form a solid foundation for informed decision-making in WP3.

1 Introduction

1.1 Background

The shipping industry is the backbone of the global economy, carrying about 90% of international trade and transporting over 11 billion metric tons of goods every year. But this essential role has significant environmental impact with shipping accounting for 2% to 3% of Global Greenhouse Gas (GHG) emissions and 13.5 % of European transport emissions.

Vessels above 5000 gross tonnage (GT) account for 55% [1] of all ships and are responsible for 90% of CO2 emissions from the maritime sector. The FuelEU maritime initiative (within the Fit-for-55 legislative package) will require vessels above 5000 GT calling at European ports to reduce the GHG intensity of the energy used on board to -6% in 2030 and -80% in 2050.

To meet the ambitious goals set out in the strategy, the waterborne industry should focus on developing sustainable alternative fuels and energy efficiency technologies that can significantly cut GHG emissions and enhance vessel performance.

1.2 Objective

The objective of this deliverable is to analyse the market landscape for the EETs identified previously in the project (Task 2.1). In this report the maturity level of each EET is examined, based on TRL focusing on applicability and readiness within the maritime contexts. Additionally, the main drivers and barriers for the adoption of EETs are identified along with the market trends and adoption rates, offering valuable insights into the underlying dynamics of each technology. The analysis involves also the evaluation of both the current and anticipated market uptake of emerging technologies resulting in useful insights about the main challenges and opportunities in the evolving EETs.

The analysis examines three vessel categories, considering both retrofits and new designs: Short Sea Shipping (SSS), Inland Waterway Transport (IWT), and Oceangoing vessels (OG).

A comparative analysis of the categorized EETs is conducted to highlight those technologies that are nearing market readiness, specifically those with a TRL between 7 and 9. The study also aims to match the suitability of specific EETs to different ship types, identifying where each technology can be most effectively applied.

This task offers valuable input across multiple areas of the project. Beginning with WP 2, it contributes to the development of the decision support tool in Task 2.5 by providing key indicators related to the market readiness of each EET. In addition, it supports the evaluation

and selection of use cases in WP3, as well as the engineering design activities carried out in WP4.

2 Methodology

2.1 Identified EETs – Categorization

A comprehensive and extended list of EETs was carefully pre-identified during the project proposal stage and was further evaluated and assessed in Task 2.1. A total of 67 EETs are identified and to support a comprehensive analysis, those EETs were grouped into seven thematic clusters according to their functional roles and integration principles. This clustering also captures the varying levels of technological maturity and adoption across the sector. Specifically, the accurate number per category is as follows:

1. **Power Conversion, Electrification, and Energy Devices**: 18 EETs
   Includes onboard power electronics, electric propulsion systems, and energy management components.

2. **Sustainable, Climate-Neutral, and Low-Emission Fuels**: 9 EETs
   Covers technologies supporting the use of hydrogen, methanol, ammonia and biofuels.

3. **Propeller and Propulsion Optimisation**: 9 EETs
   Includes advanced propellers, azimuth thrusters, and propulsion control systems.

4. **Operations and Digital Optimisation**: 9 EETs
   Encompasses voyage planning tools, AI for fuel efficiency, and condition-based maintenance systems.

5. **Renewable Energy Integration**: 8 EETs
   Includes wind-assisted propulsion, onboard solar Photovoltaic (PV) systems.

6. **Optimised Engineering Approaches**: 7 EETs
   Encompasses modular construction, lightweight materials, and thermal insulation.

7. **Hydrodynamic Efficiency Improvements**: 7 EETs
   Covers air lubrication systems, hull shape optimisation, and antifouling coatings

2.2 Input Source

2.2.1 TIN Contribution

The Technologies Innovation Network (TIN) comprises an extended board of EETs providers that plays a central and strategic role in the successful implementation of the FLEETfor55 project, particularly in supporting the identification, evaluation, and integration of EETs across various vessel types. Its main contribution lies in reinforcing the technical depth and market relevance of the project, ensuring that the selected technologies are both scientifically validated and practically viable.

The enrichment of the TIN membership will stop at a specific point in the project. The initial intention was at M06 (June 2025), but based on Milestone No. 3 (Technologies Innovation Network and External Advisory Board defined), this can be extended to M12 (December 2025). In addition, it is the TIN Committee representatives who make suggestions regarding potential members, particularly when they already have a contact person. However, the coordinator is the one responsible for formally contacting the individuals/organizations. .

At the Grant Agreement (GA) stage, the TIN consisted of a group of confirmed members. As of early September 2025, the list has significantly expanded to include a large pool of prospective companies. Official joining of the TIN committee takes place through the signing of a Non-Disclosure Agreement (NDA). The network encompasses a broad range of technologies, each represented by at least one company among the potential stakeholders.

In Task 2.2, the TIN provides critical expertise to support the maturity assessment of each EET. To fully leverage the experience of TIN members, a questionnaire was developed to collect detailed information on the TRL, current and projected market uptake, and the applicability of each EET across different vessel types and sizes (see Annex A). In addition, TIN input offers valuable insights into the GHG emission reduction potential and energy savings associated with each technology that are key factors driving market adoption. Feedback also highlights incompatibilities or integration issues between certain EETs, which greatly supports the selection of suitable use cases in WP3.

2.2.2 Partners' Contribution

The consortium has a multidisciplinary composition, bringing together classification societies, technical universities, research institutes, dissemination organizations, industry partners, a port authority and a shipyard. All members actively contributed to the completion of the task, providing valuable feedback on the maturity, applicability, and feasibility of each EET across

various ship segment types (Inland Waterway Transport, Short Sea Shipping, Oceangoing) for both newbuilds and retrofits. The TRL levels as assessed by the partners are presented in Annex B.

In particular, the classification societies offered insights through class approval inputs and technical reports. During this task, specific questionnaires (QS#1) have been prepared by the TIN Committee. QS#1 is addressed to ship managers/representatives, the port authority, and the shipyard, with the purpose of collecting technical and economic data on EETs. Specifically, it aims to identify which EETs have already been installed, any difficulties faced during implementation and intentions for future installations. Through QS#1, the TIN Committee - and subsequently the consortium - will gain an initial understanding of end-user preferences, existing practices and future plans.

Special acknowledgment should be also given to SYNERGETICS project, which shares common partners with FLEETfor55. Within SYNERGETICS, a detailed pilot database was developed, which was further utilized during the developments of the present report. This database contains valuable information on the integration of sustainable alternative fuels (hydrogen, ammonia, methanol) and related conversion technologies (batteries, fuel cells and alternative-fuelled internal combustion engines) in inland and coastal vessels.

2.2.3 Clarksons Research Database

For this study, data from Clarksons Research SIN [2] has been utilized in order to enhance the analysis. SIN is a globally recognized and ISO 9000-certified database contained 114,383 vessels in its active fleet records (≥100 GT), representing the majority of the world's commercial maritime fleet. It provides comprehensive insights into fleet composition, orderbook trends, vessel characteristics, and the adoption of energy-saving technologies (ESTs) and alternative fuels. Given the platform's real-time tracking and industry-wide adoption, it is widely recognized as a reliable source for shipping analytics, used by financial institutions and organizations such as United Nations Conference on Trade and Development (UNCTAD) and International Maritime Organization (IMO).

2.3 Technology Readiness Level

The readiness of EETs for commercial use in shipping is assessed using the TRL framework. Originating from NASA [3], TRLs employ a numerical scale from 1 to 9 to indicate the maturity of a given technology. Each level has a specific definition, which is used to evaluate evidence and determine a technology's development stage as indicated in Table 1 [4]. The TRL is assessed qualitatively based on evidence gathered through an extensive literature review (see

Annex C), including technical reports from classification societies, peer-reviewed journals and other sources, as well as input from partners who contributed their expertise on the applicability, feasibility and TRL level for each segment type (IWT, SSS,OG) for both newbuilds and retrofits (see Annex B).

Table 1: TRL description

Maturity	Rating	Description of readiness level
Basic research	TRL1	Basic principles of scientific research observed and reported
	TRL2	Invention and research of practical application
	TRL3	Proof of concept with analytical and experimental studies to validate the critical principles of individual elements of the technology
Development	TRL4	Development and validation of component in a laboratory
	TRL5	Pilot scale testing of components in a simulated environment to demonstrate specific aspects of the design
	TRL6	Prototype system built and tested in a simulated environment
Demonstration	TRL7	Prototype system built and validated in a marine operational environment (including small-scale/auxiliary use/demonstration deployments)
	TRL8	Active commissioning where the actual system is proven to work in its final form under expected marine operating conditions (pilot/trial deployments)
Deployment: early adoption	TRL9	Operational application of system on a commercial basis – technically ready but a limited number of vessels/first-of-a-kind facilities

2.4 Key Regulatory Drivers

At Marine Environment Protection Committee (MEPC) 80 in June 2023, the IMO marked a big step forward in cutting carbon emissions from the maritime industry. It calls for using new

technologies, cleaner fuels and alternative energy sources, with the goal that these will make up at least 5% of all energy used in international shipping by 2030. The strategy sets clear targets:

- By 2030, cut total annual GHG emissions from shipping by at least 20%, aiming for 30%, compared to 2008 levels.
- By 2040, reduce emissions by at least 70%, with a stretch goal of 80%.
- By around 2050, reach net-zero GHG emissions.

In April 2025, the IMO in MEPC 83, approved the Net-Zero Framework (NZF). The NZF is designed to achieve the emission reduction targets outlined in the 2023 IMO GHG Strategy. Pending adoption in October 2025, the framework will introduce a GHG Fuel Intensity (GFI) metric, combined with a two-tier GHG pricing mechanism, requiring operators to reduce their ships' GHG emissions intensity by 21% by 2030. Non-compliance will trigger financial penalties, while requirements will become progressively stricter beyond 2030. In this context, shipowners must carefully identify, assess, and implement technologies, fuels and operational solutions that reduce energy consumption and lower GHG fuel intensity across their fleets.

In parallel, the European Union (EU) is also raising the bar with its "Fit for 55" package, a bold climate policy plan aimed at reducing emissions by 55% by 2030 compared to 1990 levels. Introduced in 2021, the package includes wide-reaching measures that affect multiple sectors, including maritime. For the first time, the EU Emissions Trading System (ETS) is being extended to cover shipping, placing a carbon price on emissions from vessels. Alongside this, the package also promotes cleaner fuels, tighter vehicle emission standards and more renewable energy use across the board. In Deliverable 3.1 the regulatory aspects of each EET category were extensively analyzed.

2.4.1 EU ETS Compliance

The EU ETS is a "cap-and-trade" scheme created under Directive 2003/87/EC to help reduce greenhouse gas emissions. The "cap" sets a limit on the total emissions which are acceptable from sectors covered by the system, with this limit shrinking each year to support the EU's climate targets. Today, the EU ETS regulates emissions from electricity and heat generation, energy-intensive industries, aviation, and maritime transport [5].

The EU ETS strategy is being applied gradually in a three-year period. Initially, it covers 40% of emissions in 2024, 70% in 2025, reaching 100% by 2026. From 2024, it applied to cargo and passenger ships over 5,000 GT, with offshore ships over 5,000 GT coming under the system

from 2027. Currently, the ETS includes only carbon dioxide (CO_2) emissions, but by 2026, it will also contain methane (CH_4) and nitrous oxide (N_2O). Additionally, offshore ships and general cargo vessels between 400 and 5,000 GT will be required to monitor and report their emissions, and they could be brought into the ETS in the future. [6]

Under the EU ETS, 100% of emissions from voyages and port calls within the EU/ European Economic Area (EEA) are covered, along with 50% of emissions from voyages entering or leaving the EU/EEA. To prevent avoidance tactics, container ships calling at transshipment ports located less than 300 nautical miles from an EU/EEA port must also count 50% of emissions for the full voyage to the EU port, not just the short final leg. The EU will issue an official list of these transshipment ports.

By default, the shipowner is considered the responsible party for complying with both Monitoring, Reporting and Verification (MRV) and EU ETS rules. However, this responsibility can be passed to the International Safety Management (ISM) Company if there's a signed agreement stating that the ISM Company has been officially authorized by the shipowner to handle ETS compliance. This agreement must then be submitted to the relevant Administering Authority.

2.4.2 Carbon Intensity Indicator

The Carbon Intensity Indicator (CII), adopted by the IMO under MARPOL Annex VI, entered into force in January 2023 and represents a key regulatory driver for decarbonization in shipping. It applies to all cargo vessels, Ro-Pax ships, and cruise vessels above 5,000 GT engaged in international trade.

Ships must report their attained annual operational CII to their flag Administration, or a Recognized Organization (RO) authorized by it, within three months after the end of each calendar year. The attained CII is then compared against the required annual operational CII, which reflects the reduction factor needed for continuous improvement in operational carbon intensity.

Based on this assessment, vessels are assigned a performance rating on a scale from A to E:

- A = major superior performance
- B = minor superior performance
- C = moderate performance
- D = minor inferior performance
- E = inferior performance

The rating must be recorded in the vessel's Ship Energy Efficiency Management Plan (SEEMP). Ships rated D or E for three consecutive years are required to submit a corrective action plan outlining measures to achieve at least a C rating [7,8].

2.4.3 Energy Efficiency Design Index/ Energy Efficiency Existing Ship Index

The Energy Efficiency Design Index (EEDI), introduced by the IMO in 2013, applies to newly built ships and establishes mandatory design efficiency standards measured in grams of CO_2 per tonne-mile.

Since 1 January 2013, following a two-year transitional phase, all new ship designs must comply with reference efficiency levels defined for their respective ship types. These requirements are progressively tightened every five years, with the aim of driving continuous innovation and technical improvements in ship design. Importantly, the EEDI is a non-prescriptive, performance-based mechanism as designers and builders are free to select the most cost-effective technologies, provided the required efficiency level is achieved [9].

The EEDI for an individual vessel is expressed in grams of CO_2 per tonne-mile, with lower values reflecting higher efficiency. In the first phase, the reduction requirement was set at 10% below a reference line based on the average efficiency of ships built between 2000 and 2010. The stringency is gradually increased every five years, reaching a 30% reduction by 2025 for applicable ship types.

Initially, the EEDI applied to the largest and most energy-intensive vessel categories, including tankers, bulk carriers, gas carriers, general cargo ships, containerships, refrigerated cargo carriers, and combination carriers. In 2014, its scope was expanded to cover LNG carriers, ro-ro cargo ships (including vehicle carriers), ro-ro passenger ships, and cruise ships with non-conventional propulsion. With these amendments, the EEDI now applies to ship types responsible for around 85% of CO_2 emissions from international shipping, making it one of the cornerstone regulatory measures for improving efficiency in new vessels.

While the EEDI addresses the efficiency of newbuilds, the IMO recognised the need for a comparable framework for the existing fleet and for this reason the Energy Efficiency Existing Ship Index (EEXI) introduced in 2023. A ship's attained EEXI reflects its efficiency relative to a defined baseline and is compared against a required EEXI which is determined by applying a reduction factor (expressed as a percentage) to the Energy Efficiency Design Index (EEDI) baseline.

The EEXI applies to all ships of 400 GT and above with specific requirements varying by ship type and size category. To comply, the calculated attained EEXI for each vessel must fall below the required value, thereby ensuring that the ship meets a minimum efficiency standard. This

measure effectively extends the IMO's technical efficiency framework, originally developed for newbuilds under the EEDI, to the existing global fleet [8].

2.4.4 FuelEU Maritime Regulation

The FuelEU Maritime Regulation complements the EU ETS by ensuring that a gradual reduction in the GHG intensity of fuels used in the shipping sector. It supports the EU's broader climate objectives of reducing net emissions by at least 55% by 2030 and achieving climate neutrality by 2050.

The political agreement on the Regulation was reached on 23 March 2023, formally adopted on 13 September 2023 and has applied from 1 January 2025 (with monitoring plan requirements applying from 31 August 2024). Its main objective is to decarbonise maritime transport by setting maximum limits on the yearly GHG intensity of the energy used by ships. These limits tighten progressively over time, from 2% in 2025 to as much as 80% by 2050.

The regulation adopts a well-to-wake approach, covering not only CO_2 emissions but also methane (CH_4) and nitrous oxide (N_2O) across the entire fuel lifecycle. In addition, it introduces a zero-emission requirement at berth, mandating the use of onshore power supply (OPS) or equivalent zero-emission technologies for passenger ships and containerships. This provision is designed to cut local air pollution in ports which are often located close to densely populated urban areas.

The regulation covers all vessels above 5,000 GT calling at European EEA ports, regardless of flag (EU or non-EU) with the requirements apply to 100% of energy used for intra-EU/EEA voyages, 50% of energy used for voyages into or out of EU/EEA and 100% of energy used when ships are at berth in EU/EEA ports [10].

2.4.5 Alternative Fuels Infrastructure Regulation

The Alternative Fuels Infrastructure Regulation (AFIR), adopted in July 2023 as part of the EU's Fit for 55 package, establishes mandatory requirements for the deployment of alternative fuels infrastructure across the European Union. Unlike the FuelEU Maritime Regulation, which focuses on the use of fuels onboard ships, AFIR is concerned with ensuring that the necessary port-side infrastructure exists to enable the uptake of alternative fuels and electrification in maritime transport [11].

Under the AFIR, specific obligations now apply to Trans-European Transport Network (TEN-T) ports:

- From January 2025, TEN-T maritime ports must provide an appropriate number of refueling points for liquefied methane.
- From January 2030, main TEN-T ports are required to ensure a minimum level of shore-side electricity supply for seagoing container ships and passenger vessels above 5,000 GT.
- The Regulation also foresees a single solution for shore-side battery recharging points, covering both maritime and inland waterway vessels.
- Infrastructure for hydrogen, methanol, and ammonia refueling points are included in the scope of future developments.
- At the same time, AFIR allows for the possible removal of the current obligation for LNG bunkering in TEN-T core ports, reflecting the shift towards other alternative fuels.

3 Energy Efficient Technologies

This chapter provides a brief overview of each EET across the different categories identified in Task 2.1, highlighting their main technical challenges and positive aspects. In addition, the maturity of each technology is assessed using the TRL framework described in Section 2.3. A summary table of TRLs identified through the literature review is provided in Annex C, while the TRLs reported by the partners for each segment type are presented in Annex B. The observed differences between the two sources can be attributed to the inherent subjectivity in defining TRL. Making use of Clarksons SIN complete database with absolute numbers, the analysis also focusses on the current adoption rates for each vessel type and examines the competitive dynamics based on confirmed orders for each EET.

3.1 Renewable Energy Integration

Solar panels are devices that produce electricity onboard, contributing to meet energy demands for various ship systems such as lighting, air conditioning, navigation and communications. They are not very common in vessels at present, but some installations have been done over the past years (TRL9) [12].

Solar panels offer a low-operating-cost alternative with well-established maturity in onshore energy applications and have the potential to reduce fuel consumption. However, they consume space and can deliver a limited fraction of the onboard required energy. Moreover, they are trade dependent as their efficiency is affected directly by the sunlight.

The available space for solar panels is restricted to accommodation area and partly on the aft deck. Hazardous areas, such as tank or bulk areas, can pose significant risk to the integrity of solar panels and for this reason they are not considered suitable for installation.

According to Clarksons research database, solar panels are currently installed on 120 vessels, with a further 51 planned installations. Among ship vessel types, Ro-Ro vessels and passenger ferries/cruise ships account for the majority of both existing and planned solar panel adoption (Figure 1).

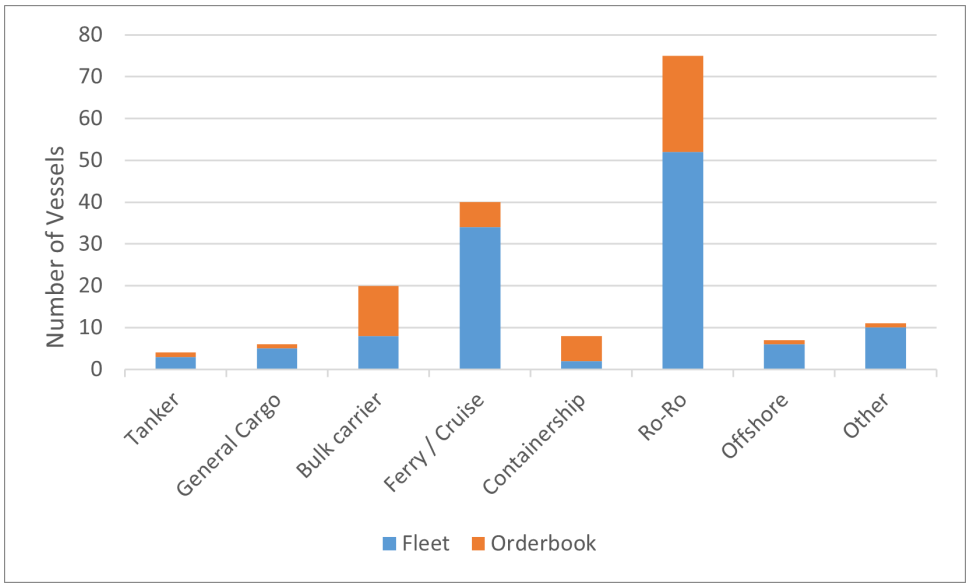

Figure 1: Solar panels installation and order by vessel type, number of vessels; Source: Clarksons Shipping Intelligence Network, 1 September 2025

Wind-Assisted Propulsion Technologies (WAPS) refer to a range of technologies (e.g. soft and rigid sails, flettner rotors, kites and suction wings) that supplement conventional engines using wind power to reduce fuel consumption and CO_2 emissions [13].

WAPS are currently achieving fuel savings of up to 20%, with the potential to reach as high as 40%, depending on the specific technology and vessel type. At the beginning of 2024, 29 vessels were equipped with WAPS with the majority of installations occurring since 2020. More specifically, according to European Maritime Safety Agency (EMSA) report [14], four systems were installed in 2018, one in 2019, two in 2020, eight in 2021, five in 2022 and nine in 2023.

By January 2025, this number had increased to around 50 commercial vessels, indicating the strong dynamics and growing adoption of this type of EET. Rotor sails were the most popular wind-assisted propulsion technology, accounting for close to half of all installations (48%). They are followed by suction wings (31%), rigid and soft sails (19%) and kite propulsion systems, which represent just 2%. The orderbook signals strong growth in the coming year, with 97 newbuildings scheduled to use the technology [12].

Data from Clarksons SIN, retrieved in August 2025, confirms the aforementioned trends. WAPS installations have increased by 37.5% compared to January 2025, with 80 systems installed and 85 additional orders placed by the end of the first half of 2025 (Table 2).

The forecasts for the next years are really promising, with CE Delft predicts 3,700 to 10,700 WAPS installations by 2030 across newbuilds and retrofits tankers and bulk carriers [15].

Table 2: WAPS installation and order by technology, number of Vessels; Source: Clarksons Shipping Intelligence Network, 6 August 2025

WAPS	Installed	Orderbook	Total Vessels
Flettner rotor	33	35	68
Suction Wing	33	30	63
Rigid sail	10	19	29
Wind Kite	4	1	5
Total	80	85	165

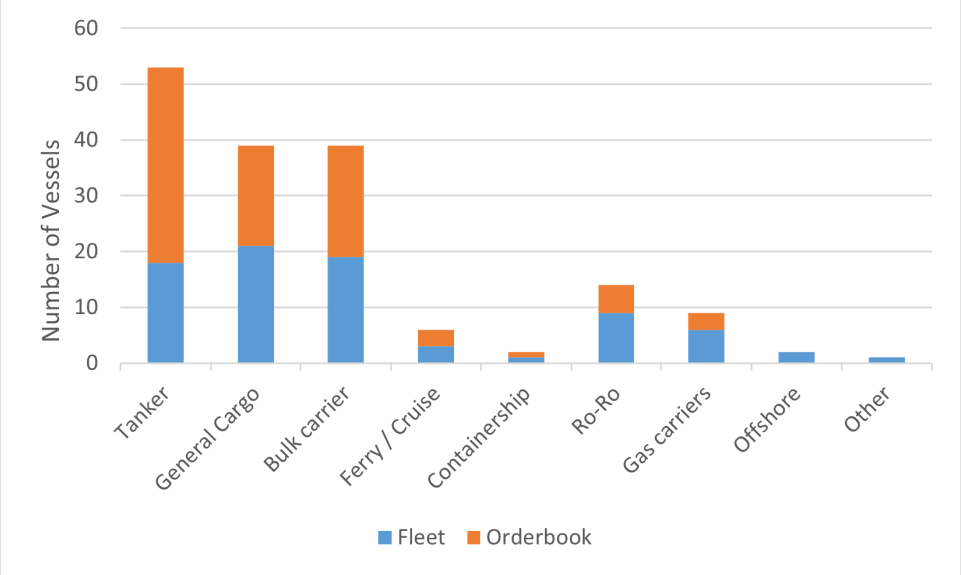

Figure 2: WAPS installation and order by essel Istype, number of vessels; Source: Clarksons Shipping Intelligence Network, 6 August 2025

Main adoption barriers for WAPS

There are several barriers to the wider adoption of WAPS in the waterborne sector. One of the primary challenges is the lack of standardized criteria for verifying fuel-saving claims which leads to uncertainty about the actual fuel savings achieved after WAPS implementation [13].

The operational profile of the vessel is a key barrier as well, as the benefits of WAPS depend on specific weather conditions. Shipowners without fixed trading patterns may therefore be reluctant to invest in such an expensive EET if their vessels are likely to operate in regions where WAPS are less effective.

Another barrier is the potential hidden operational costs behind the WAPS implementation. WAPS can offer a fuel cost reduction of up to 10% with the investment cost reaching up to USD 2.5 million. The installation costs for retrofit amount to approximately 25% of the unit cost, whereas for newbuilds this percentage drops to around 18%. The difference is justified by the need for additional structures which were not part of the original design. In addition to the capital cost of installation, shipowners should also have in mind operational costs related to maintenance, surveys and crew training [14,16].

Another key concern is the regulatory compliance as current maritime regulations may not fully address or accommodate WAPS.

Structural integration presents a significant challenge as well. To ensure the robustness, reliability, and operational safety of these systems in adverse marine environments, extensive testing and the development of new safety protocols are required. Additionally, port operations may need to be adapted to accommodate the presence and operational characteristics of WAPS [12]. Furthermore, navigation issues (e.g. line of sight, navigation lights and manoeuvrability) may require updates and appropriate adjustments to practices and equipment. Lastly, special attention should be given to the noise and vibrations that WAPS may generate to safeguard crew comfort and maintain vessel integrity.

3.2 Sustainable, Climate-neutral, and Low-emission Fuels

Hydrogen serves as a promising alternative fuel for shipping because it offers some significant environmental benefits. When used onboard, it produces zero CO_2 emissions from tank to wake and can also significantly cut harmful pollutants such as nitrogen oxides (NO_x), sulphur oxides (SO_x) and particulate matter. This makes it an attractive option for meeting stricter emission regulations and improving air quality in and around ports.

However, hydrogen also comes with important challenges. Initially, fuel cells and internal combustion engines which convert hydrogen into useful energy on ships are not fully mature. Moreover, in terms of storage, ships either need high-pressure tanks for compressed hydrogen or cryogenic systems to keep liquid hydrogen at extremely low temperatures. Both options are costly and require additional safety measures. In addition, the global bunkering infrastructure for hydrogen is still undeveloped and there are currently no comprehensive international safety standards for hydrogen-powered vessels.

Hydrogen has the potential to play a pivotal role to the reduction of GHG emissions, particularly when produced from renewable energy sources as green hydrogen. Conversely, if it is derived from fossil fuels the overall life-cycle emissions may even exceed those of conventional marine fuels.

Currently, hydrogen is in use as a fuel on 20 vessels, with an additional 38 ships on order (Figure 3). This reflects a positive trend, particularly in the passenger ferry and cruise segments, which together account for nearly half of the orders (16 vessels). Nevertheless, the fleet-wide adoption remains nascent.

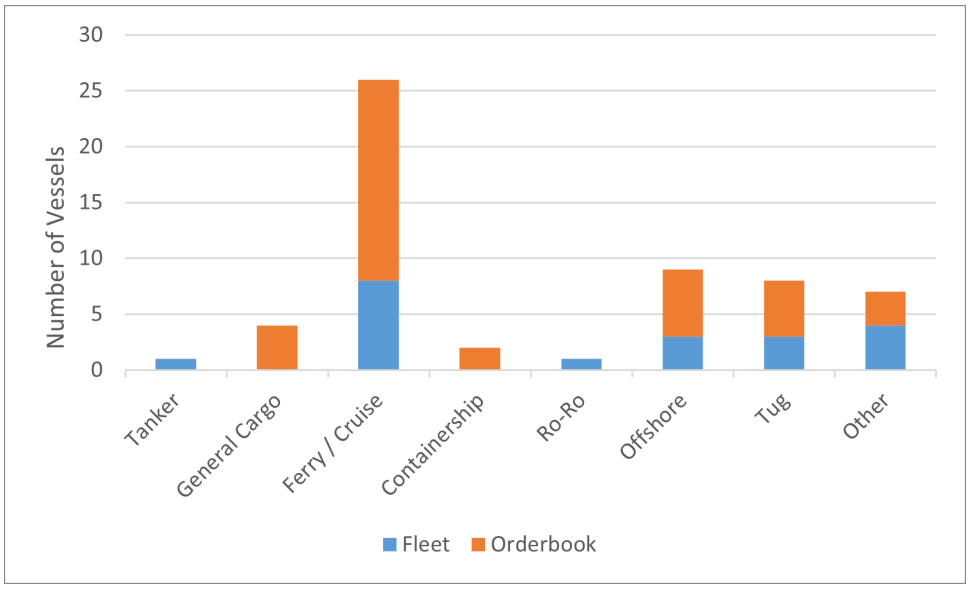

Figure 3: Hydrogen-fuelled vessels; current fleet and orderbook by vessel type; Source: Clarksons Shipping Intelligence Network, 10 August 2025

Ammonia is another sustainable alternative fuel which have concentrated strong interest in recent years. It produces zero tank to wake CO_2 emissions and eliminates sulphur oxides (SO_x) and particulate matter. A strong advantage of ammonia is that dedicated storage terminals already exist near many major ports due to its widespread use in the fertilized industry.

However, ammonia comes with some significant challenges. The major concern is related to safety, as ammonia is toxic and corrosive and in order to enhance its adoption in specific ship segments, comprehensive international safety standards for ship design and operations should be set. Additionally, conversion technologies (e.g. fuel cells and internal combustion engines) for ammonia are still at an early development stage with a MAN engine is expected to commercially debut in 2027 [17].

Like hydrogen, it is crucial to scale up the production of ammonia from renewable sources. Relying on ammonia produced from fossil fuels would undermine both its economic competitiveness and its environmental benefits compared to conventional marine fuels.

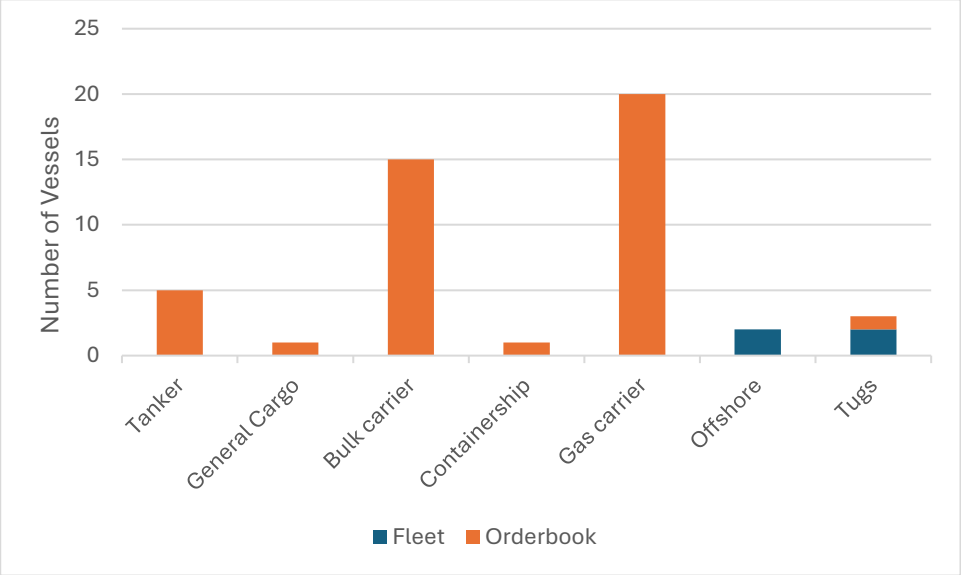

Figure 4: Ammonia-fuelled vessels; current fleet and orderbook by vessel type; Source: Clarksons Shipping Intelligence Network, 10 August 2025

The distribution across ship segments looks quite different from hydrogen. Whereas hydrogen is primarily being adopted in ferries and cruise ships, ammonia is generally considered unsuitable for these vessel types mainly due to safety concerns. At present, only four ammonia-fuelled vessels are in operation. However, uptake is expected to increase, with 43 vessels already on order. Most of these projected orders are concentrated in gas carriers and bulk carriers, which are the leading segments for ammonia adoption (Figure 4).

Demand for ammonia as a maritime fuel is expected to increase from 2.3 million Tonnes Per Annual (MTPA) in 2030, to 62 MTPA in 2040 and 245 MTPA in 2050 based on DNV Pathway model [18].

According to DNV forecast report, ammonia is projected to account for around 35% of total shipping fuels by 2050 [19]. Over the same period, hydrogen use in maritime applications is expected to quadruple. As a result, marine ammonia will represent less than 10% of the combined supply of clean hydrogen, ammonia and e-fuels by 2050.

Methanol is considered as one of the key alternative solutions for the decarbonization of maritime industry. It is not a completely neutral fuel, but it can lead to 8–9% reductions in CO_2

emissions from tank to wake compared to conventional marine fuels [12]. In contrast to hydrogen or ammonia, methanol is stored as a liquid in ambient conditions without serving concerns related to handling and storage procedures. Moreover, storage infrastructures as conversion technologies and safety standards are well developed and can support the methanol market adoption.

Nevertheless, there are still barriers restricting its wider application. The current range of engines designed specifically for methanol is limited. Supply also poses a challenge, as the availability of methanol production volumes remains limited, particularly when focusing on green methanol produced from renewable sources. In addition, safety risks related to its toxicity and flammability must also be managed carefully through proper handling procedures and crew training.

The Figure 5 shows the distribution of methanol-fuelled vessels across different ship categories. At present, methanol is primarily adopted in tankers and containerships, with 72 vessels already in operation. The orderbook is considerably larger, consisting of 321 vessels, which highlights the strong upcoming dynamics of methanol as an alternative fuel. Containerships will dominate the future uptake, representing the most prominent vessel type in upcoming deliveries (168 orders).

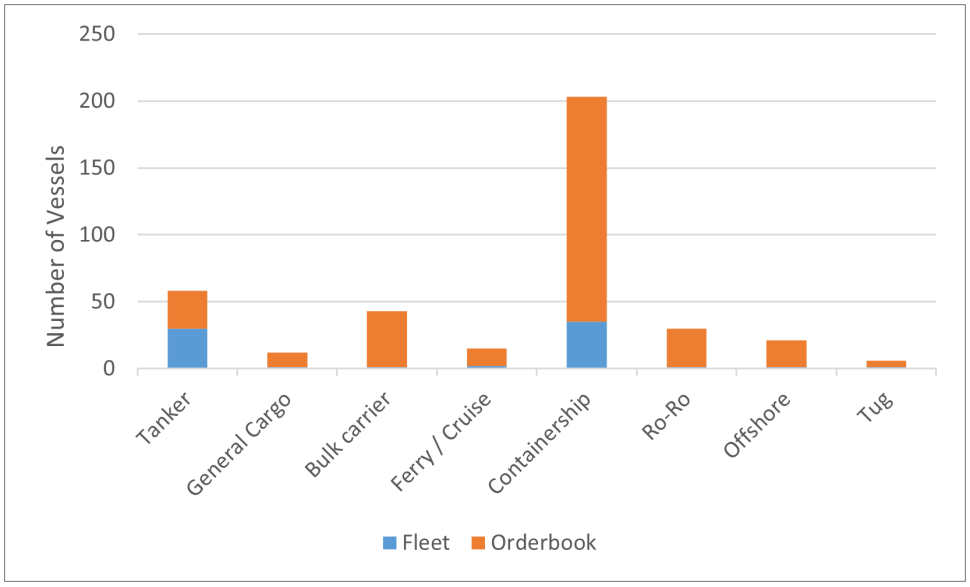

Figure 5: Methanol-fuelled vessels; current fleet and orderbook by vessel type; Source: Clarksons Shipping Intelligence Network, 10 August 2025

Clarksons projects that nearly two-thirds of the existing fleet is unlikely to be retrofitted for future fuels, primarily due to economic constraints. For conventionally fuelled vessels that are too old or uneconomic to justify the investment needed for conversions to fuels such as

Liquified Natural Gas (LNG), methanol, ammonia or hydrogen, **biofuels** represent a practical alternative as the majority of world fleet is equipped with engines that that can make use of them. They offer a pathway to achieve carbon reduction targets with comparatively minimal Capital Expenditure (CAPEX). GHG emissions savings from the use of **biofuels** must be at least 65% for fuels used in the transport sector [20].

Biomethane is being used by the waterborne sector in small quantities. With the growing number of LNG and methanol-fuelled vessels capable of utilising these biofuels, their uptake is expected to expand significantly driving to wider adoption in the shipping sector within the next 5–10 years [21].

Biodiesel use is already well established in road transport and has also entered the maritime sector, primarily as blends with conventional fuel oil. Present production methods include transesterification to produce Fatty Acid Methyl Ester (FAME), and hydroprocessing to produce **Hydrotreated Vegetable Oil (HVO)**. HVO is considered a superior diesel substitute compared with FAME at higher blending ratios. Although further technological development is expected, wider adoption will depend mainly on scaling up production capacity and securing waste-based feedstocks. Ultimately, as with other biofuels, expansion is likely to be constrained by the availability of sustainable feedstocks [20].

According to Clarksons SIN, biofuels are currently used in 201 merchant vessels, with adoption particularly concentrated in containerships and ferry/cruise ships (Figure 6). However, the orderbook remains limited, with only 18 vessels on order, 10 of which are tankers. This relatively low number of new orders indicates a slow pace of future market uptake.

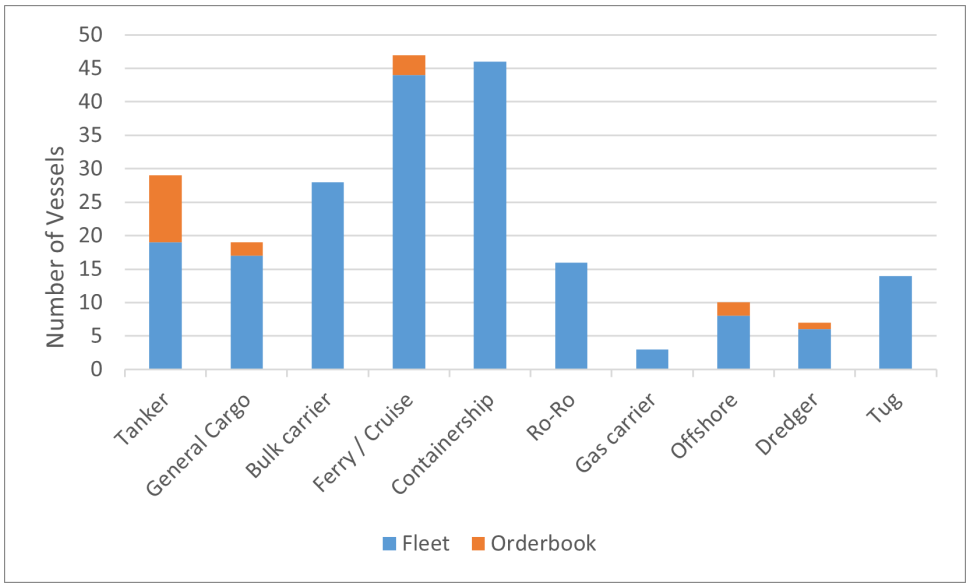

Figure 6: Biofuel-fuelled vessels; current fleet and orderbook by vessel type; Source: Clarksons Shipping Intelligence Network, 10 August 2025

Overall, sustainable alternative fuels have not yet been adopted at the scale needed to drive the maritime energy transition. As shown in Figure 7, conventional fuels still dominate, accounting for 98.3% of the global fleet tracked by Clarksons SIN. Among the alternatives, LNG has seen the widest uptake, followed by biofuels and Liquefied Petroleum Gas (LPG), while methanol, hydrogen, and ammonia together represent less than 0.1% of the fleet. The picture looks more promising when examining the orderbook (Figure 8) which highlights the potential for meeting decarbonisation targets. LNG, viewed as a key transition fuel, accounts for more than 16% of all new orders. Methanol stands out for its rapid momentum as despite its current implementations accounts for 0.06% of the current fleet, it already represents around 5.5% of new orders. Ammonia and hydrogen also show an increase relative to their minimal presence today, while biofuels remain stable at current levels.

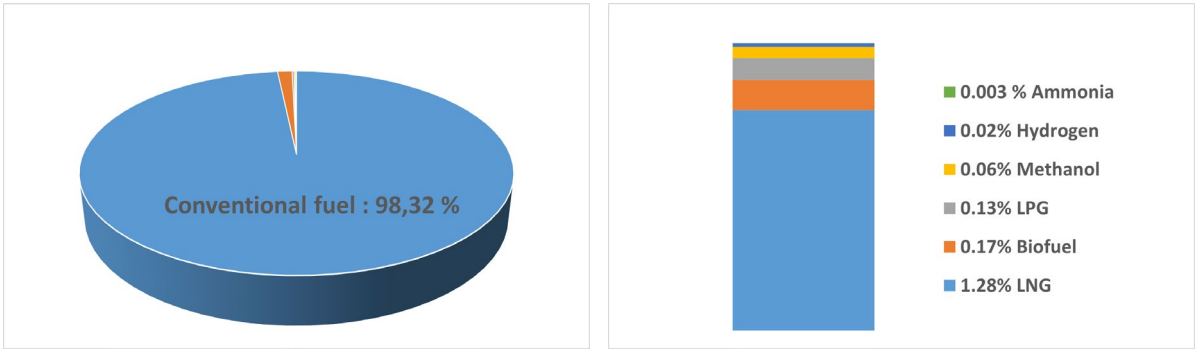

Figure 7: Alternative fuels uptake in the world fleet in number of ships; Source: Clarksons Shipping Intelligence Network, 10 August 2025

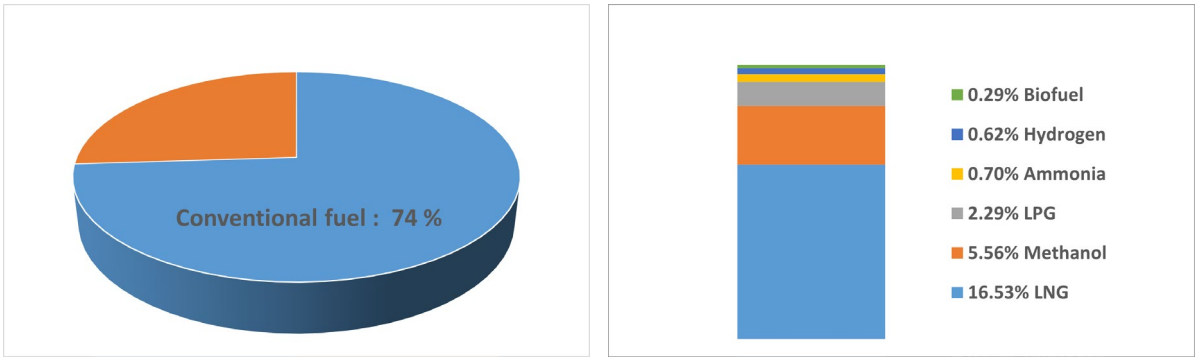

Figure 8: Alternative fuels uptake in the orderbook in number of ships; Source: Clarksons Shipping Intelligence Network, 10 August 2025

3.3 Adoption Barriers of Alternative Fuels

The use of alternative fuels faces several overarching challenges that hinder widespread adoption. For this reason, it is essential to leverage technologies that enhance energy efficiency and reduce overall fuel demand. The main barriers are outlined in the following paragraphs. Notably, these barriers do not apply uniformly: fossil-derived alternatives (e.g., grey hydrogen, grey methanol, fossil ammonia) and e-fuels/green variants (renewable hydrogen, e-methanol, e-ammonia) face different challenges, both in terms of technical requirements and regulatory treatment.

3.3.1 Sustainability and Certification of Fuels

The sustainability of alternative fuels presents a major barrier as their environmental impact relies on the production methods. Sustainable alternative fuels such as ammonia, hydrogen,

and methanol can be derived either from fossil or renewable sources, necessitating robust certification to distinguish “green” from “grey” fuels. Likewise, the GHG benefits of biofuels depend on feedstock origin and indirect land-use changes, which remain difficult to monitor. The lack of harmonized international sustainability standards and rigorous certification systems creates risks of rogue trading (e.g. grey hydrogen labelled as green hydrogen).

3.3.2 Availability of Alternative Fuels

Another fundamental barrier is the limited availability of alternative fuels, as global production is insufficient to support large-scale maritime utilization. Achieving the desired adoption of alternative fuels needs substantial expansion of production facilities or appropriate conversion of traditional refineries to be capable of meeting the upcoming demands [22]. While fossil-derived alternatives already rely on established industrial infrastructure, for e-fuels it is especially important to consider co-locating new carbon-neutral production plants with existing facilities, as this can reduce environmental impacts, lower costs and shorten project lead times. Moreover, achieving widespread adoption of e-fuels will require a massive expansion of renewable energy generation, grid capacity, electrolyser installations, and carbon capture infrastructure.

3.3.3 Fuel Bunkering Infrastructure

The deployment of bunkering infrastructure for alternative fuels is another critical challenge. While drop-in fuels such as hydrotreated vegetable oil (HVO), fatty acid methyl ester (FAME), and BioLNG can utilize existing bunkering infrastructure, fuels like ammonia, hydrogen and methanol require new refuelling facilities. The geographical mismatch between production sites and demand centres further complicates logistics and increase the cost [4]. The low volumetric energy density of alternative fuels such as liquid hydrogen and ammonia compared to conventional marine fuels poses a significant operational challenge. Since these fuels require three to four times more tank volume to deliver the same energy, ships either need to carry substantially larger fuel storage systems, reducing available cargo space, or rely on more frequent refuelling. This characteristic increases the importance of a densely distributed and reliable network of bunkering facilities, as vessels powered by hydrogen or ammonia may have shorter operational ranges between refuelling stops.

3.3.4 Engine Technology

Another significant barrier to achieving decarbonisation targets is the lack of technologically mature engines capable of operating with alternative fuels. While methane and methanol

engines are already commercially available across a wide power range, ammonia and hydrogen ones are projected to enter the market in the coming years. At present, ammonia and hydrogen internal combustion engines remain at an early stage of deployment with most activity limited to demonstration projects and pilot implementations. This technology readiness gap creates uncertainty for shipowners considering investments in new buildings designed for alternative fuels. Scaling these engine technologies to commercial use will require both successful large-scale demonstrations and the establishment of stable market incentives.

3.3.5 Price Differential

The price gap between conventional marine fuels and low-carbon alternatives remains a major barrier. Fossil fuels retain a strong cost advantage due to their maturity and global availability. Investors hesitate to fund unproven or capital-intensive solutions and shipowners face weak incentives to switch without regulatory intervention. The gap is going to be mitigated through policy mechanisms and stricter regulatory frameworks.

Among alternative solutions, a clear distinction exists between fossil-derived options and green/e-fuels, with the latter facing greater economic challenges. Production costs for e-fuels remain several times higher than those of fossil-derived alternatives, primarily due to the high price of renewable electricity and the limited maturity of large-scale production. However, under the FuelEU Maritime framework, fossil-derived fuels impose significant compliance costs on ship operators, making fully renewable e-fuels comparatively more attractive.

3.4 Hydrodynamic Efficiency Improvements

There are several EETs which aim to improve the hydrodynamic performance of the vessel. Ship's hydrodynamic resistance and especially calm water resistance remains a major factor reducing harmful emissions through vessel's energy demand. The solutions identified, address various aspects of a vessel's interaction with water, including hull and bow shape, wetted surface area and operating parameters. By applying measures such as hull form optimization, bulbous bow reshaping, specialized low-drag coatings and air lubrication systems it is possible to achieve significant reductions in fuel consumptions and GHG emissions.

Technologies related to ship hydrodynamic optimization are not limited to newbuilds, but most of them can be applied to retrofits as well. Testing through Computational Fluid Dynamic (CFD) simulations and onboard performance monitoring can play key role in assessing different EETs and finally identifying the most prominent hydrodynamic solutions for each ship segment type, route and operational profile.

The following sections outline the hydrodynamic efficiency optimization technologies, identified in early stages of the project FLEETfor55 and assess the maturity and market uptake for each one.

The IMO classifies **Air Lubrication Systems** (ALS) as an "Innovative Energy Efficiency Technology", indicating their potential for further fuel savings in the future. These systems provide a constant flow of air bubbles to lubricate significant parts of a vessel's hull (typically the flat bottom area), resulting to a reduction in the frictional resistance of the hull [23].

The effectiveness of this technology depends strongly on the vessel's operational profile and prevailing wave and weather conditions, which can disrupt the "air mattress" effect. It is estimated to achieve a GHG emission reduction of around 7% [21]. However, net fuel savings are heavily influenced by factors such as the air compressors' power demand (varies with draught and speed), the method of power generation (shaft generator and auxiliary diesel engines) and the specific fuel oil consumption when operating at partial loads [12].

ALS is a technologically mature energy-saving solution (TRL9), and applicable to both newbuilds and retrofits. According to the Clarksons SIN research database, ALS has been installed on 317 vessels to date (0.27% of total global fleet which is available in SIN), with the majority belonging to the OG segment. The main vessel types include gas carriers and containerships, while a significant number have also been implemented on ultra-large cruise ships, freight Roll-on/Roll-off (Ro-Ro) vessels and large ferries (Figure 9).

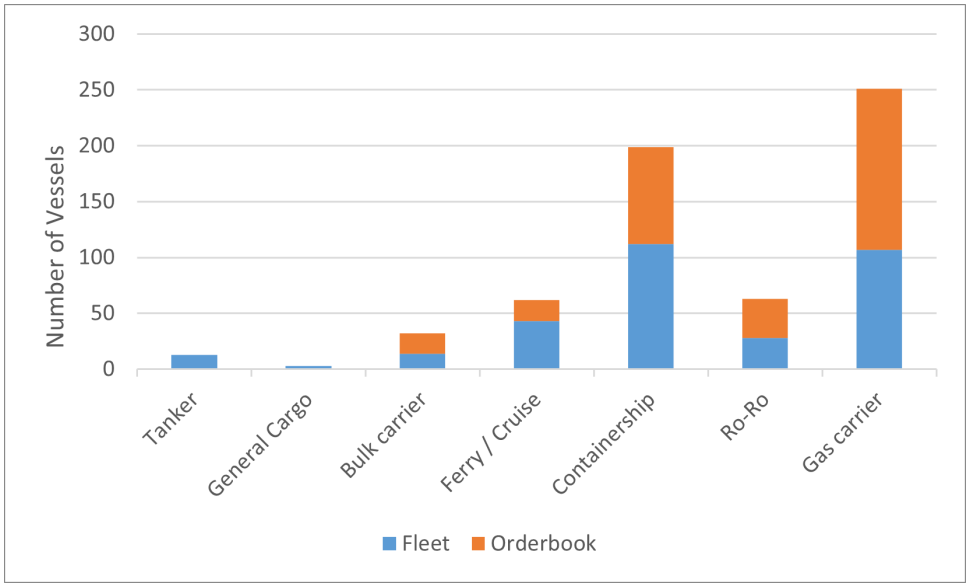

Figure 9: Air lubrication systems installation and order by vessel type, number of vessels; Source: Clarksons Shipping Intelligence Network, 10 August 2025

Hull Form Optimization (Streamlined Design for Efficiency) is one of the key techniques for improving a vessel's hydrodynamic performance. The objective is to design or modify the hull shape to minimize water resistance while ensuring stability, capacity, and operational requirements are met. For this purpose, a combination of parametric modelling, high-fidelity CFD tools as well as stochastic and deterministic optimization algorithms can be utilized to maximize the overall ship performance.

The reduction potential depends on factors such as vessel size, operational profile, and route type. Significant role plays the extent and methodology applied in optimizing the hull lines during the original design phase. A reduction of 4–8% in main engine fuel consumption is achievable if the vessel is optimized for a specific speed and draft using traditional tank testing methods.

This energy efficient solution is technologically mature (TRL9) and applicable to almost all ship types regardless of the vessel size and route, but only in the case of newbuildings.

Advances in computational power have made CFD simulations more capable and accurate. The increasing availability of data, along with the advancement of machine learning methods, can further enhance CFD applications. Techniques such as surrogate modelling can support genetic algorithms and improve CFD-based optimization. For these reasons, hull form optimization is expected to grow significantly in the coming years.

Hull surface coatings are applied to the ship's exterior to mitigate corrosion and structural damage, typically on a five-year maintenance cycle. Certain coatings, such as epoxy, polyurethane, silicon-based, can also decrease resistance through water, improving the overall vessel's performance. This technology can be applied to all vessel types, both retrofits and newbuilds, with better efficiency being observed in ships with higher block coefficients [24]. Friction-reducing hull coatings are ready for deployment (TRL9) and are already in widespread commercial use.

In many cases, a vessel's initial design is optimized for an operating profile different than the actual operating profile of the vessel at sea. Over the vessel's lifetime, operational changes such as slow steaming, absence of high speeds, different trading routes or loading patterns, may require a new optimization process adjusting the bulb's hydrodynamic characteristics to better align with vessel's actual operating profile. By **reshaping the bulbous bow**, it is possible to achieve significant efficiency gain (2-15%) and lower GHG emissions [12].

According to the Clarksons SIN database, the adoption rate is close to 3%, representing 3,457 vessels, with around 1,200 additional vessels planned to implement this energy-saving solution (orderbook). While its applicability to IWT vessels is limited, it is considered technically mature (TRL9) for OG and SSS vessels (see Annex B). The technology is most found

on oceangoing bulk carriers and containerships which together account for 70% of the global merchant fleet covered by Clarksons database.

The trim and draft of a vessel directly influence hull resistance and fuel consumption. By optimizing these parameters through careful adjustment and cargo loading, it is possible to achieve fuel savings and a corresponding reduction in GHG emissions.

Trim and draft optimization is applicable for all vessel types and vessel ages, especially in SSS and OG ships. In IWT options are very limited. Draft is chosen based on cargo and water depth while trim is set to minimize ventilation risk and to suit upstream/downstream navigation. Some vessels have limited flexibility in adjusting trims. For example, cruise ships are designed to meet passenger comfort needs. Similarly, in tankers and bulk carriers, where the viscous friction is higher than the wave-making resistance, the energy savings are lower. On the contrary, containerships demonstrate the highest gains from this technology [12].

This energy saving method has been in use for more than 30 years and it is considered fully mature (TRL9) [4].

3.5 Propeller and Propulsion Optimization

EETs including propeller modifications and Propulsion-Improving Devices (PIDs) are well-established in the market and are considered technologically mature (TRL9) for deployment. They can be classified in two categories based on the location of installation: EETs aft of the propeller (post-swirl EET) and EETs forward of the propeller (pre-swirl devices) [25]. The main EETs which were identified for the purposes of FLEETfor55 are outlined below.

A **Contra-Rotating Propeller (CRP)** uses two propellers mounted on the same axis, rotating in opposite direction, to improve efficiency and consequently reduce fuel consumption. This design recovers the energy lost in the slipstream of the first propeller, leading to a higher thrust force. CRPs have been researched widely in academia and have been installed in several vessels in recent years (TRL9) [26].

The **Propeller Boss Cap Fins (PBCF)** system consists of small fins mounted on the boss cap of the propeller, designed to recover energy from the propeller's hub vortex. The number of fins corresponds to the number of propeller blades. [25].

The potential gains of the PBCF amount to 1.4% to 1.7% and depend on the inflow to the propeller, the design of the propeller and the type and design of the propeller hub cap itself [12]. This ESD is suitable for all vessel types and can be applied to both retrofits and newbuildings.

The **Grim Vane Wheel** is a freely rotating device positioned behind the propeller, consisting of a turbine section located within the propeller slipstream and a propeller section placed outside the slipstream. Its main role is to extract energy from the slipstream through the turbine section and convert it into additional thrust through the propeller section [25].

Kort nozzles are ring-shaped ducts, with hydrofoil cross-section what surround the propeller. They have been well-developed by the maritime industry in recent years and are now applied across a variety of sea-going vessels [4]. By fitting the propeller with a non-rotating nozzle, the efficiency of the propeller is increased and the GHG emissions reductions accounted for 0.5 – 5%.

Their technology readiness level 9 was ensured by the partners for IWT and OG ships for both retrofits and new budlings (see Annex B).

A **gate rudder** improves the efficiency of a vessel by replacing the drag of a traditional rudder with a thrust-enhanced arrangement. The resulting reduction in fuel consumption depends on vessel type, its operational profile and the reference propeller and rudder. This EET can reach fuel savings up to 20% [27].

Apart from the fuel savings, gate rudders can enhance manoeuvring performance and reduce noise and vibration.

Pre-swirl PIDs are placed immediately before the propeller and pre-correct the flow that the propeller faces and consequently improve the propeller's efficiency [28].

One of the identified pre-swirl PIDs from Task 2.1 is **Wake Equalizing Duct (WED)**, which consists of two half-ring ducts fitted to the hull ahead of the propeller, as well as pre-swirl fins. [25].

The potential gains from this EET depend on the losses in the aft-body flow of the specific hull and the thrust force coefficient of the given vessel. In optimal cases, model tests have predicted gains of up to 9%. However, in less favourable cases the predicted gains may be as low as 2% or even less. To have the highest energy savings, an optimization for the individual hull form should be conducted [12].

Reports indicate a TRL of 9 for pre-swirl PIDs with several applications have been completed to date [21,4]. Partners of FLEETfor55 ensure these levels for OG retrofits and new buildings.

Installing **advanced propeller blade sections** on retrofits can enhance propulsion efficiency and lower fuel consumption. A newly designed propeller, which is optimised for the vessel's actual operational profile, can lead power savings of up to 5%. This is a mature technology (TRL 9) that can be applied to nearly all vessel types, with large containerships being among the most suitable segments.

3.6 Operations and Condition-based Monitoring

Cleaning and polishing the hull on a regular basis can improve the surface finish, reduce the water resistance and consequently improve the overall vessel's performance. The gain from this operational measure depends on the method used (e.g. in worst cases, hull cleaning can affect negatively the paint and result in marine growth). It is widely implemented (TRL9) and can contribute to GHG emissions' reduction up to 4% [21],[12].

Weather routing and voyage planning minimize the exposure to harsh weather conditions (e.g. waves and winds) which may pose substantial risk to a vessel, its cargo, crew and passengers. Moreover, by defining the exact arrival time with weather routing, it is possible to optimize fuel consumption by avoiding routes that will increase the propulsion power demand and respectively the fuel consumption due to adverse weather conditions. These systems rely on forecast weather data, the reliability and accuracy of which have been continuously improving over the years.

Slow vessels, defined as those operating substantially below their design speed, which travel in high sea states above 3m demonstrate the highest gains from weather routing systems. This is considered a mature operational measure for oceangoing ships, with a TRL of 9. According to project partners, in IWT the deployment is more limited, with reported TRL levels of 5–6 (Annex B).

Just In Time (JIT) arrival is a logistics and supply chain management measure which aims to optimize the voyage efficiency by ensuring that vessels arrive exactly when needed. With the appropriate exploitation of real-time data, careful voyage planning and effective communication between vessels and port authorities, shipping companies can benefit from this operational strategy.

To deal with potential barriers, shipping companies should adjust their vessel speed without breaching charter party clauses and the ships should be capable of exchanging high-quality data with all the port stakeholders.

According to partners, prototype just-in time strategies have built and validated in marine operational environments with small-scale demonstration deployments (TRL7).

Vessel's **speed optimization** by appropriate speed management during voyage and slow steaming can result in significant fuel savings. The reduction of speed can reduce fuel consumption, but it is translated with increased voyage time and consequently a greater number of actively sailing ships. The benefits of slow steaming vary depending on the types,

sizes and routes of the ships, with this technology being most suitable for tankers, containerships and bulk carriers, while its applicability in cruise vessels / ferries is limited [12].

This EET is considered fully mature for OG and SSS (TRL9), while in inland water transportation their technology maturity level is lower (5 to 6) for both retrofits and new buildings (Annex B).

Port turnaround time reduction is related to the optimization of all activities in port, including port entrance, departure and waiting time. This is mainly applicable to container vessels and Pure Car and Truck Carriers (PCTCs), as they typically operate on fixed schedules and face no contractual barriers to adjusting speed during voyages.

According to project's consortium experts, port procedure optimization techniques have been tested in relevant environments but have not yet been fully adopted in the market, with a TRL of 5–6.

Cargo load factor optimization strategies aim to improve transport efficiency by optimizing cargo capacity utilization. Shipment consolidation, route planning, stakeholder coordination and utilization of load planning systems are strategies in this category which aim to save energy and reduce GHG emissions [29].

According to FLEETfor55 consortium experts, this EET has a TRL of 5–6 across all ship segments for both retrofits and new buildings, indicating that further development and validation are needed before it can achieve widespread market adoption.

The already mature **autopilot technology** can be upgraded and adjusted in a way that it can contribute to voyage optimization. Small deviation to course-line with fewer and smaller-angle rudder movements can reduce fuel consumption and improve the vessel's performance. For this measure, appropriate crew training is important.

This is a widely implemented operational measure, particularly in SSS and OG segments (TRL9), while in IWT it is noted a TRL of 7 to 8 (Annex B).

3.7 Optimized Engineering Approaches

The concept of **Onboard Carbon Capture (OCC)** is based on technology that captures CO_2 directly on the vessel before it is released into the atmosphere through the exhaust.

OCC solutions are currently at the pilot stage of development, supported by a limited number of projects. As maritime applications remain rare and still under evaluation, only a few scientific articles on the subject are available [30,31]. The TRL is generally assessed at around 8, as pilot projects have already been completed or are currently in progress.

OCC is expected to reach commercial availability by 2030 [4,32]. In terms of vessel type, the application appears most favourable for large tankers and gas carriers, due to their greater space availability and higher CO_2 generation rates. By contrast, small bulk carriers and cruise vessels present the lowest suitability for OCC implementation [7,32].

Main adoption barriers of OCC

The wide adoption of OCC will require overcoming several barriers. The main challenge lies in the need to develop infrastructure to support this technology. Sustainable disposal pathways for the captured CO_2 will be required, necessitating the establishment of a dedicated CO_2 value chain. This includes the development of reception facilities at ports, along with processes for the effective management and sustainable handling of the captured carbon. In addition, there is still a lack of regulatory clarity regarding the acceptance of CO_2 capture and how it will be accounted for within various emissions schemes [33,34]. Furthermore, depending on the vessel's route and the size of the onboard storage tanks, intermediate port calls to offload the captured CO_2 may be required [12].

At reduced engine loads, fuel consumption is higher when operating at constant high revolutions per minute (rpm) which is a common issue in generator-driven systems designed for fixed speed. By integrating a **Variable Frequency Drive (VFD)**, the generator rpm can be adjusted to match the actual power demand, enabling more efficient operation and reducing fuel consumption [12].

Variable frequency drive is a mature EET (TRL9) with several commercial maritime applications [4] with containerships appear to be the most suitable vessel type for their implementation [12].

The main **light materials** which can substitute conventional materials in the naval sector are composites and aluminum.

Composite materials serve as a sustainable alternative to conventional metals, offering both economic and environmental advantages. They are less prone to corrosion, require lower maintenance and their reduced weight decreases propulsion energy demand leading to lower fuel consumption and reduced GHG emissions [35,36]. Although their initial manufacturing cost is higher compared to conventional materials like steel, if the full life-cycle costs are considered (maintenance and operating costs), then the composite materials may serve as a more affordable alternative [37]. To address existing economic and sustainability concerns, both an environmental life-cycle assessment and a life-cycle cost assessment should be conducted for different vessel types and operational profiles.

The first applications of composites in the marine sector were in military ships. After that, their use has expanded to small and medium-sized vessels, particularly in leisure, military, and competitive craft [35].

Similar to composite materials, aluminium alloys is a reliable alternative for shipbuilding, offering a favourable strength-to-weight ratio, excellent corrosion resistance, and low maintenance requirements.

However, according to project's consortium experts, super-light ships remain at a low technology readiness level (TRL 5–6) (see Annex B) and are still at a very early stage of commercialization, requiring further improvements in performance [38].

Engine tuning is the adjustment of key engine parameters close to their rated values in order to optimize the vessel's performance. This procedure can be completed manually on older engines and semi-automatically in more modern ones. The key aspect of this technique is the efficient use of diagnostic and prognostic simulation tools to evaluate different operating engine scenarios and define case-specific target parameters such as efficiency, power output, and emissions. This method can be applied to all vessel types, engines, sizes and operational profiles [12].

Electronic auto-tuning is another cutting-edge alternative which adjust operational parameters of each cylinder automatically, ensuring higher efficiency without perturbing the engine balance and functionality. The main technical challenge related to this optimized engineering approach is that conventional engines with mechanical injectors and governors need significant rebuild to support this solution. Most suitable vessel types, according to DNV experts [12], are large bulk carriers, tankers and PCTCs retrofits where the technology is considered fully mature (TRL9), while in IWT the operational deployment has not occurred yet (TRL 7-8) (Annex B).

Possible operating **improvements in boilers and steam network** can contribute to lower energy demand. Such corrective measures are updating the related maintenance procedures, optimizing the efficiency of steam production, installing sensors for automated accurate control, implementing better insulation for lower energy losses.

Cruise vessels and large tankers can benefit more from such improvements as these are equipped with large oil-fired boilers, where cargo handling and discharge represent significant steam-consuming operations [12].

Despite the fact that steam plant optimization methods are technically mature (TRL9), the adoption rates remain low due to the requirement for specialized crew [12], [38].

Optimization of HVAC and cooling systems can be applied to both retrofits and newbuildings and can lead to energy consumption savings. With the appropriate use of modelling and simulation techniques the optimal systems can be identified for the specific vessel type. This measure has significant potential for passenger and cruise vessels.

3.8 Power Conversion, Electrification and Energy Devices

Fuel cells are electrochemical devices which generate electricity through a reaction between fuel and oxygen. It produces no GHG emissions, with water and heat being the only byproducts of the reaction. Furthermore, they function as highly efficient power conversion devices, with typical efficiencies ranging between 50-60%. In the case of high temperature fuel cells, such as solid oxide fuel cells combined with heat recovery systems, overall efficiencies can reach up to 85% [39]. While hydrogen is the most common fuel used, sustainable alternative fuels such as methanol, ammonia or LNG can also be reformed to produce hydrogen for use in fuel cells.

Apart from the high efficiency and neutral environmental impact, other drivers for the wider implementation of fuel cells include their modular design and quiet operation [12].

On the other hand, operational barriers related to the storage, handling and supply of hydrogen onboard remain despite the broad research have been carried out in the development of fuel cells over the years. Due to their slow load-change capabilities, fuel cells require batteries onboard. The high capital expenditure due to the cost of fuel-cell systems, hydrogen storage and associated infrastructure sets an additional barrier for their wide market adoption [12]. The degradation of electrolytes, electrodes, and bipolar plates significantly reduces overall fuel cell system performance in terms of catalyst performance loss, reduced electrolyte conductivity, cracking, and corrosion [40]. To address these issues, new materials and technologies must be developed to mitigate the various types of fuel cell stack degradation.

There are several fuel cell technologies with different characteristics and levels of development. **Proton-Exchange Membrane** (PEM) hydrogen fuel cells are currently the most widely developed. Concerning high temperature fuel cells, **Solid Oxide Fuel Cells** (SOFCs) offer notable advantages, including fuel flexibility and higher power ratings. Other fuel cell types under development for shipping include Alkaline Fuel Cell (AFC), Phosphoric Acid Fuel Cell (PAFC), Montel Carbonate Fuel Cell (MCFC), high-temperature PEM fuel cell (HT-PEMFC).

Extensive research on fuel cells in the maritime sector has been funded by various countries and tested across different vessel types. In a review study on maritime fuel cell systems, Elkafas et al. [41] reported 33 funded projects between 2000 and 2022 aimed at deploying

fuel cell systems onboard ships. Among these, PEM fuel cells were the most widely tested, applied on 23 ships, while SOFC were demonstrated on two vessels.

Generally, hydrogen fuel cells have been widely tested in maritime environments and certain pilot/trial deployments have been completed so far (TRL8).

Fuel cells can be more easily adopted on inland water transport and short-sea shipping routes. This is due to challenges such as limited bunkering infrastructure, hydrogen storage constraints and dependence on batteries for energy storage, which make their application in oceangoing vessels more difficult. Data retrieved from Clarksons indicates a significant increase in the number of fuel cell installations in the orderbook, particularly for ferries and cruise ships (Figure 10).

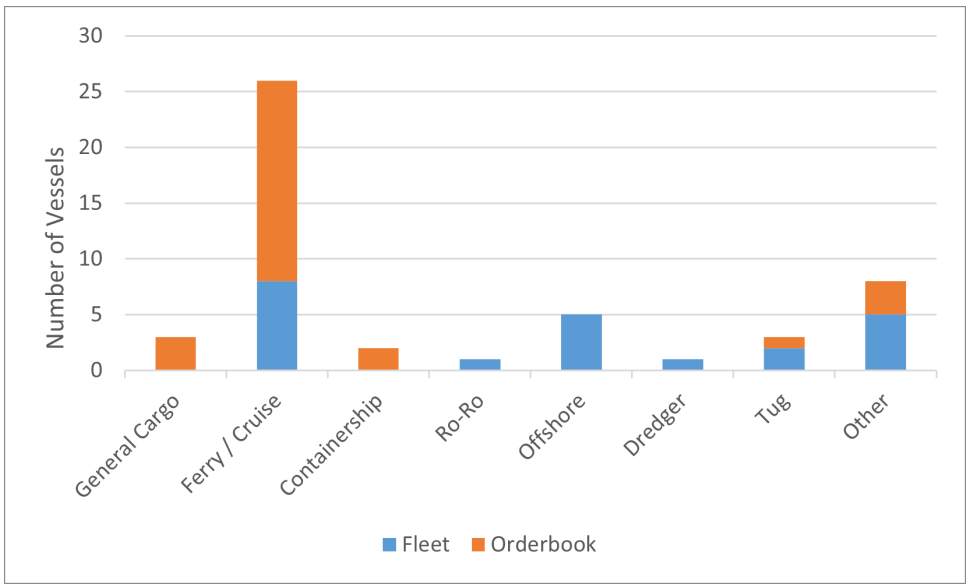

Figure 10: Fuel cells installation and order by vessel type, number of vessels ; Source : Clarksons Shipping Intelligence Network, 10 August 2025

The **electrification of ships**, particularly those used in short-distance transport, such as passenger ferries, has attracted significant attention in recent years. These vessel types are especially suitable due to their predictable docking schedules and shorter routes, which make battery recharging more practical [42].

Battery energy is integrated into ship systems in two main forms: all-electric and hybrid configurations. All-electric ships rely entirely on electricity stored in large onboard battery packs. Instead of relying on internal combustion engines, these ships meet their entire energy demand for both main propulsion and auxiliary systems through electricity supplied by

batteries. By contrast, hybrid ships combine battery power with an additional energy source, typically a diesel or gas engine [43].

According to Clarksons SIN, there are 740 battery vessels (hybrid or fully electric) in operation worldwide and 516 on order. Of these, 88% are hybrid configurations, while the remaining 12% are full electric vessels. The vessel segments with the highest number of battery-powered installations are offshore vessels and ferry/cruise ships (Figure 11). The use of battery-electric vessels is limited to cases where it is practical to store sufficient energy for the voyage. Although battery technology is already technologically mature (TRL9) and expected to advance further, it is not anticipated to become a viable alternative for the main propulsion of oceangoing vessels [4].

Despite space and weight constraints and the complexity of integration that older ships may present, batteries have also been installed through retrofits. A DNV report [12] indicates that approximately 30% of battery-powered vessels currently in operation worldwide are retrofitted.

Lithium-ion (Li-ion) batteries are the most prominent battery technology which were first introduced in the market in 1991. Over the past two decades they have gained broad popularity mainly because of their favourable technical characteristics, such as high energy and power densities, low self-discharged rate, ability to operate in a wide temperature range and long cycle life, compared with other batteries technologies [44]. On the other hand, the main concern with this battery type is safety, as thermal instability can lead to the risk of thermal runaway. This necessitates robust monitoring and management systems to ensure safe operation. Another key challenge which delays its market adoption is the high cost which is less competitive than that of other technologies [45].

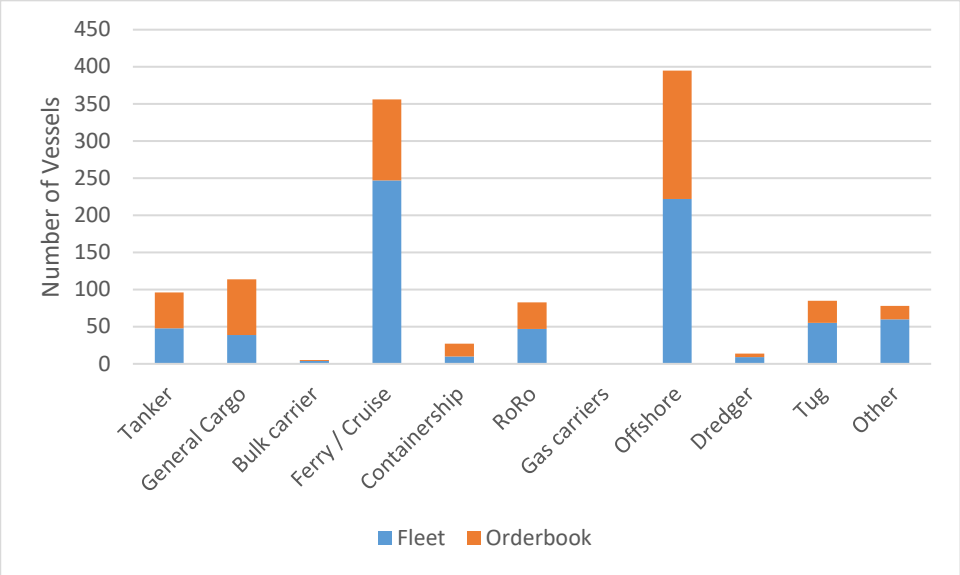

Figure 11: Battery-fuelled vessels; current fleet and orderbook by vessel type; Source : Clarksons Shipping Intelligence Network, 10 August 2025

The **Internal Combustion Engine (ICE)** has been the dominant vessel powertrain for more than a century. Despite its drawbacks, such as air pollution with GHG emissions, noise and vibration, it has established in the energy market due to its robustness, reliability, versatility in size and fuel type, high power density, relatively low cost and ease of maintenance [4].

ICEs operating on biofuels and synthetic e-fuels require only minimal engine adaptation and therefore face no significant technical barriers to widespread market adoption. These engines are technologically mature (TRL9), with their main drawbacks compared to ICEs running on conventional fuels being the higher costs and supply constraints.

Similar to biofuels and e-fuels ICEs, methanol 2-stroke and 4-stroke engines are also already in use (TRL9) supporting the increasing popularity of methanol as an alternative fuel solution [4].

On the other hand, hydrogen and ammonia engines have not yet entered the market. According to project experts, ICEs using these alternative fuels are currently at TRL 5–6, meaning that prototype systems have been built and tested in simulated environments. Other sources [46,4], however, indicate a TRL of 7–8, suggesting that these systems have already been validated in operational environments and undergone pilot or trial deployments.

Cracking ammonia into hydrogen allows for the use of a wider range of fuel cell types. However, the need for cracking and subsequent hydrogen purification adds technical complexity. Current TRL of this technology is estimated at 5 as pilot scale testing of

components in marine environment is on progress, with market entry expected within the next 3-5 years.

Waste Heat Recovery (WHR) is a highly effective energy-efficiency technique that captures heat rejected during engine operation and converts it into useful energy, typically in the form of electricity and service heat [12].

Although relatively few of these systems are currently installed on vessels, the technology is already commercially available and operating at full maturity (TRL9) [21].

According to Clarksons SIN, a total of 94 waste heat recovery systems is currently in operation worldwide, with an additional 82 on order. The majority of installed systems are found on ferries and cruise ships (28), while the greatest growth potential is observed in containerships, which represent the 56% of the systems on order (Figure 12).

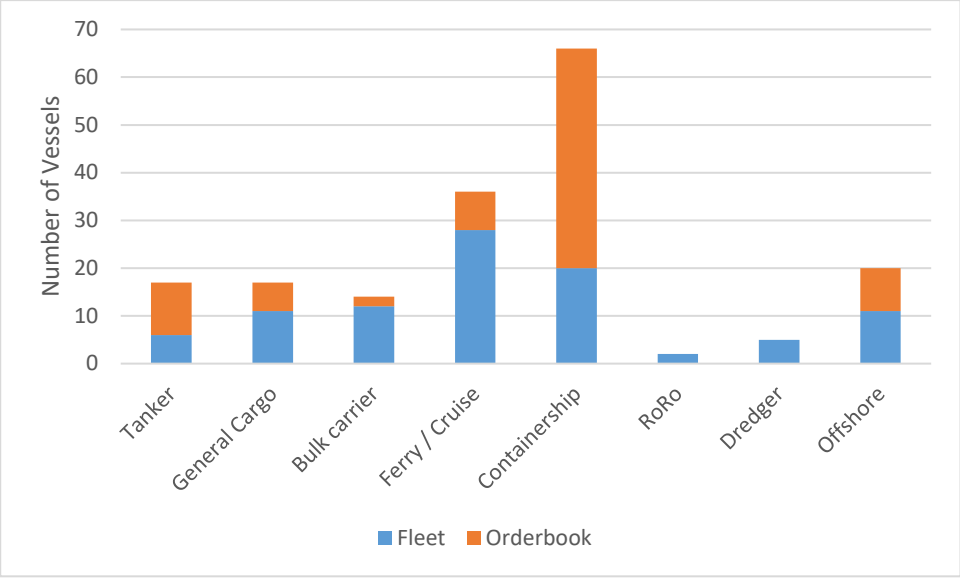

Figure 12: WHR systems installation and order by vessel type, number of vessels; Source: Clarksons Shipping Intelligence Network, 6 August 2025

By using an energy-efficient main engine to generate electrical power through a Power Take-Off (PTO), the system can also operate in reverse to boost the main propulsion shaft via Power Take-In (PTI), while Power Take-Home (PTH) offers an additional layer of redundancy. Furthermore, this configuration enables integration with energy storage systems, shore-to-ship power, and other new energy sources and functionalities within the vessel's power and propulsion plant. While the implementation of PTO/PTI makes ships more efficient and

flexible, it may require engine recalibration, shaft redesign and extra electrical systems to ensure safe and reliable function.

The PTO/PTI technology is considered mature (TRL9), with such systems already implemented on several vessels worldwide. Indicatively, in 2022 ABB equipped 10 containerships of COSCO Shipping Corporation Limited with its magnet shaft generator technology [47], while in 2024, 15 LNG carriers under construction for Qatar Energy were equipped with similar systems [48]. According to DNV report, PTI/PTO have been integrated especially in LNG carriers and containerships, while lately an increased trend is also detected in tankers and bulk carriers [12].

Onshore power supply (OPS), often called cold ironing, refers to the supply of electricity from the port to a vessel while it is docked. This power can be used to meet onboard energy demands, such as lighting, heating, cooling and cargo handling, eliminating the need to operate the ship's generators during port stays. As a result, OPS can contribute to the reduction of GHG emissions and the mitigation of noise in port areas. Moreover, it enables the charging of plug-in electric vessels.

OPS has been in commercial use since the early 2000s (TRL9), providing the industry with extensive operational experience. While it is common in smaller vessels, its broad implementation in larger ships remains challenging due to their higher electrical demands [12,4].

J. Williamsson et. al conducted an extensive literature review for the main barriers and drivers related to OPS [49]. This review indicates that the main barriers include high capital and operating costs, particularly for retrofitting vessels and upgrading port infrastructure, limited grid capacity, lack of compatibility between port and vessel systems and complex safety requirements. Moreover, the inconsistent regulation and inadequate international standards hinder the wider implementation of OPS. On the other hand, economic drivers such as subsidies and differentiated port fees, combined with technological advancements (e.g., smart grids, local renewable energy production, and more efficient grid integration) and fruitful stakeholder collaboration, can support and accelerate the adoption of OPS, helping it reach the desired standards.

The FuelEU Maritime Regulation, which came into effect on 1 January 2025, further facilitates the adoption of OPS. It requires passenger vessels and containerships above 5,000 GT to use OPS or an equivalent zero-emission solution to cover their electricity demand while at berth in main EU ports. By 2035, these obligations will be extended to include other ports equipped with OPS infrastructure [50].

A study by DNV on behalf of Transport & Environment, evaluated the readiness of 31 major European ports for the regulation related to OPS infrastructure required by 2030. The results showed that only 20% of the necessary OPS connections have been installed and just four ports (Algeciras, Livorno, Świnoujście and Valletta) have installed or contracted more than half of the connections required. The study also reveals significant disparities by vessel type. Cruise and passenger ships already have 38% of their required connections ready, while the container vessels lag far behind at only 11% [51].

Onboard power systems and associated power electronics, such as converters, switches, and solid-state transformers, are highly mature (TRL9) and commercially advanced technologies. They are already widely applicable in inland IWT, SSS and OG segments for both retrofits and new buildings (see Annex B).

The **Direct Current (DC)** distribution system has been proposed as an alternative to the conventional Alternating Current (AC) power distribution system currently used in electrically propelled ships.

Onboard DC grids offer multiple advantages such as higher efficiency, seamless integration of diverse power sources, smaller and lower-rated switchboards, elimination of reactive power flows and enhanced reconfiguration flexibility. Vessel efficiency is improved because the power generation system is no longer constrained to operate at a fixed frequency. Additional gains are achieved through reductions in both space and weight [52].

On the other hand, the widespread adoption of DC systems faces several technical challenges, such as the development of reliable DC circuit breakers, ensuring voltage stability, and maintaining power quality. [52].

Low-voltage direct current (LVDC) systems are already readily available on the market. In contrast, the application of high-voltage direct current (HVDC) systems in large vessels remains challenging, as high-power converters and breakers are still limited in availability and currently come at a high cost. [53].

The technology readiness level of DC grid technology is assessed by consortium experts close to 7-8 in small ships and near to 4 in larger ships since as power demand increases, DC grids continue to lack essential components and other supporting equipment (see Annex B).

Energy Management System (EMS) monitors and controls the power distribution and energy consumption. As part of the readiness assessment, this technology has been characterised as approaching maturity (TRL9).

4 Market Uptake

In this chapter, data from Clarksons SIN are used to analyse the adoption rates and market uptake of selected energy efficiency technologies (EETs). While the uptake of fuel cells, batteries, as well as carbon-neutral fuels has been addressed in Chapter 3, the present analysis focuses on hydrodynamic optimisation devices, PIDs, WAPS, solar panels, and WHR systems. The adoption rates of each EET are presented for both the current fleet (Table 3) and the confirmed orders (Table 4), to illustrate the current and short-medium term projected market uptake. The analysis has been carried out across the vessel types available in the database, namely general cargo ships, bulk carriers, passenger ferries and cruise ships, Ro-Ro vessels, gas carriers, and tankers. Whereas the previous chapter analysed adoption within each vessel type in absolute numbers, where the data are available for Clarksons, (see for example Figure 10), this chapter focuses on percentages, calculated by dividing the number of vessels equipped with EETs by the size of the existing fleet or the orderbook.

4.1 Current Adoption Rates

As shown in Table 3, propeller related EETs are currently the most widely adopted, largely driven by the relatively high uptake of established solutions such as rudder bulbs, pre-swirl stator fins, propeller ducts and propeller boss cap fins. This trend can be partly attributed to the shift in operational profiles of certain vessel types towards lower speeds, where these technologies deliver greater efficiency gains. Hydrodynamics optimization measures, such as bow enhancements, also demonstrate promising levels of adoption, while other technologies, such as air lubrication systems, remain at an earlier stage of deployment and require further testing to validate their performance benefits as well as scaling up through larger demonstrations and pilot projects. Concerning renewable energy integration systems and WHR technologies, their overall uptake in the fleet remains limited. Among WAPS, flettner rotors and suction wings are the most widely adopted solutions.

According to Clarksons SIN, only around 1 in 10 vessels has incorporated at least one EET. Regarding ship segments, bulk carriers lead in the adoption of EETs, with more than 40% having incorporated such measures, followed by containerships. In contrast, general cargo and passenger ferries/cruise ships show the lowest level of EET implementation. A similar picture emerges when examining adoption rates by EET category, with bulk carriers and containerships again leading overall uptake. In contrast, the use of renewable technologies remains very limited across all vessel types, with adoption rates below 0.5%, with Ro-Ro vessels being the only exception with an adoption rate of around 3.5%.

Table 3: Adoption rates of EETs in the world fleet

Vessel type		General cargo	Bulker	Ferry /cruise	Containership	Ro-Ro	Gas carrier	Tanker	Total
Category	EET								
Hydrodynamic optimization	Air-lubrication	0.01%	1.00%	0.45%	1.58%	1.59%	4.01%	0.07%	0.27%
	Bow enhancement	0.97%	13.27%	0.22%	9.0%	7.17%	5.70`%	1.39%	3.02%
	Hull fin	0.11%	8.57%	0.10%	1.0%	1.64%	0.12%	1.19%	1.38%
	Stern enhancment	0%	0%	0.01%	0%	0%	0%	0%	0.01%
	Bow foil	0%	0%	0.02%	0%	0%	0%	0%	0.001%
	Hull skating system	0%	0.007%	0%	0.13%	0%	0%	0%	0.008%
	Total	1.02%	17.42%	0.79%	11.12%	10.2%	9.21%	2.15%	4%
Renewables	Solar panel	0.02%	0.06%	0.35%	0.02%	2.94%	0%	0.02%	0.1%
	Flettner rotors	0.01%	0.08%	0.02%	0%	0.29%	0.12%	0.04%	0.03%
	Rigid sail	0%	0.03%	0.01%	0%	0.11%	0%	0.02%	0.009%
	Suction wing	0.08%	0.01%	0%	0.01%	0.11%	0.08%	0.05%	0.03%
	Wind Kite	0%	0.02%	0%	0%	0%	0.04%	0%	0.004%
	Inflatable sail	0%	0%	0%	0%	0.06%	0%	0%	0.0009 %
	Total	0.10%	0.18%	0.38%	0.03%	3.46%	0.24%	0.11%	0.17%
Energy devices	Waste heat recovery	0,05%	0.08%	0.29%	0.28%	0.11%	0%	0.03%	0.08%
Propeller	Propeller Duct	0.17%	13.08%	0%	0.76%	0.06%	4.91%	6.71%	2.88%
	Boss cap fin	0.20%	8.35%	0.22%	11.57%	8.47%	3.70%	3.61%	2.57%
	Stator fin- pre swirl	0%	11.98%	0%	12.98%	4.52%	2.24%	2.61%	2.83%
	Rudder bulb	0.36%	18.47%	0.85%	17.52%	10.58%	9.17%	3.98%	4.51%
	Rudder fin	0.009%	2.58%	0.01%	0.01%	0.06%	0%	0.14%	0.35%
	Stator fin- post swirl	0%	0.07%	0%	0%	1.47%	0.43%	0%	0.04%
	Wake Equalizing duct	1.12%	1.61%	0.01%	1.45%	0.24%	0.56%	1.03%	0.69%
	Gate rudder	0.01%	0.01%	0%	0.07%	0%	0%	0%	0.009%
	Total	1.83%	38.47%	1.04%	32.81%	20.59%	16.11%	14.11%	10.17%
Total		3,11%	41.57%	2.21%	33.8%	23.93%	21.91%	14.71%	11,38%

4.2 Orderbook Statistics

The inclusion of the orderbook increases the adoption from 11.38% to 12.72%. The following section offers a detailed commentary on the orderbook statistics.

Notably, around 3 out of 10 vessels in the orderbook (2455 out of 7356 vessels) are going to be fitted with at least one EET, which is 3 times greater than the adoption rates observed in the existing fleet. Ro-Ro vessels are the segment with the highest number of planned EET integrations, followed by containerships, gas carriers, and bulk carriers. Passenger ferries and cruise ships stand out as the only vessel type with an adoption rate below 33%, at just 15%. Naturally, the results are influenced by the difference in absolute numbers between the orderbook (7,356 vessels) and the existing fleet (114,724 vessels) tracked by Clarksons. Nevertheless, the percentage increases observed across all EET categories highlight future investment strategies and show a progressive trend of adoption.

The propeller – related EETs are again the most prominent category in the market, with at least one such EET planned to be installed on 1 out of 4 vessels, with rudder bulbs and stator fin-pre swirl devices be the most common ordered EETs. Bulkers, containerships and Ro-Ro ships are the vessel types with the highest percentage of integrated propeller-related EETs.

Within hydrodynamic optimisation devices, bow enhancement remains the most widely installed EET in the orderbook, followed by air lubrication systems, which are expected to be installed on more than 4% of confirmed ordered vessels. By contrast, stern enhancements and bow foils continue to show very low adoption rates. Ro-Ro vessels stand out as the segment with by far the highest integration rates of hydrodynamic improving devices, with more than half of ordered Ro-Ro ships expected to be equipped. In contrast, passenger ferries/cruise ships and tankers rank lowest in implementation of such EETs.

In terms of renewable integration systems, solar panels are the most widely adopted solution among confirmed orders, followed by flettner rotors and rigid sails. Although adoption rates have shown some increase, they remain relatively limited, with total uptake in this category not exceeding 2%. Ro-Ro vessels show again the highest integration rates among the analysed ship segments, while gas carriers and containerships record adoption rates lower than 1%.

WHR systems are planned for around 1% of vessels in the orderbook, with containerships accounting for the highest rate of these installations. By contrast, no WHR system orders have been recorded for Ro-Ro vessels and gas carriers.

Table 4: Adoption rates of EETs in orderbook

Vessel type		General cargo	Bulker	Ferry /cruise	Contai nership	Ro-Ro	Gas carrier	Tanker	Total
Category	EET								
Hydrodyna mic optimizatio n	Air-lubricatio n	0%	1.30%	5.46%	8.42%	19.55%	22.27%	0%	4.11%
	Bow enhancem ent	26.1%	23.87%	3.45%	30.49%	40.22%	15.67%	10.28%	16.33%
	Hull fin	0%	7.95%	0%	2.52%	0%	0%	0.98%	2.04%
	Stern enhancem ent	0%	0%	0.58%	0%	0%	0%	0%	0.12%
	Bow foil	0.13%	0%	0%	0%	0%	0%	0%	0.01%
	Hull skating system	0%	0%	0%	0%	0%	0%	0%	0%
	Total	26.1%	26.27%	8.91%	32.81%	54.75%	35.33%	10.41%	19.53%
Renewable s	Solar,pan el	0.13%	0.87%	1.73%	0.58%	12.85%	0%	0.06%	0.69%
	Flettner rotors	0.27%	1.30%	0%	0%	2.24%	0.46%	0.52%	0.47%
	Rigid sail	0%	0%	0.58%	0.10%	0.56%	0%	1.70%	0.41%
	Suction wing	2.12%	0.07%	0.29%	0%	0%	0%	0.06%	0.26%
	Wind Kite	0%	0%	0%	0%	0%	0%	0%	0%
	Inflatable sail	0%	0%	0%	0%	0%	0%	0%	0%
	Total	2.52%	2.24%	2.58%	0.68%	15.64%	0.46%	2.34%	1.83%
Energy devices	Waste heat recovery	0.80%	0.14%	2.29%	4.36%	0%	0%	0.72%	1.10%

Vessel type		General cargo	Bulker	Ferry /cruise	Containership	Ro-Ro	Gas carrier	Tanker	Total
Category	EET								
Propeller	Propeller Duct	1.06%	9.19%	0%	0.48%	0%	3.69%	5.96%	3.48%
	Boss cap fin	1.33%	13.97%	0%	3.39%	19.55%	4.15%	14.01%	6.95%
	Stator fin-pre swirl	1.06%	25.25%	0%	25.27%	19.55%	4.76%	17.29%	12.82%
	Rudder bulb	6.1%	15.63%	6.61%	30.60%	19.55%	23.81%	12.84%	13.36%
	Rudder fin	0%	5.07%	0%	0%	0%	0%	0%	0.95%
	Stator fin-post swirl	0%	0%	0%	0%	0%	0%	0%	0%
	Wake Equalizing duct	0%	0%	0%	0%	0%	0%	0%	0%
	Gate rudder	0.80%	0%	0%	0%	5.03%	0%	0%	0.20%
	Total	8.21%	41.39%	6.61%	39.60%	39.67%	29.19%	31.70%	24.55%
Total		33.38%	47.17%	15.51%	48.60%	63.68%	47.61%	35.30%	33.33%

4.3 Combination of EETs

Clarksons provides data on the absolute number of vessels that have integrated each individual EET. However, it does not directly report on vessels where multiple EETs are combined. To infer combinations, one must manually cross-check the total number of vessels fitted with all selected EETs against the sum of vessels with each EET individually. Given the potentially large number of possible combinations, this analysis focuses only on selected cases that are considered to have practical value.

For example, among the 326 vessels equipped with ALS, 180 also incorporate propeller-related EETs. Of the 83 vessels in the current fleet fitted with WAPS, 26 also feature propeller-related technologies, while 22 are combined with hydrodynamic optimization devices. Solar

panels and WHR systems show much less overlap: of the 120 vessels equipped with solar panels and the 96 with WHR systems, only two vessels have adopted both.

Furthermore, to identify the clusters of EETs that typically appear together by vessel type, a co-adoption matrix was developed using the extensive data available in Clarksons SIN. It is obvious from Table 5 that co-adoption patterns vary significantly across vessel types with propeller-related and hydrodynamic improvement technologies is the most widely combined. Bulkers and containerships most frequently combine propeller-related and hydrodynamic optimization technologies. Ro-Ro vessels demonstrate the greatest diversity, including the use of renewable technologies. Ferries and cruise ships show overlaps across all categories, although at relatively low rates. Gas carriers display minimal overlap, while tankers and general cargo vessels record generally low levels of combination.

Table 53: Co-adoption patterns of EETs

Containership				
Cluster of EET	Hydrodynamic optimization	Propeller	Renewables	WHR
Hydrodynamic optimization	-	722	0	5
Propeller	722	-	0	12
Renewables	0	0	-	0
WHR	5	12	0	-

Ro-Ro				
Cluster of EET	Hydrodynamic optimization	Propeller	Renewables	WHR
Hydrodynamic optimization	-	140	40	0
Propeller	140	-	46	1
Renewables	40	46	-	0
WHR	0	1	0	-

Ferry/Cruise				
Cluster of EET	Hydrodynamic optimization	Propeller	Renewables	WHR
Hydrodynamic optimization	-	19	2	2
Propeller	19	-	3	2
Renewables	2	3	-	2
WHR	2	2	2	-

Bulker				
Cluster of EET	Hydrodynamic optimization	Propeller	Renewables	WHR
Hydrodynamic optimization	-	2092	10	7
Propeller	2092	-	16	12
Renewables	10	16	-	0
WHR	7	12	0	-

Tanker				
Cluster of EET	Hydrodynamic optimization	Propeller	Renewables	WHR
Hydrodynamic optimization	-	285	4	4
Propeller	285	-	12	4
Renewables	4	12	-	0
WHR	4	4	0	-

General cargo				
Cluster of EET	Hydrodynamic optimization	Propeller	Renewables	WHR
Hydrodynamic optimization	-	38	11	6
Propeller	38	-	0	1
Renewables	11	0	-	0
WHR	6	1	0	-

Gas carrier				
Cluster of EET	Hydrodynamic optimization	Propeller	Renewables	WHR
Hydrodynamic optimization	-	98	2	0
Propeller	98	-	0	0
Renewables	2	0	-	0
WHR	0	0	0	-

Although direct insights into EET combinations are not provided in the Clarksons SIN dashboard, information on the integration of EETs within the different alternative-fuelled vessels is available.

Among hydrogen-fuelled ships, half of the existing vessels (10 out of 20) are equipped with at least one EET, while around 30% of vessels on order also incorporate EETs. The most adopted technology in this segment is WHR systems, followed by rudder bulbs and ALS (Figure 13).

In the case of methanol-fuelled vessels, the majority of the existing fleet is equipped with at least one EET. Propeller-related technologies, such as rudder bulbs, pre-swirl stator fins, propeller boss cap fins, and propeller ducts, are by far the most widespread, present in nearly all EET-equipped methanol-fuelled vessels (61 out of 62). The aforementioned EETs, together with hydrodynamic improvement measures such as bow enhancement and ALS, dominate the orderbook. Other technologies, including WHR systems, Flettner rotors, hull fins, and solar panels are also expected to emerge in this kind of vessels (Figure 14).

Among the current fleet tracked by Clarksons SIN only four vessels are ammonia-fuelled and none of which are equipped with EETs. In the orderbook, however, 43 ammonia-fuelled vessels are on record, with a total of 13 expected to incorporate technologies such as rudder bulbs, bow enhancements, pre-swirl stator fins, and solar panels (Figure 15).

Among biofuel-fueled vessels, EETs are found in 33% of the existing fleet (70 out of 209 vessels). The most common technologies include rudder and propeller ducts, pre-swirl stator fins, propeller boss cap fins, and WHR systems. With regard to the relatively limited orderbook, the confirmed biofuel-operated vessels will be featured only rudder bulbs and bow enhancement measures (Figure 16).

According to Clarksons SIN, the existing fleet includes 751 vessels utilizing batteries, either for full-electric propulsion or as part of hybrid propulsion systems. Among these, 204 vessels have adopted at least one EET, with bow enhancement measures, rudder bulbs, and solar panels being the most common. In the orderbook, bow enhancement stands out as by far the most

common EET, incorporated in roughly one out of every four hybrid or fully ordered electric vessels (Figure 17).

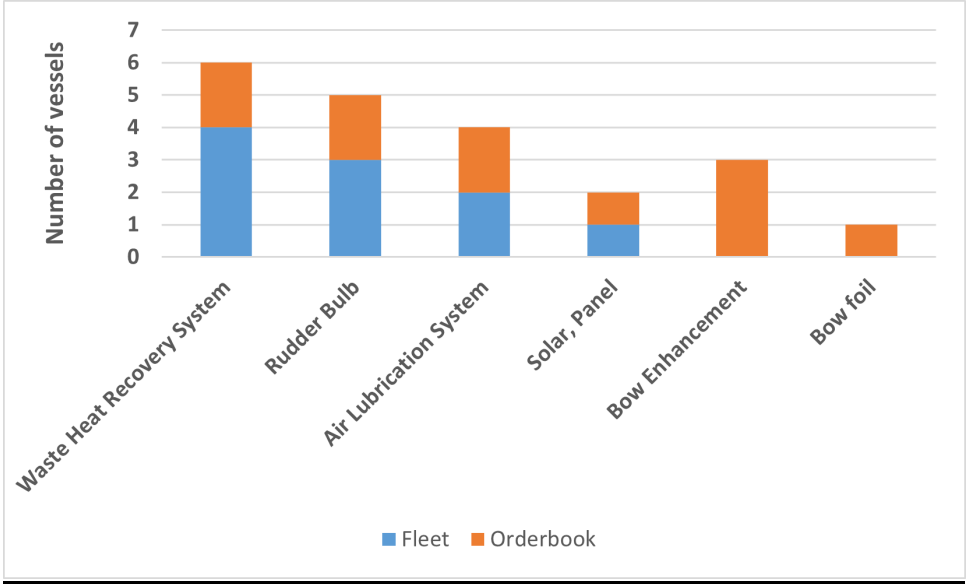

Figure 13: EETs uptake in hydrogen-fuelled vessels, number of vessels; Source: Clarksons Shipping Intelligence Network, 11 September 2025

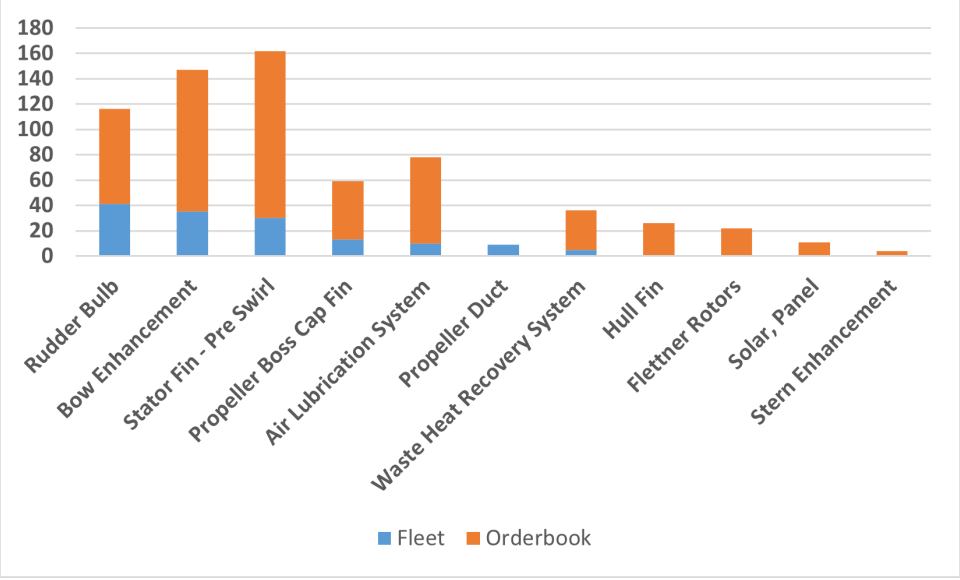

Figure 14: EETs uptake in methanol-fuelled vessels, number of vessels; Source: Clarksons Shipping Intelligence Network, 11 September 2025

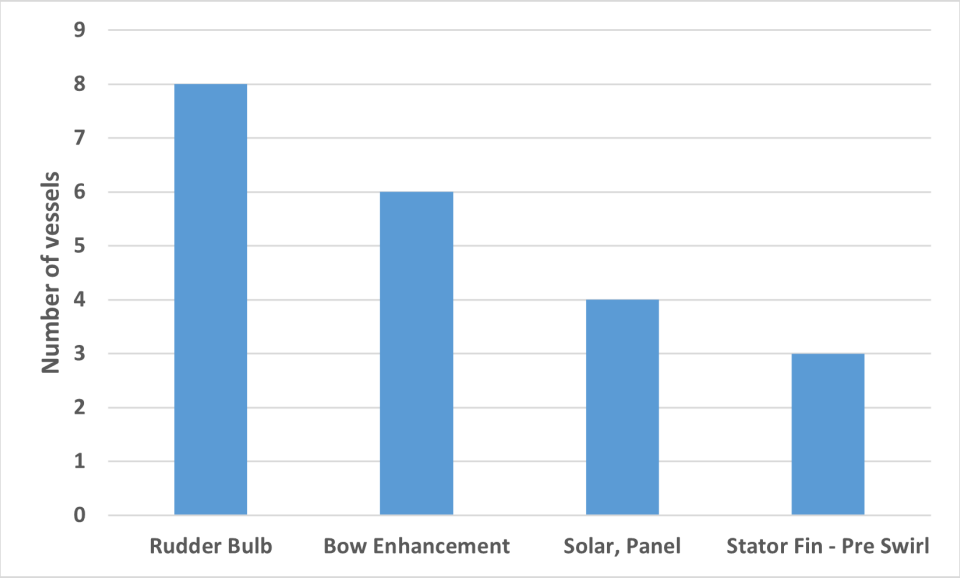

Figure 15: EETs uptake in ammonia-fuelled vessels, number of vessels; Source: Clarksons Shipping Intelligence Network, 11 September 2025

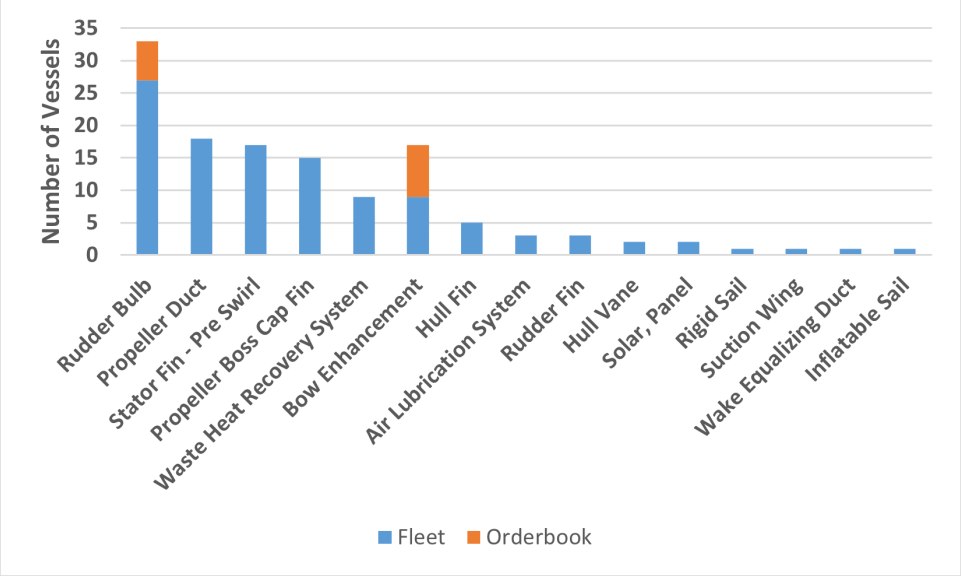

Figure 16: EETs uptake in biofuel-fuelled vessels, number of vessels; Source: Clarksons Shipping Intelligence Network, 11 September 2025

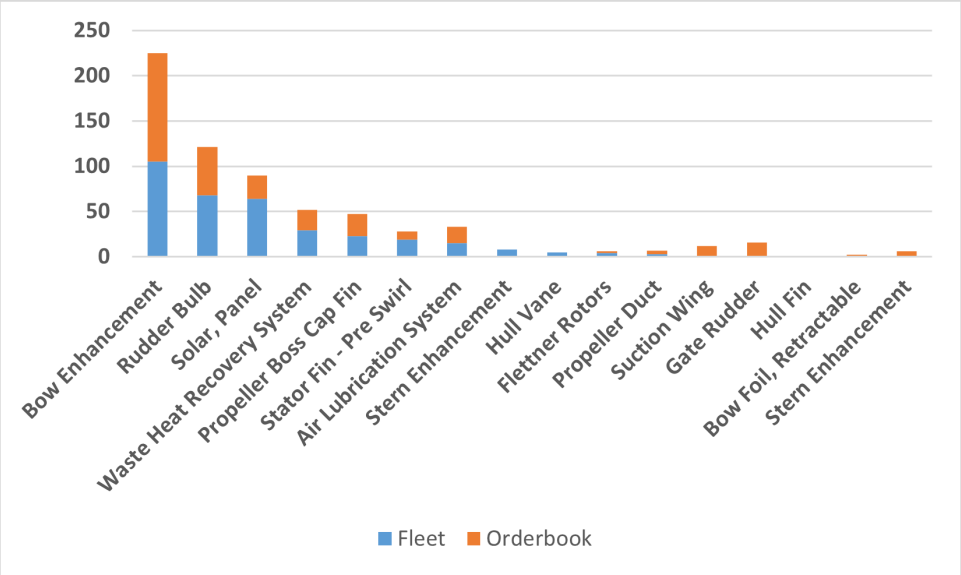

Figure 17: EETs uptake in hybrid and full electric vessels, number of vessels; Source: Clarksons Shipping Intelligence Network, 11 September 2025

4.4 IWT Database

Various SSS and OG vessels are covered with the information related to IWT be limited in Clarksons SIN. For this reason, a pilot database has been developed within the SYNERGETICS project and shared with project's consortium by DST is utilized in this section.

In this database there are 109 projects which covers technologies such as methanol and hydrogen ICEs and fuel cells as well as batteries.

Regarding hydrogen fuel cells, there are 48 related projects, of which 2 have been completed successfully and 6 achieved partial success. Some projects have not finished yet, while other have failed and yielded unclear results. One of the main barriers identified and block the commercialization of these technologies in the bunkering procedures.

Among the 6 projects related to hydrogen ICEs, 2 have been completed successfully, with one progressing to commercial application.

Methanol-related projects account for a total of 27. Among them, only 3 are fuel cell projects, none of which have recorded successful results. In contrast, 24 projects are related to methanol ICEs, of which 5 have been successfully completed, including 3 that have reached commercial operation.

The majority of projects (65) involve the use of batteries, either as the sole propulsion system or in combination with fuel cells. A large share of these (39) have been successfully completed, highlighting the strong potential of battery technologies for inland and coastal vessels.

5 Market Players

For each EET category, brief lists of operating companies and shipyards integrating these EETS has been compiled and are presented in Annex D and Annex E respectively. These lists are not exhaustive, as many more companies are active in these technologies, and they are based exclusively on data reported in Clarksons SIN.

5.1 Shipping Companies

The adoption of hydrodynamic optimization devices is concentrated among several large shipping companies. Around ten companies each operate fleets with more than 60 vessels equipped with such EETs, positioning them as frontrunners in their adoption.

For WAPS, Clarksons data shows that uptake is led by a small number of companies, with only one or two shipping companies having integrated the technology in their fleet at a notable scale, while the rest have fewer than ten vessels equipped. By contrast, the adoption of solar panels is more broadly distributed across companies, without a clear concentration among just a few players.

Propeller-related EETs, such as boss cap fins, ducts, and stator fins, represent the most widely adopted category. The largest operating companies each have more than 200 vessels equipped with these technologies, demonstrating their widespread application across large fleets.

Fuel cell deployment remains at a very early stage. Only a small number of operators have integrated these systems into their fleets, typically on a handful of vessels.

Battery integration shows more advanced uptake compared to fuel cells. A group of operators each manage fleets with 30 or more vessels equipped with batteries, while the top ten shipping companies in this category each own at least 12 battery-equipped vessels (hybrid or fully electric).

5.2 Shipyards

The integration of hydrodynamic optimization devices is dominated by shipyards in East Asia, particularly in China and Japan, which together account for about four-fifths of global vessel installations. Within this segment, one leading Japanese shipyard alone has completed or confirmed more than 600 integrations, highlighting its position as a frontrunner.

For WAPS, Chinese shipyards are the main centres of integration, followed by builders in Japan and selected European countries (e.g. Netherlands, Germany and Norway). A similar trend applies to solar panels, where Chinese shipyards represent more than half of confirmed applications.

Propeller-related devices are more evenly distributed across major shipbuilding regions, with leading shipyards in South Korea, Japan, and China collectively accounting for the majority of integrations.

Fuel cell projects remain limited in number and are primarily concentrated in European shipyards. Several builders in Italy, Germany, France, and the Nordic region have taken the lead in these demonstration projects. In one case, a European shipyard has confirmed around ten vessels with fuel cells either in operation or on order.

Battery integration is most advanced in China, followed by Norway and Turkey, where shipyards collectively account for more than 700 vessels equipped with such systems. Within these countries, a few shipyards stand out as frontrunners, each having delivered several dozen battery-equipped vessels.

6 Conclusions

Work Package 2 of the FLEETfor55 project has delivered systematic benchmarking of key EETs that are expected to play a pivotal role in the maritime sector's transition toward greater sustainability and competitiveness. Task 2.1 as the backbone of the Work Package, identified a broad range of EETs, categorized them into seven clusters and established a robust foundation for the evaluation of them providing useful material for the subsequent analysis. Building on this, Task 2.2 broadened the scope by presenting a comprehensive overview of the full spectrum of identified EETs. This mapping highlighted the key drivers (e.g., energy savings, emissions reduction potential, and suitability across vessel types) with the main challenges (such as high capital costs, limited operational feasibility and applicability and immature development status) for each EET. In addition, this task incorporated an assessment of the technology readiness levels (TRLs) of each EET, exploiting insights from both literature review and partner expertise.

Furthermore, by combining evidence from shipping database with literature analysis, this task has provided insights into both the current and projected adoption of various EETs, considering confirmed orders. This market-oriented perspective ensures that the evaluation not only reflects technical maturity but also aligns with industry uptake trends.

In summary, Task 2.2, together with the forthcoming analyses of preliminary economic feasibility (Task 2.3) and technical applicability and feasibility (Task 2.4), will generate valuable inputs for the decision support tool to be developed in Task 2.5. This integrated approach will enable a holistic assessment of the sustainability of each EET, thereby ensuring that the outcomes of Work Package 2 provide a strong basis for informed decision-making in the WP3.

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Annex A: TIN Questionnaire

Annex A presents the TIN Questionnaire. Since this questionnaire has now been digitalised and is available online in the project's repository, this Annex contains the previous version for reference purposes.

FLEETfor55

State-o**F**-the-art sustainab**L**e **E**nergy **E**fficiency **T**echnologies roadmap for waterborne transport towards the fit-**for-55** guidance compliance

Technologies Innovation Network (TIN)

TIN Members' Introduction Form

TIN MEMBER CONTACT INFORMATION

COMPANY NAME	
COMPANY ORIGIN (Country / City)	
BUSINESS AREA	
MAIN CONTACT NAME	
MAIN CONTACT'S ROLE	
MAIN CONTACT EMAIL	

1

Co-funded by the European Union

FLEETfor55

State-o**F**-the-art sustainab**L**e **E**nergy **E**fficiency **T**echnologies roadmap for waterborne transport towards the fit-**for-55** guidance compliance

Technologies Innovation Network (TIN)

TIN Members' Introduction Form

ENERGY EFFICIENCY TECHNOLOGY (EET) INFORMATION

ENERGY EFFICIENCY TECHNOLOGY (EET)	
EET DESCRIPTION	
CATEGORY OF THE SOLUTION *	
VALIDATION REPORTS / PUBLICATIONS FOR THE EET *(if applicable)*	

Category of the solution
- *Power conversion/electrification/energy devices (WHRS, PTI/PTO, cold ironing etc.)*
- *Sustainable climate-neutral fuels (Hydrogen, Ammonia, Biofuels, etc.)*
- *Renewables (PV solar panels, WASPs sails, etc.)*
- *Hydrodynamic efficiency improvements (air lubrication, hull coatings, etc.)*
- *Operations & Digital Optimization (Just-in-time scheduling, Weather routing, etc.)*
- *Optimized Engineering Approaches (Main Engine Tuning, Advanced HVAC & cooling, VFDs, etc.)*
- *Propeller & Propulsion Optimization (Pre-swirl ESDs, propeller nozzle, etc.)*
- **** any other category naming as defined by your side*

Co-funded by the European Union

FLEETfor55

State-o**F**-the-art sustainab**L**e **E**nergy **E**fficiency **T**echnologies roadmap for waterborne transport towards the fit-**for-55** guidance compliance

Technologies Innovation Network (TIN)

TIN Members' Introduction Form

ENERGY EFFICIENCY TECHNOLOGY (EET) DETAILS

CURRENT TRL* OF EET						
EXPECTED TIME OF ENTERING THE MARKET (if not already)						
IS THE EET MARINE TYPE APPROVED?						
APPLICABILITY	NEW BUILDING		RETROFIT		BOTH	
NUMBER OF VESSELS APPLIED ALREADY						

ENERGY EFFICIENCY TECHNOLOGY (EET) DETAILS FOR INTEGRATION ON VESSELS:

INTEGRATED EET	VESSEL TYPE	VESSEL SIZE	ENERGY SAVING (%)	GHG EMISSIONS REDUCED AND REDUCTION (%)	NON-COMPLIANCE WITH OTHER EETs? WHICH ONES?

***TRL: Technology Readiness Level**

TRL1 Define basic properties, TRL2 Analytical study, TRL3 Proof of concept, TRL4 Pre-prototype, TRL5 Pre-prototype tested in lab, TRL6 Prototype tested in relevant environment, TRL7 Approved prototype, TRL8 Pre-serial manufacturing, TRL9 Product on market

Annex B: Matrix of EETs vs Segments – TRL (Partners' Input)

EET	Newbuilding			Retrofit		
	IWT	SSS	OG	IWT	SSS	OG
Onboard Carbon Capture and Storage (CCS) Systems	-		5-6	-		5- 6
Hull Form Optimization (Streamlined Design for Efficiency)	9		9	9		9
Air lubrication systems (ALS)	8	9	9		9	9
Hull Surface Coatings & Low-Drag Paints	-		9	-		9
Bulbous Bow Optimization			9			9
Hull Openings and Skeg Shape Optimization	9		9	9		9
Trim & draft optimization	9		9	9		9
Variaton of block coefficient/lengthening (Inland)	9		9	9		9
Hull Cleaning & Condition-Based Monitoring - onboard measurements	-		9	-		9
Hull Protection based on Ultrasound tech	-			-		
CPP pitch optimization and propeller performance monitoring - onboard measurements	8			9		
Weather routing systems for voyage speed/fuel optimization	5-6		9	5-6		9
Just-in-time (JIT) arrival strategies	7	7	7	7	7	7
Speed optimization (slow steaming)	5-6	9	9	5-6	9	9
Port Turnaround Time Reduction	5-6	5-6	5-6	5-6	5-6	5-6
Cargo Load Factor Optimization	5-6	5 -6	5-6	5-6	5-6	5-6
Autopilot Upgrade and Adjustment	7-8	9	9	7-8	9	9
Main Engine Tuning & Optimization	7-8			7-8		
Variable Frequency Drive (VFD) for speed control (e.g. pumps, fans)						
Lightweight shipbuilding materials (composites, aluminum)	5-6	8	4	5-6	5	5
Reduced Auxiliary Power Demand						

EET	Newbuilding			Retrofit		
	IWT	SSS	OG	IWT	SSS	OG
Steam/heat plant improvements/optimization						
Advanced HVAC & cooling systems						
Heaving Oscillating Systems						
Full Electric Propulsion Concepts (e.g. dynafin, Superconducting electric motors)		4	4		4	4
Alternative Fuelled 2-S ICEs (e.g. hydrogen, ammonia, methanol)	5	5	5		5	5
Alternative Fuelled 4-S ICEs/Gensets (e.g. hydrogen, ammonia, methanol, biofuels)	5-6	5	5	5-6	5	5
Waste heat recovery systems (WHRS)			9			9
PEM fuel cells	8	7		8	7	
SOFC fuel cells						
Other type of fuel cells						
Energy storage systems (ESS) – lithium-ion batteries		8			8	
Energy storage systems (ESS) – redox flow batteries (RFB)						
Onshore Power Supply [OPS]		9	9		9	9
Low-Loss Power Distribution Systems (for new builds)						
Shaft Generator PTI, PTO, PTI/PTO			9			9
Hydrofoil-Based Wave Energy Converters	-	-	-	-	-	-
Post-swirl ESD Contra-rotating propellers (CRP)			9			9
Pre-swirl ESD Wake Equalizing Ducts (WEDs)			9			9
Pre-swirl ESD ESD Fins			9			9
Manoeuvring devices (e.g. Gate rudder)			9			9
Propeller Nozzle (e.g. Kort)	9		9	9		9
Post-swirl ESD PBCF (Propeller Boss Cap Fins)			9			9
Post-swirl ESD Grim Vane Wheel			9			9
Pulling Azimuth Thrusters	9		9	9		9

EET	Newbuilding			Retrofit		
	IWT	SSS	OG	IWT	SSS	OG
Propeller-Retrofitting Advanced propeller Blade Sections (e.g. Winglets/kappel)						
WAPS - Soft Sails			9			9
WAPS- Flettner Rotors (Magnus Effect Rotors)			9			9
WAPS - Rigid Wing Sails			9			9
WAPS - Kite Propulsion Systems			9			9
WAPS - Suction Wings (Ventifoils)			9			9
WAPS - Turbosails			9			9
WAPS - Dynarig (DynaRig) System			9			9
SOLAR - Photovoltaic (PV) Panels for Ships		6	6		6	6
Fuel Reforming/Cracking			9			9
Methanol			7-8			7-8
Biomethane			9			9
Ammonia			5			5
Biodiesel	7		9			9
Synthetic Biofuels (Power-to-Liquid E-Fuels)						
Hydrotreated Vegetable Oil (HVO - Renewable Diesel)	8		9			9
Hydrogen	7		6			6
Synthetic e-fuels						
Onboard Power Systems and Power Electronics (converters, switches, solid-state transformers)	9	9	9	9	9	9
DC Grid technologies	7	7	4	8	7	4
Electric propulsion systems and thrusters (including Rim-driven thrusters)	9	9	9	9	9	9
Energy Management Systems (EMS)			9			9

Annex C: TRL from Literature Review

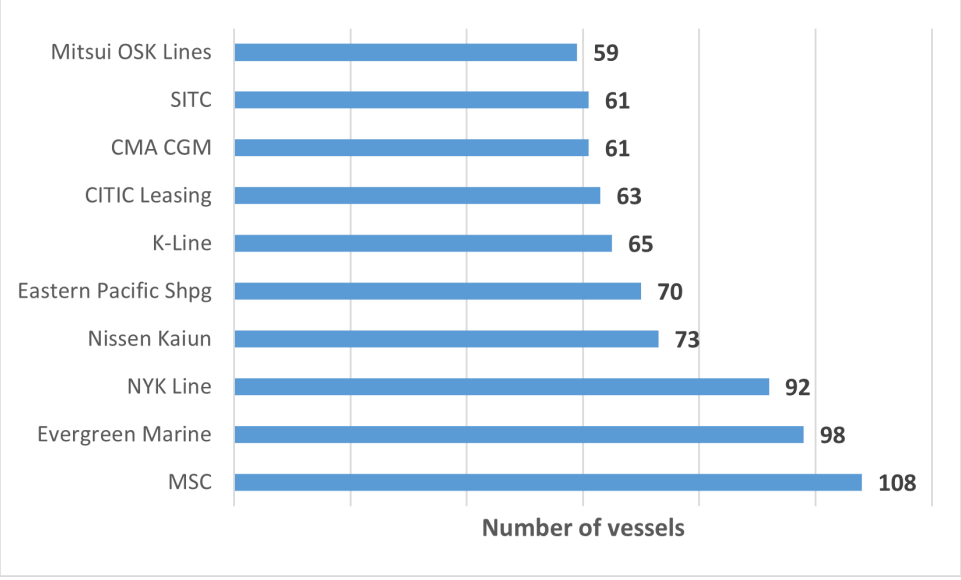
EET	TRL
Onboard Carbon Capture and Storage (CCS) Systems	8
Hull Form Optimization (Streamlined Design for Efficiency)	9
Air lubrication systems (ALS)	9
Hull Surface Coatings & Low-Drag Paints	9
Bulbous Bow Optimization	9
Hull Openings and Skeg Shape Optimization	9
Trim & draft optimization	9
Variation of block coefficient/lengthening (Inland)	
Hull Cleaning & Condition-Based Monitoring - onboard measurements	9
Hull Protection based on Ultrasound tech	
CPP pitch optimization and propeller performance monitoring - onboard measurements	9
Weather routing systems for voyage speed/fuel optimization	9
Just-in-time (JIT) arrival strategies	9
Speed optimization (slow steaming)	9
Port Turnaround Time Reduction	9
Cargo Load Factor Optimization	9
Autopilot Upgrade and Adjustment	9
Main Engine Tuning & Optimization	9
Variable Frequency Drive (VFD) for speed control (e.g. pumps, fans)	9
Lightweight shipbuilding materials (composites, aluminum)	9
Reduced Auxiliary Power Demand	9
Steam/heat plant improvements/optimization	9
Advanced HVAC & cooling systems	9
Heaving Oscillating Systems	
Full Electric Propulsion Concepts (e.g. dynafin, Superconducting electric motors)	
Alternative Fuelled 2-S ICEs (e.g. hydrogen, ammonia, methanol)	Hydrogen and ammonia 7-8 / Methanol 9

EET	TRL
Alternative Fuelled 4-S ICEs/Gensets (e.g. hydrogen, ammonia, methanol, biofuels)	Methanol, Hydrogen and Ammonia 7-8 / Biofuels 9
Waste heat recovery systems (WHRS)	9
PEM fuel cells	8
SOFC fuel cells	8
Other type of fuel cells	
Energy storage systems (ESS) – lithium-ion batteries	9
Energy storage systems (ESS) – redox flow batteries (RFB)	
Onshore Power Supply [OPS]	9
Low-Loss Power Distribution Systems (for new builds)	
Shaft Generator PTI, PTO, PTI/PTO	9
Hydrofoil-Based Wave Energy Converters	
Post-swirl ESD Contra-rotating propellers (CRP)	9
Pre-swirl ESD Wake Equalizing Ducts (WEDs)	9
Pre-swirl ESD ESD Fins	9
Manoeuvring devices (e.g. Gate rudder)	9
Propeller Nozzle (e.g. Kort)	9
Post-swirl ESD PBCF (Propeller Boss Cap Fins)	9
Post-swirl ESD Grim Vane Wheel	9
Pulling Azimuth Thrusters	
Propeller-Retrofitting Advanced propeller Blade Sections (e.g. Winglets/kappel)	9
WAPS - Soft Sails	9
WAPS- Flettner Rotors (Magnus Effect Rotors)	9
WAPS - Rigid Wing Sails	9
WAPS - Kite Propulsion Systems	9
WAPS - Suction Wings (Ventifoils)	9
WAPS - Turbosails	
WAPS - Dynarig (DynaRig) System	
SOLAR - Photovoltaic (PV) Panels for Ships	9
Fuel Reforming/Cracking	5
Methanol	9
Biomethane	9
Ammonia	9
Biodiesel	9

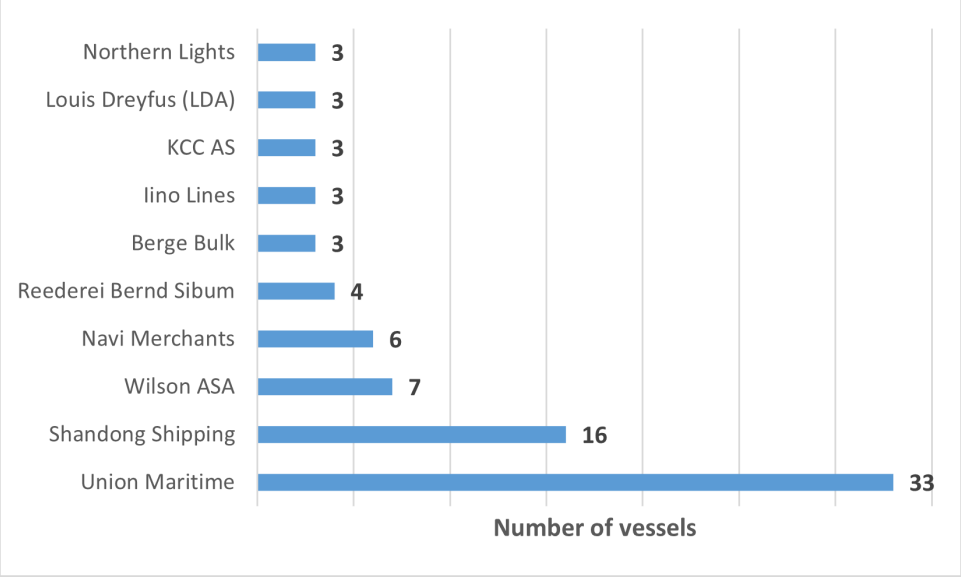
EET	TRL
Synthetic Biofuels (Power-to-Liquid E-Fuels)	9
Hydrotreated Vegetable Oil (HVO - Renewable Diesel)	9
Hydrogen	9
Synthetic e-fuels	9
Onboard Power Systems and Power Electronics (converters, switches, solid-state transformers)	9
DC Grid technologies	9
Electric propulsion systems and thrusters (including Rim-driven thrusters)	
Energy Management Systems (EMS)	9

Annex D: Top Shipping Companies per EET Category

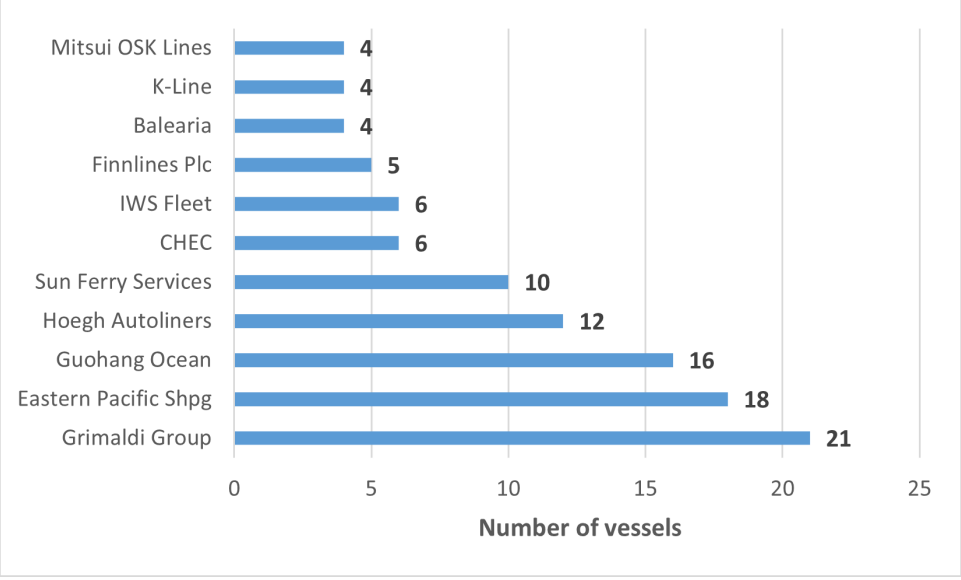
HYDRODYNAMIC OPTIMIZATION



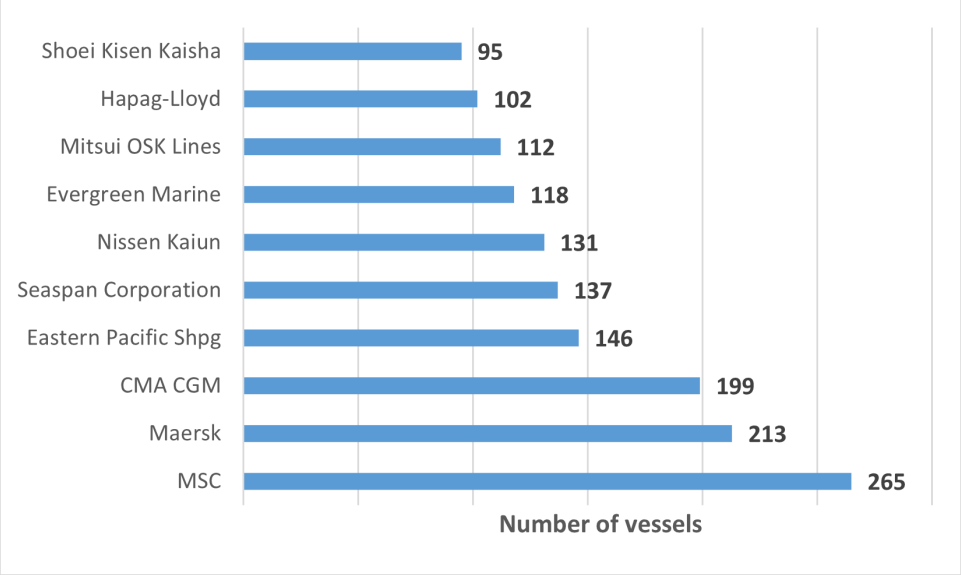
WAPS



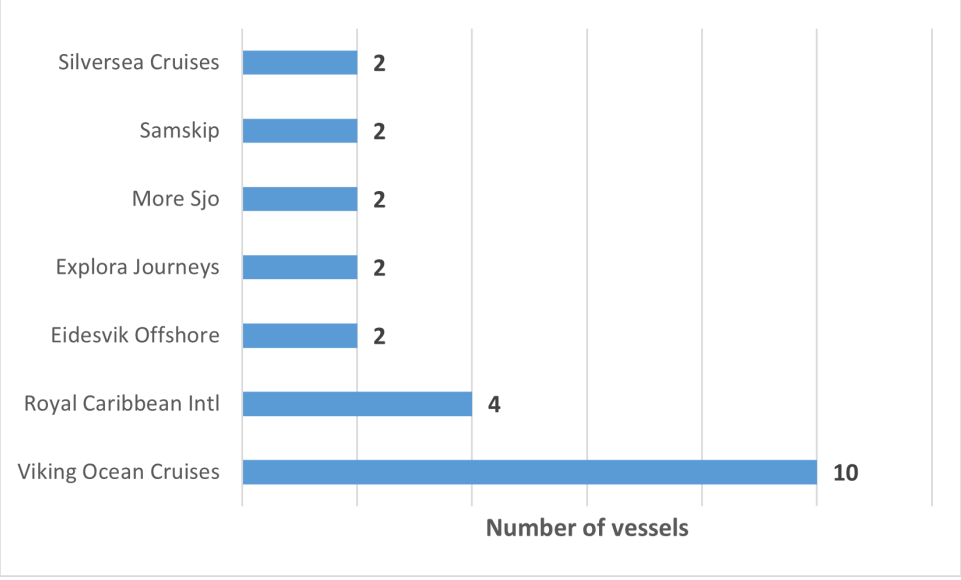
SOLAR PANELS



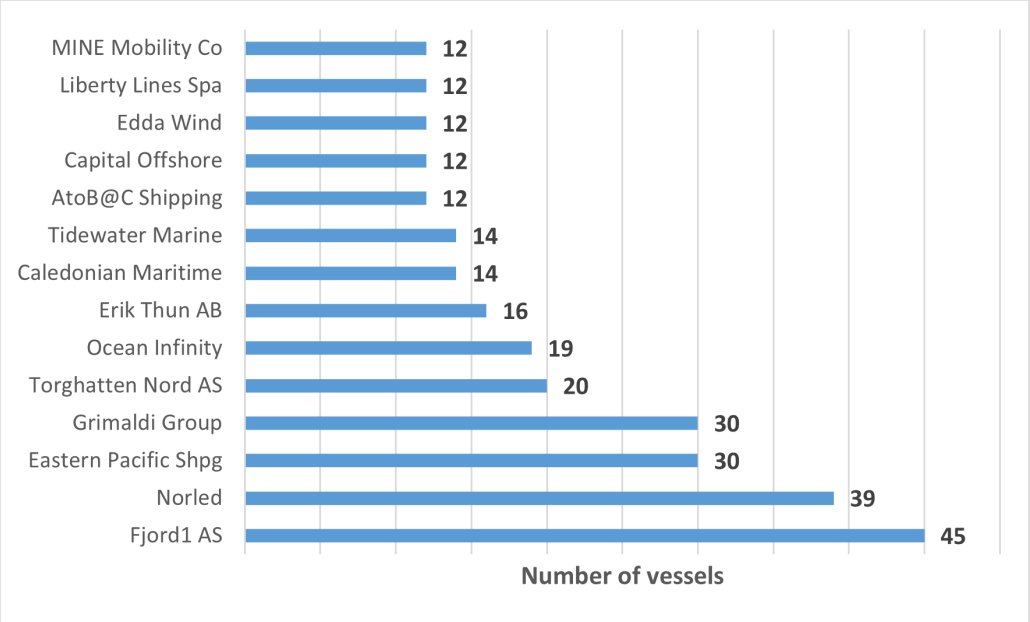
PROPELLER/PROPULSION OPTIMIZATION



FUEL CELLS

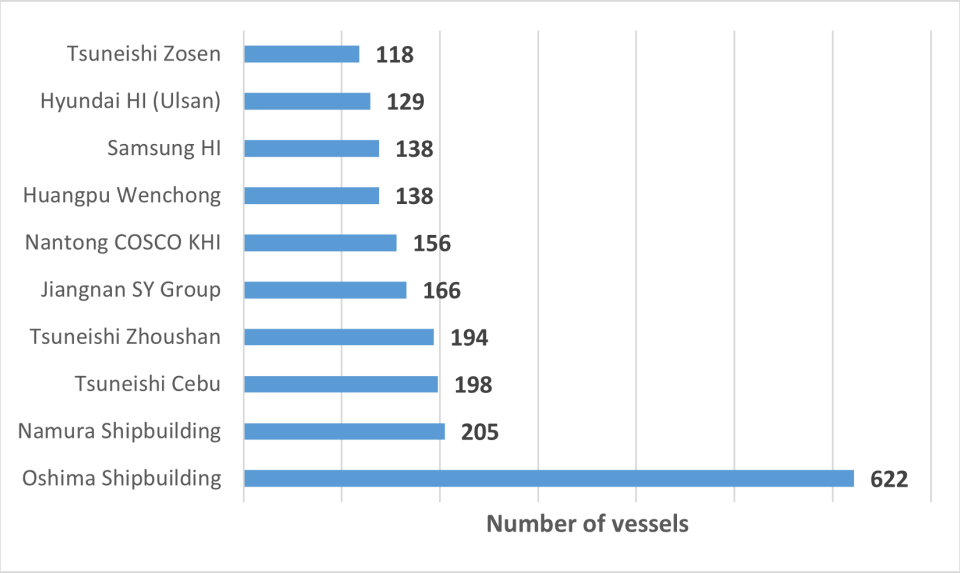


BATTERIES

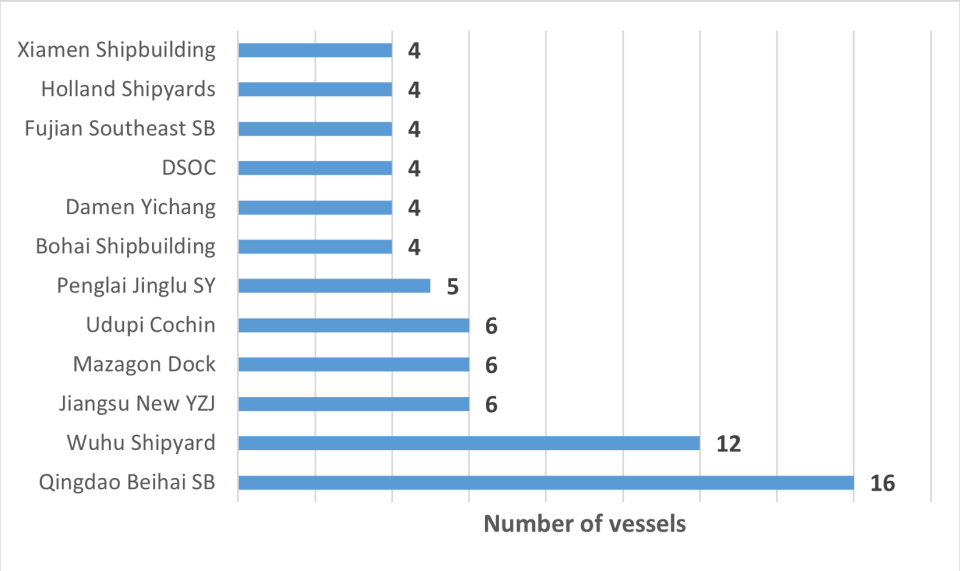


Annex E: Top Shipyards per EET Category

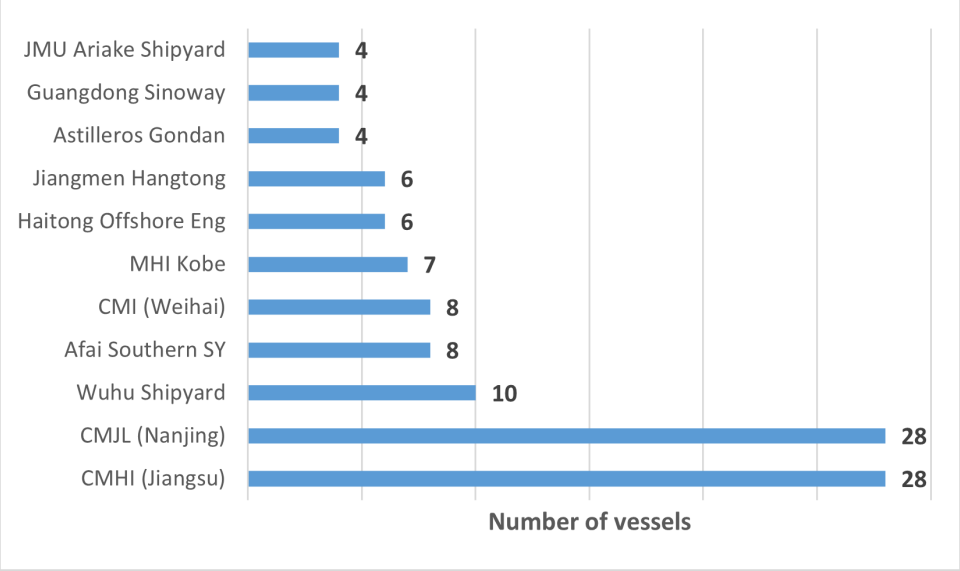
HYDRODYNAMIC OPTIMIZATION



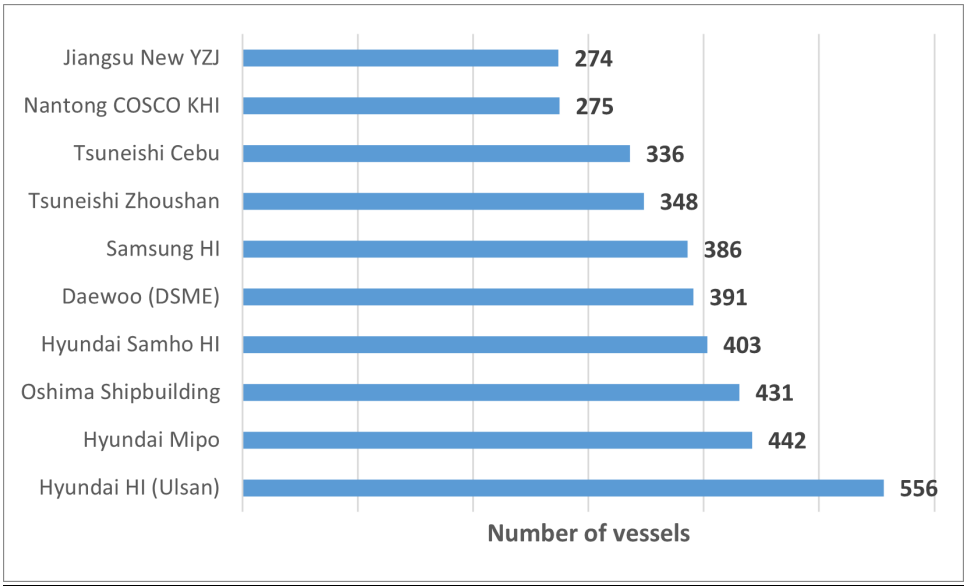
WAPS



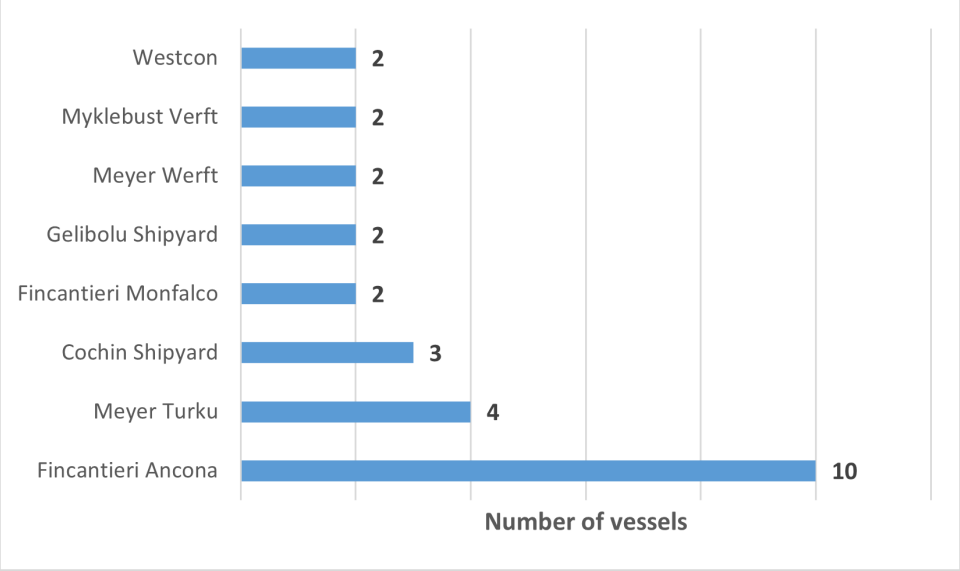
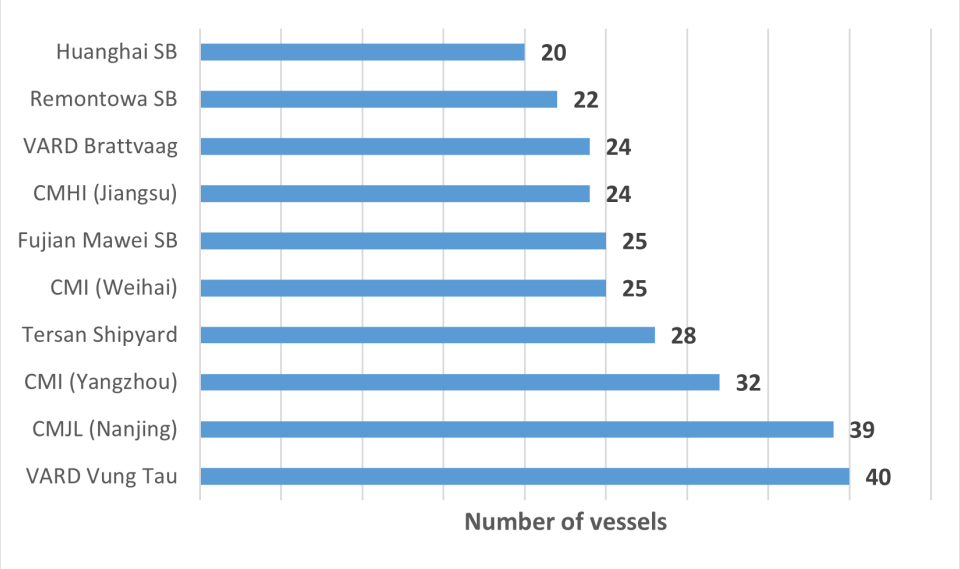
SOLAR PANELS



PROPELLER/PROPULSION OPTIMIZATION



FUEL CELLS



BATTERIES