HEMOS

www.hemosproject.eu

D6.4 MARKET ANALYSIS

InEpact

LTH Baas anno 1934

Università degli Studi di Napoli Federico II

www.bia.ee
BIA Baltic Innovation Agency

Co-funded by the European Union

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HEMOS

Goal:
14%
efficiency increase

EFFICIENCY BOOST

Up to 14% increase through optimised heat flow.

FUEL SAVINGS AND EMISSION CUTS

Lower fuel consumption and emissions with smart optimisation.

QUICK ROI

Potential 2-year payback time for investments.

SYSTEM OPTIMISATION

Heat used for ship needs.
From water heating to electricity production.

DYNAMIC MANAGEMENT

Adaptive system predicts heat needs.
Based on weather and operations.

FIGURE 1 | HEMOS offer

The HEMOS project ("Holistic heat energy management on ships by implementing innovative dynamic calculation models towards maximum waste heat capture and energy efficiency") is a 36-month Horizon Europe project that aims to contribute to decarbonizing EU's fleet by improving ships' heat energy systems through the optimization of heat flow topology with a dynamic calculation model, as well as including the latest advancements in heat energized technologies. The aim is to create a new innovative approach towards the design method of heat energy systems on ships. The main target is to reach a 14% efficiency increase by calculation and scale it down to prototype to validate.

The project is divided into **three phases.** The first phase focuses on the research and development of the calculation tool based on the collected on-board data from a case study ship, with an outcome of new heat energy system topology with the best efficiency based on limitations given by the ship owner. The second phase continues with the development of process and system engineering for the optimized system arrangement, with an outcome of initial automation and interface principles. The third phase involves the practical installation of the prototype on board of the case study ship and validation of the calculation model vs real installation.

The validation will impact shipowners' perception of the possibilities to **upgrade and retrofit their ships,** providing valuable experience to strengthen EU companies' position on the market with high-end technology and heat energy efficiency optimization on ships. The efficiency increase will help to reduce ship emissions in CO_2, NOx, SOx and particulate matter which is critical in EU environmental strategies.

The ambitious HEMOS project is implemented by **AS LTH-Baas** (Estonia), **Baltic Innovation Agency OÜ** (Estonia), **InEpact AB** (Sweden) and **University of Naples Federico II** (Italy) in partnership with **the Royal Caribbean Group** (USA) from 2022 to 2025. Read more from the HEMOS website and follow HEMOS on LinkedIn to be among the first who learn about the project's progress and latest achievements.

This market analysis has been prepared as an **official deliverable** of the HEMOS project (D6.4). The aim of the deliverable is to identify the state of the maritime industry and give an overview of the relevant markets, trends, drivers and barriers, impacting the uptake potential of the HEMOS offer.

MEET THE PARTNERS

AS LTH-Baas
A leader in the executing complex cruise ship retrofits, newbuild outfitting and implementing decarbonisation initiatives

University of Naples Federico II
A top research institution founded in 1224, the first Academy of Southern Italy and the oldest public university in Europe.

InEpact AB
Transforms low-temperature waste heat into clean electricity using patented rotor machine tech.

Baltic Innovation Agency
Innovation management company providing innovation, business development, and tech transfer services.

Co-funded by the European Union

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No. 101056909.

METHODOLOGY

In terms of its methodology, this market study takes a **mixed approach.** The first chapters focus on describing the maritime industry as it appears from literature analysis. A variety of online sources contributed to this state of the industry analysis. In order to validate the results of the literature analysis, an additional anonymous online survey was conducted along with a number of in-depth stakeholder interviews. The findings are presented as aggregates, ensuring the anonymity of the participants. This helps to offer new value to existing literature and provide maritime stakeholders with the opportunity to voice their perspective in the state of business.

The **survey respondents** come from a diverse range of professional backgrounds, primarily based in Europe, with extensive experience in the maritime field. Many have worked in their respective organizations for over a decade, with expertise spanning research and development, engineering, consulting, and ship management. Several respondents, such as those involved in ship operations, technology supply, and shipyard management, bring a broad perspective from both technical and operational roles. While the majority have long-standing tenures in their organizations, a few, particularly in engineering and consulting, have worked for 3 to 5 years, contributing valuable insights from their experience in industry-specific research and technical services.

To complement the online survey with an even more personal dimension, a total of **8 stakeholder interviews** were conducted. The interviewees for this market analysis represent a mix of experts from both academia and industry with experience in maritime engineering, shipbuilding, energy systems, and project management. Their collective insights reflect a deep understanding of the challenges and opportunities in the maritime sector, particularly around decarbonization and technological innovation.

From **academia,** we engaged with 3 experienced experts who specialize in naval engineering, shipbuilding, and maritime operations, as well as energy storage and decarbonization technologies. Their collective focus spans ship design, commercial shipping navigation, and the application of advanced electrical technologies, such as batteries and supercapacitors, aimed at achieving zero- and low-emission vessels. With years of research and leadership in projects focused on sustainable maritime solutions, these academic professionals are involved in advancing the next generation of energy systems to support the decarbonization of the maritime industry.

The 5 interviewees from the **industry** bring extensive hands-on experience in various aspects of maritime operations, process analysis, project management, and technological innovation. They have worked in areas such as shipbuilding, equipment design, system optimization, retrofitting, and the application of advanced technologies in maritime engineering. Their expertise spans decades, with experience in managing large-scale global projects, implementing technical installations on new and existing vessels, and driving initiatives that enhance safety, performance, and efficiency in the maritime sector. These professionals are experienced in integrating advanced systems and digital tools into maritime operations, contributing to both the operational and technological advancements within the industry.

In terms of its results, this study is **limited in its scope.** The small number of survey respondents and interviewees (altogether 15 stakeholders involved) influences the analysis so that it focuses on aspects that the participants found important to mention. As such, the market analysis by no means claims to be conclusive in any way – rather, it offers complementary ideas and insights to existing studies.

This market study takes a **mixed approach** of literature review, survey and interviews.

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CRUISING TOWARDS EFFICIENCY

The push for energy-saving technologies in the maritime industry

OVERVIEW OF THE INDUSTRY

The global maritime industry is the backbone of international trade, **facilitating the movement of approximately 80% of global goods** (UNCTAD). It consists of various sectors, including container ships, tankers, bulk carriers, and cruise ships, each with unique operational characteristics and energy needs. The cruise ship segment, in particular, has witnessed rapid growth, driven by the increasing demand for leisure travel and rising disposable incomes. According to data from the Cruise Lines International Association (CLIA 2018), the cruise industry contributed around $150 billion to the global economy in 2018 with more than 1.1 million jobs, and although it faced significant challenges due to the COVID-19 pandemic, it has shown strong signs of recovery.

In terms of energy consumption, cruise ships are **among the most energy-intensive vessels** (see also Figure 2), due to their large size and the wide array of amenities provided onboard, from air conditioning systems to recreational facilities (UNCTAD 2021). Managing heat energy on these ships is critical not only for operational efficiency but also for maintaining passenger comfort. As environmental regulations tighten, cruise lines are seeking innovative solutions to reduce energy consumption, emissions, and operational costs, creating opportunities for advanced heat energy management systems.

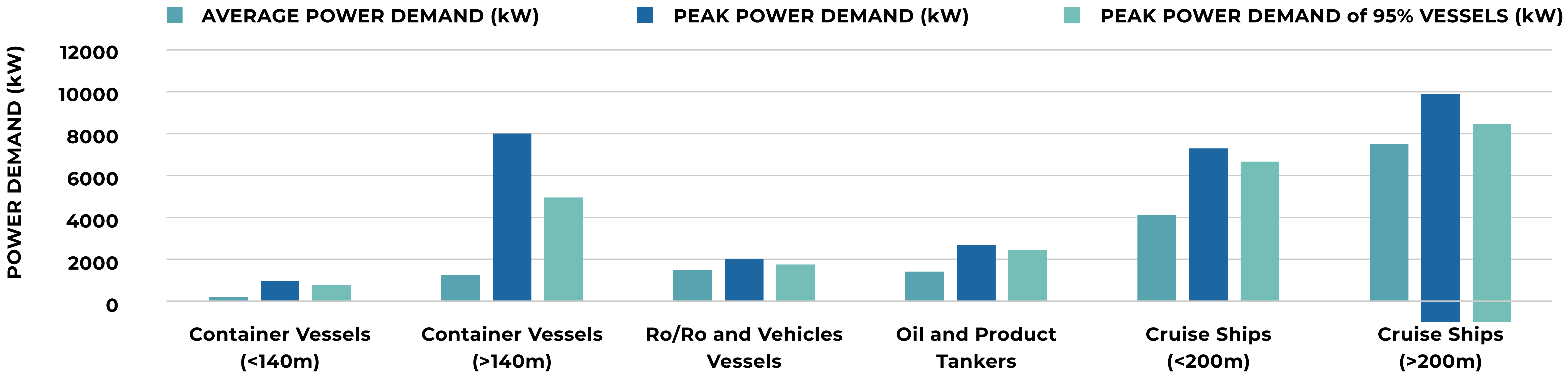


FIGURE 2 | Power demand of different types of ships. Sadiq et al.

The global maritime industry is **facilitating the movement of approximately 80% of global goods.**

CURRENT TRENDS

The maritime industry has traditionally relied on heavy fuel oil (HFO) as its primary energy source, but this is changing due to **increasing environmental awareness and regulatory pressure** (see also Figure 3). Total carbon dioxide emissions have increased over the last ten years and continue to grow, even though the emissions per ton-mile have decreased (UNCTAD 2023). Global maritime transportation is responsible for around 3% of total anthropogenic greenhouse gas emissions and significant proportions of SOx, NOx and PM emissions (Wang, Wright 2021), and reducing these emissions is now a priority. Decarbonization efforts are pushing the adoption of cleaner fuels, energy-efficient technologies, and more sustainable operational practices.

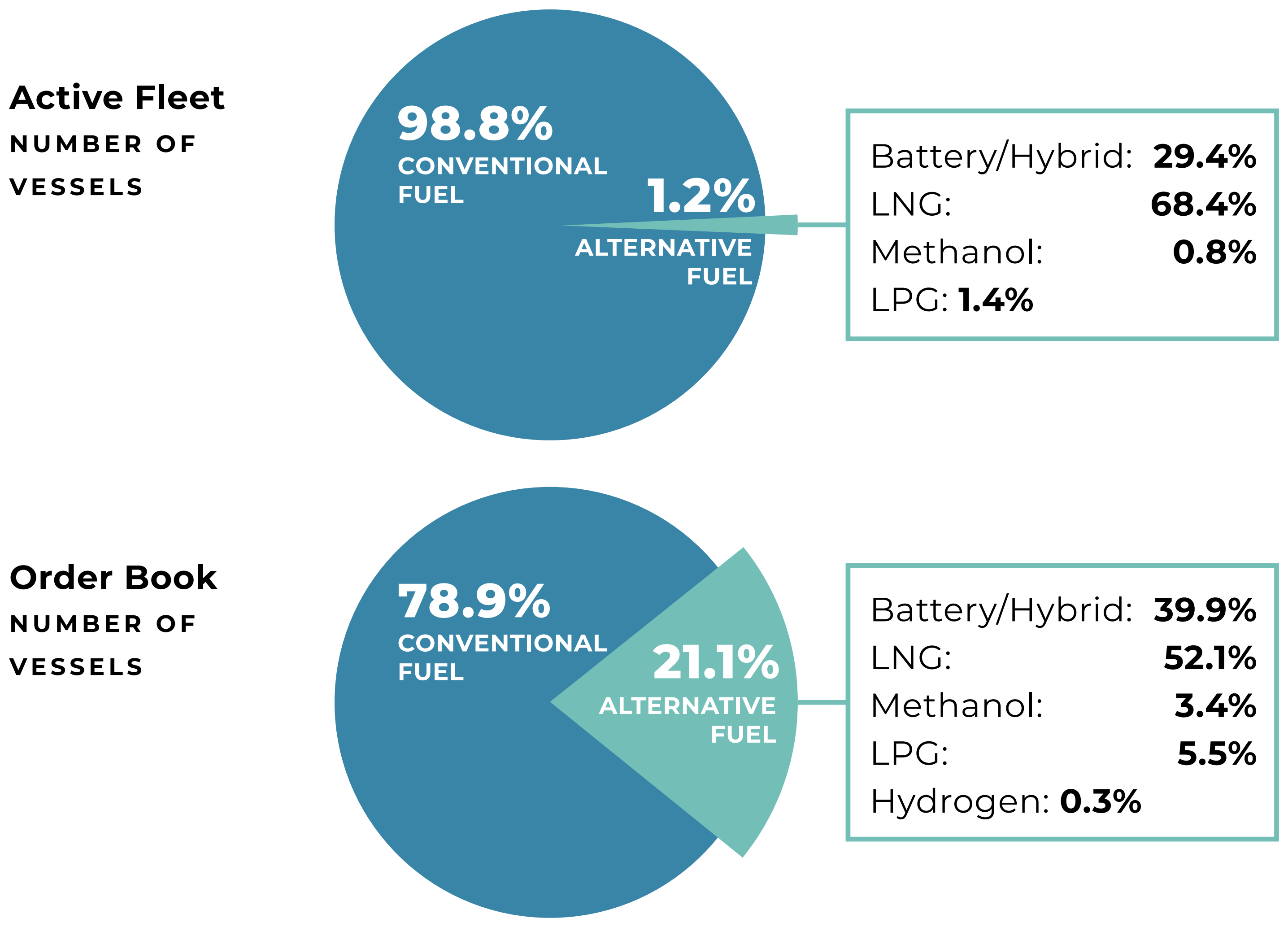


FIGURE 3 | Alternative fuel uptake, world active fleet vs orderbook, number of vessels. UNCTAD based on DNV (2022a)

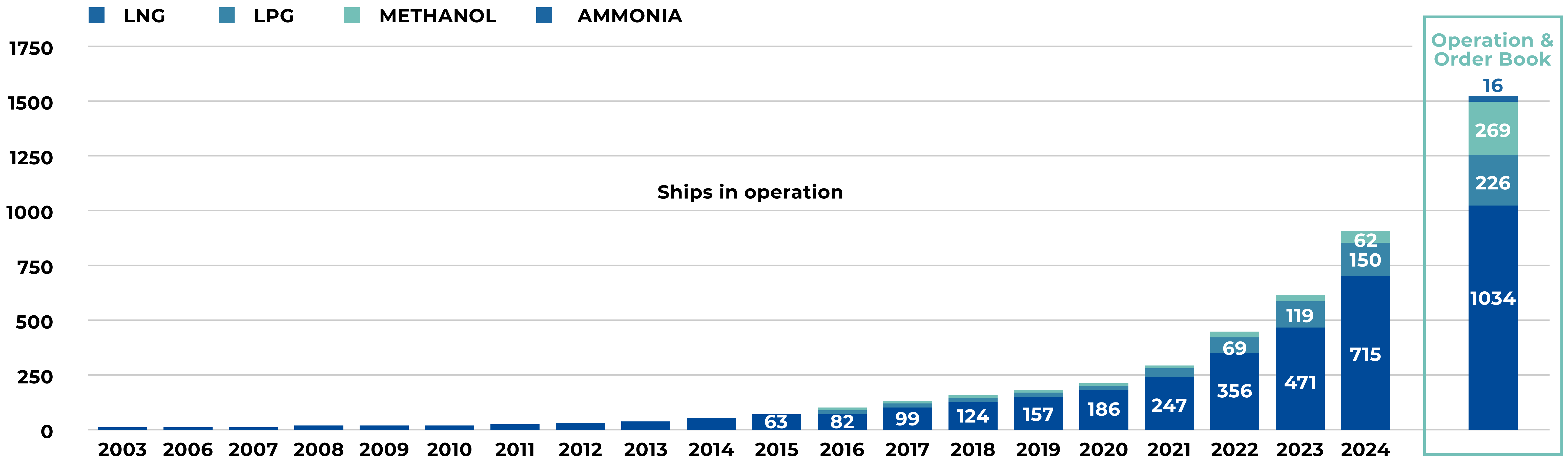


FIGURE 4 | Growth of the number of ships capable of using selected alternative fuels, excluding LNG carriers. DNV 2024.

A significant trend is the growing focus on **improving energy efficiency on ships,** including optimizing propulsion systems, installing scrubbers, using renewable energy sources like wind and solar, and improving heat recovery processes. Heat energy systems play a critical role in these efforts, as effective heat management can significantly reduce fuel consumption and enhance energy efficiency. (Green Voyage 2050) Additionally, energy-saving devices like heat exchangers and heat pumps are gaining traction as ship operators look for ways to optimize onboard energy consumption.

In order to achieve enhanced energy efficiency in the existing fleet, it is crucial to **retrofit existing ships with energy-efficient technologies** (Lloyd's Register). Ship retrofitting is a cost-effective alternative to building new, energy-efficient ships and is being increasingly embraced by shipowners and operators. Rather than scrapping older vessels, shipowners are thus opting for retrofits to meet new environmental standards. As cruise ships have long operational lifetimes, upgrading their energy systems through retrofits is seen as an increasingly viable pathway to meeting future sustainability targets.

Sustainability is also driving the development of **alternative fuels** such as liquefied natural gas (LNG), biofuels, and hydrogen (see also Figure 4). These fuels require new infrastructure and technologies for efficient use and energy management onboard ships, including novel heat energy systems that can handle the specific thermal properties of these fuels.

There is also a growing trend towards **digitalization and automation** in heat energy management. Modern systems are increasingly equipped with sensors and software to monitor energy flows in real-time, enabling dynamic adjustments to heat management based on operational needs. This trend toward intelligent, automated energy management systems is expected to dominate the market in the coming years, offering significant fuel savings and emissions reductions through data-driven optimization. (MarineLink)

KEY DRIVERS

The drive toward greater energy efficiency and sustainability is fueled by several factors. First, the introduction of the International Maritime Organization's (IMO 2020) **MARPOL Annex VI regulations**, which limit sulfur oxide (SOx) emissions, has forced shipowners to adopt cleaner fuels and improve energy efficiency. The IMO's goal to reduce the carbon intensity of international shipping by at least 40% by 2030 (compared to 2008 levels) further underscores the importance of energy-efficient systems, including heat energy management. Additionally, the IMO's Energy Efficiency Existing Ship Index (EEXI) and the Carbon Intensity Indicator (CII), after coming into effect in 2023, will further pressure ship operators to adopt energy-efficient technologies. (IMO 2022)

In addition to regulatory drivers, **rising fuel costs** are a significant incentive for shipowners to invest in heat recovery and energy optimization systems. Fuel expenses account for a large portion of a ship's operating costs, and improving the ship's energy balance through efficient heat management can lead to substantial fuel savings, particularly on long-haul voyages.

The industry faces several challenges in implementing dynamic heat energy systems. These include the **high upfront costs** of new technologies, the **complexity of retrofitting systems** on existing vessels, and the **conservative nature** of the maritime sector, which tends to adopt new technologies slowly.

Additionally, there are technical challenges related to the integration of new heat energy systems with existing shipboard equipment, which can vary significantly across different ships. This makes a one-size-fits-all solution impractical and necessitates a tailored approach for each vessel. (DNV 2023)

TECHNOLOGY LANDSCAPE

The maritime sector has long employed various heat energy technologies aimed at improving fuel efficiency and reducing operational costs. **Traditional systems** include waste heat recovery (WHR), steam turbines, and thermal oil heaters, which utilize excess heat generated by the ship's engines and exhaust systems. (GloMEEP)

However, these traditional systems are often **static and operate at fixed capacities,** which limits their ability to respond dynamically to fluctuating energy demands on ships. As the maritime industry moves toward more flexible and energy-efficient systems, these older technologies are being augmented or replaced with more dynamic solutions that can adapt to real-time energy needs, such as advanced heat pumps, heat exchangers, and energy storage systems. (McKinsey & Company 2023)

According to CLIA (2020), the entire shipping industry already benefits from the **early adoption** of various new technologies and practices that did not exist just five to ten years ago (see also Figure 5).

The development of **hybrid energy systems,** which combine traditional heat recovery with emerging technologies such as thermal energy storage (TES) and advanced heat pumps, is also gaining traction (Arpit, Das 2032). Hybrid systems offer more flexibility and can adapt to different operational scenarios, making them particularly attractive for cruise ships, which face highly variable energy demands.

These emerging technologies not only improve efficiency but also align with the maritime sector's goals of reducing emissions and lowering fuel costs, making them crucial for future-proofing vessels in an increasingly regulated industry.

Liquified Natural Gas (LNG)
Virtually zero sulfur oxides emissions, a 95% to 100% reduction in particulate matter emissions, and 85% reduction in nitrogen oxides emissions and up to a 20% reduction in greenhouse gas emissions

Exhaust Gas Cleaning Systems (ECGS)
98% reduction in sulfur oxides levels, 50% reduction of total particulate matter emissions and 12% reduction of nitrogen oxides emissions

Advanced Wastewater Treatment Systems
Advanced waste treatment systems that exceed international requirements and are often superior to shoreside treatment plants

Shore-side Power
Cruise ships are increasingly equipped with the ability to turn off the engines and receive shore-side electricity while in port where clean energy is available

FIGURE 5 | Innovation in the shipping industry. CLIA 2020

OPPORTUNITIES FOR INNOVATION

While significant advancements have been made in heat energy management systems, several gaps remain in current technologies, particularly in terms of **flexibility, integration, and scalability.** Traditional heat recovery systems, although widely used, often operate independently of other energy systems, leading to inefficiencies and missed opportunities for energy savings. The maritime industry has been slow to adopt fully integrated systems that manage heat, electrical power, and propulsion in a holistic manner. (Ksiuck et al. 2023)

One major opportunity for innovation lies in the development of **smart and adaptive heat energy systems.** These systems would incorporate artificial intelligence (AI) and machine learning to predict heat energy demands and adjust systems accordingly. By continuously analyzing data from various sources, such as engine performance, weather conditions, and energy usage patterns, AI-driven systems could optimize energy consumption dynamically, improving efficiency across all ship operations. (Durlik et al. 2024)

Another gap is the **lack of modularity** in existing systems, which makes retrofitting complex and costly. There is an opportunity to develop more modular heat energy components that can be easily integrated into existing ships without significant modifications. (Fayyazi et a. 2023) This would lower the barrier to entry for shipowners who are hesitant to invest in expensive retrofits and reduce the time and cost involved in upgrading ships to meet modern efficiency standards.

In addition, there is potential for **energy symbiosis** between heat energy systems and other onboard systems, such as battery storage or renewable energy sources like solar panels (Durlik et al. 2024). Integrating these systems into a comprehensive energy management framework could create significant efficiency gains by optimizing energy flows and minimizing waste across all ship operations.


RIDING
THE WAVE
Growing market demand
of smart energy solutions in
the maritime industry

MARKET SIZE AND DEMAND

The maritime industry is undergoing a **profound transformation** as it seeks to improve energy efficiency, reduce greenhouse gas (GHG) emissions, and comply with increasingly stringent environmental regulations.

The market for on-demand heat energy systems, which allow ships to optimize energy use dynamically, is an emerging yet vital segment within the broader maritime energy management market.

As of 2024, the **global marine energy market** is valued at approximately $1.33 billion. Market analysts estimate the value of the global marine energy market to be $9.12 billion by 2034 (see also Figure 6), with significant growth expected in the coming years due to regulatory drivers and technological advancements. The market is estimated to expand at a CAGR of 21.20% between 2024 and 2034. (Precedence Research) The specific market for on-demand heat energy systems is still relatively nascent but rapidly gaining traction, particularly in segments like cruise ships and large commercial vessels.

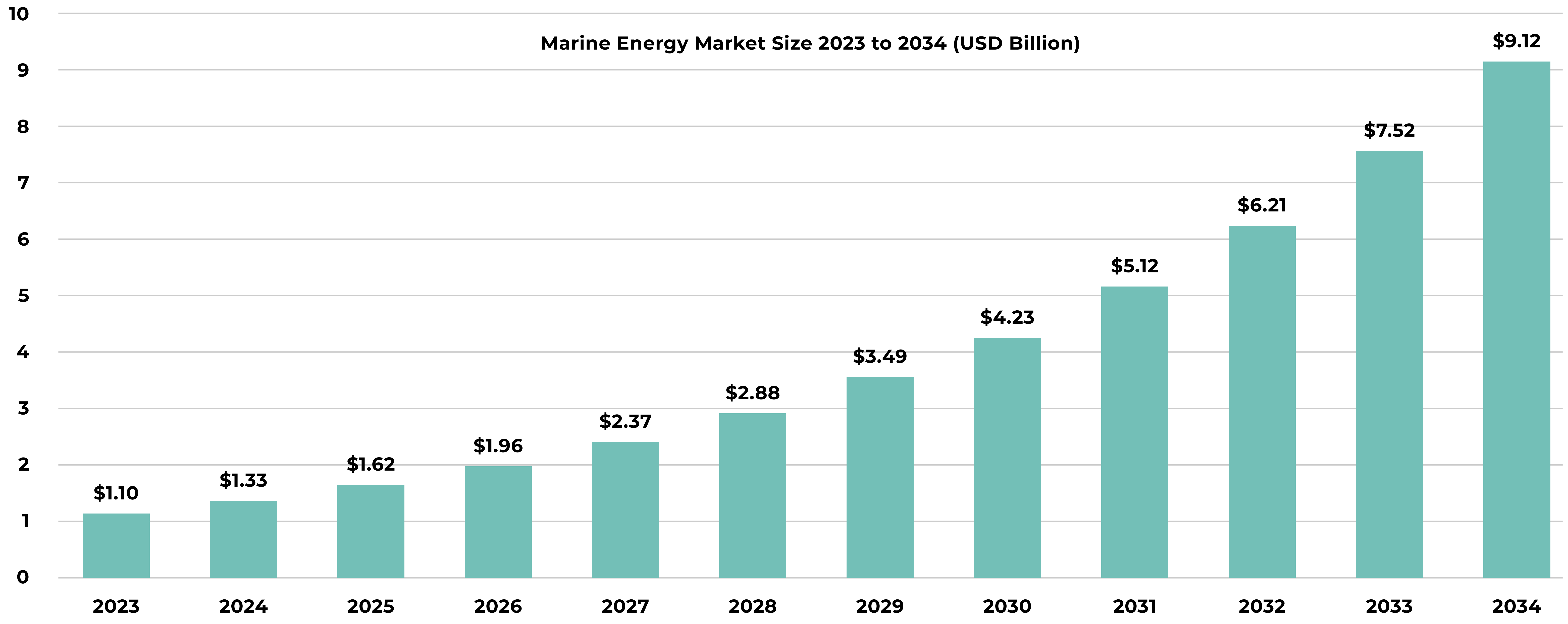


FIGURE 6 | Marine energy market size 2023 to 2034. Precedence Research

The **marine vessel energy efficiency** market size was valued at $778 million in 2022 and is expected to expand at a CAGR of 4.25% in the forecasted period of 2023-2030 (Marine Digital 2023). Cruise ships, with their high energy demands and complex onboard systems, represent a substantial portion of this market, while commercial vessels, including container ships, tankers, and bulk carriers, make up the remaining, with container ships being the second-largest market segment due to their fuel consumption patterns and longer routes.

For **cruise ships,** which are among the largest energy consumers in the maritime sector, the need for efficient heat energy management is particularly acute. With onboard systems ranging from heating, ventilation, and air conditioning (HVAC) to kitchen and laundry services, optimizing heat energy consumption can significantly reduce fuel use. As a result, the demand for advanced heat energy systems that can dynamically adjust to varying operational conditions is projected to increase rapidly over the next decade.

In addition to cruise ships, the demand for energy-efficient heat systems is rising in other segments, such as **container ships, tankers, and bulk carriers.** These vessels, which account for a substantial share of the global fleet, are also subject to increasing regulations and economic pressures. Retrofitting older ships with dynamic heat energy systems offers a cost-effective way to meet new emissions standards and reduce operational expenses.

Over the next decade, the demand for on-demand heat energy systems in the maritime industry is thus expected to **grow steadily,** driven by the convergence of environmental regulations, fuel price volatility, and advancements in energy management technologies.

Due to stringent environmental regulations, the demand for heat energy systems is highest in Europe

DEMAND BY REGION

Regionally, it can be said that the demand for heat energy systems is highest in **Europe,** driven by stringent environmental regulations such as the EU Emissions Trading System (ETS) and the broader European Green Deal. European shipowners are at the forefront of adopting energy-efficient technologies, making Europe a leading market for retrofitting and innovation in heat energy management.

In **Asia,** demand is also growing, particularly in countries like China, South Korea, and Japan, which are major shipbuilding hubs. These countries are increasingly focused on developing and adopting technologies that meet international emissions standards, presenting opportunities for energy optimization systems.

In **North America,** the market for heat energy systems is driven primarily by environmental regulations in the U.S. and Canada, particularly those related to emissions in coastal waters and ports. As the U.S. moves toward stricter environmental policies under the Clean Air Act, demand for energy-efficient technologies, including dynamic heat energy systems, is expected to rise.

KEY MARKET PLAYERS

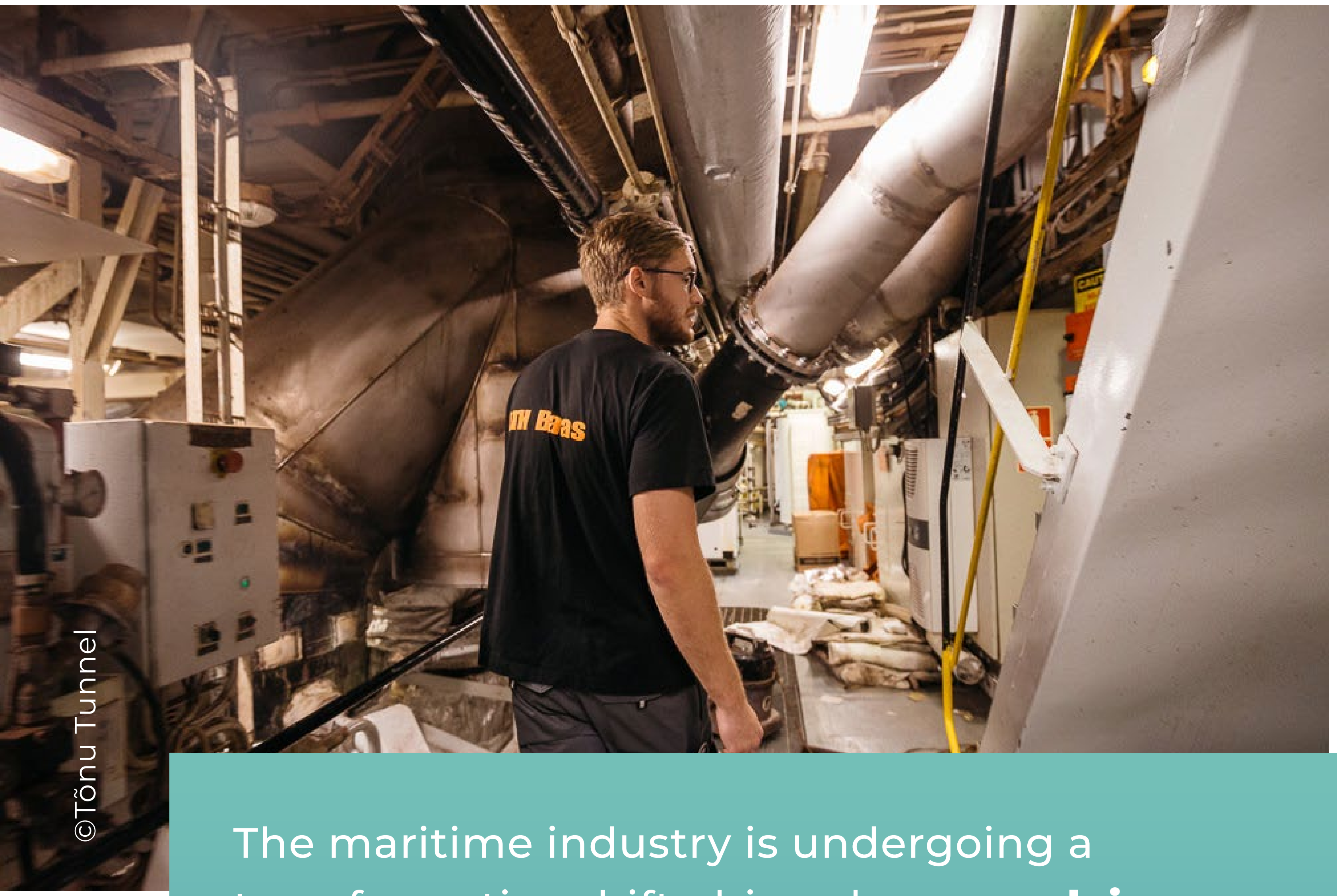
The market for maritime heat energy optimization technologies is relatively **fragmented,** with both established marine engineering firms and newer tech-driven startups competing for market share. Key players include companies specializing in energy recovery systems, heat pumps, and integrated energy management solutions.

Some of the key market players include ABB, Wärtsilä, and Alfa Laval, but also Elliot Group and Doosan Skoda Power. While **established players** have the advantage of existing market presence, strong partnerships and expertise, **newer entrants** bring fresh ideas and an emphasis on sustainability, appealing to operators looking to drastically reduce their environmental impact. The smaller players might struggle with limited resources and scale-up challenges, but can capitalize on offering more agile and flexible solutions.

The competitive landscape is **likely to shift** as regulatory pressures mount and shipowners prioritize retrofitting with energy-efficient solutions. Companies that can offer modular, scalable, and integrated systems will likely dominate the market for maritime heat energy management in the coming years. There is still room for differentiation in the ability to offer dynamic, real-time energy optimization solutions, which will be key in meeting the industry's future demands.

REGULATORY RIPPLES

The impact of policies
on maritime innovation



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The maritime industry is undergoing a transformative shift, driven by an evolving regulatory environment that emphasizes reducing greenhouse gas (GHG) emissions and enhancing energy efficiency (see Figure 7)

	2024	2025	2026	2027	2028
Adopted Regulations	Revised Data Collection System: CII Rating EU ETC for Shipping	EEDI Phase 3 (All Ship Types) FuelEU Maritime — GHG Fuel Standard (Well-to-Wake)	Revised Data Collection System: Cargo Data, More Granular Consumption Data		
In the Pipeline, or Possible Regulations				IMO GHG Pricing IMO GHG Fuel Intensity*	
Processes		CII and EEXI Review	EU ETS Review. Feasibility of Including Ships <5000 GT	FuelEU Maritime Review	IMO GHG Strategy Revision

FIGURE 7 | GHG regulatory timeline towards 2030. DNV 2024.

* Taking into account well-to-wake Key: Carbon Intensity Indicator (CII); Energy Efficiency Design Index (EEDI); Energy Efficiency Existing Ship Index (EEXI); Emission Trading System (ETS); Ship Energy Efficiency Management Plan (SEEMP)

Central to this shift are the International Maritime Organization (IMO) regulations. For instance, the 2020 sulfur cap, known as IMO 2020, has significantly influenced fuel choices across the sector as it limits the sulfur in the fuel oil used on board ships operating outside designated emission control areas to 0.50% – a significant reduction from the previous limit of 3.5% (IMO 2020). Ships now rely on low-sulfur fuels, liquefied natural gas (LNG), or exhaust gas cleaning systems (scrubbers) to meet these standards. However, the IMO's long-term strategy, which aims to reach net-zero GHG emissions close to 2050, is poised to have an even greater impact, pushing the industry towards innovative energy management solutions like dynamic heat energy systems.

Regionally, the **European Union** (EU) is leading the way with its ambitious decarbonization initiatives, including the inclusion of the maritime sector in the EU Emissions Trading System (ETS) starting in 2024 (Lynn et al. 2023) and the FuelEU Maritime initiative. These policies will impose financial penalties on shipowners who exceed emissions limits, creating a strong economic incentive to adopt energy-saving technologies. Similarly, the U.S. Environmental Protection Agency (EPA) enforces stringent emissions standards in coastal waters, further driving demand for energy-efficient solutions.

The on-demand heat energy system proposed by HEMOS aligns well with these regulatory demands, offering a solution that optimizes energy use, reduces emissions, and improves operational efficiency. This system is particularly relevant in light of **recent IMO regulations,** such as the Energy Efficiency Existing Ship Index (EEXI) and Carbon Intensity Indicator (CII), which will require existing ships to meet new efficiency standards or face penalties (IMO 2022). By enhancing heat recovery and energy management, the system supports compliance with these regulations, providing a cost-effective alternative to building new ships.

Various **international, regional, and local environmental initiatives** are also accelerating the adoption of new technologies in the maritime industry. The IMO's Greenhouse Gas (GHG) Strategy and the EU's European Green Deal, which aims for carbon neutrality by 2050, are key drivers promoting the development of energy-efficient technologies. Countries in Asia, such as Japan, South Korea, and China, have launched their own initiatives to reduce emissions, presenting additional opportunities for the adoption of the proposed heat energy system.

The stringent and rapidly evolving regulatory landscape is a **critical driver** for the adoption of dynamic heat energy systems in the maritime industry. Shipowners are increasingly incentivized to invest in technologies that ensure compliance, reduce operational costs, and support sustainability goals. The proposed system is well-positioned to address these challenges, offering a flexible, retrofit-friendly solution that aligns with global efforts to decarbonize shipping and achieve a more sustainable future for maritime transport.

VOICES FROM THE DECK

Stakeholders weigh in
on the state of business

Following the literature analysis presented above, this chapter provides an opportunity for the **maritime stakeholders** themselves to voice their opinions on the state of the industry. The aim is to validate the findings from existing sources and detect any other aspects that might be missing from this account. These perspectives are grouped together into themes – decarbonization drivers, balancing environmental responsibility with economic pressure, obstacles in decarbonization, future directions and strategic perspectives as well as collaborations.

DECARBONIZATION DRIVERS

Decarbonization efforts within the maritime sector are shaped by a **complex interplay** of regulatory pressures, economic motives, and technological advancements.

Across the field from both surveys and interviews, there is a broad consensus that regulations are the primary driving force. However, interviewees noted that these efforts are increasingly intertwined with financial and technological considerations.

Regulatory pressure emerges as the foremost **motivator for decarbonization** both from surveys and interviews. Several interviewees emphasized that without stringent policies and financial regulations, the maritime industry would struggle to adopt cleaner practices. Interviewed experts highlighted that decarbonization would likely stall in the absence of regulatory frameworks, noting that both European and international regulations, alongside financing initiatives, are key to advancing the sector's sustainability goals. In their view, the push from regulators plays a crucial role in influencing the shift towards greener operations.

Another perspective reinforces the importance of **regulatory compliance.** In this context, regulatory and economic drivers become one and the same, with companies needing to meet regulations to avoid financial penalties or restrictions, a perspective also supported by the survey results. This alignment underscores the financial urgency for shipowners and operators to invest in greener technologies.

However, decarbonization is not solely driven by regulations and financial incentives. Another viewpoint emphasizes the need for a **holistic approach,** where regulatory, economic, and technological factors are intertwined. Technological advancements underpin regulatory shifts, and innovations in areas such as fuel efficiency and alternative energy sources inform new policies. This dynamic interaction ensures that decarbonization is a continuous process, with each factor reinforcing the others. It was stressed that none of these elements can be left behind; they must evolve in tandem for sustainable progress to occur.

The role of policy in shaping industry decisions is particularly important when it comes to **technological adoption.** One interviewee pointed out that the development and adoption of decarbonization technologies, such as electrification or alternative fuels, require substantial investment. Survey results indicate that alternative fuel prices and availability of infrastructure are among the most influential factors in decarbonization. However, without clear policies offering incentives, industry players may hesitate to make the necessary investments in expensive technologies, especially when the return on investment is not immediately evident.

In both surveys and interviews, it is noted that economic motives also play a significant role in driving decarbonization. Several interviewed experts noted that companies are increasingly sensitive to sustainability issues, recognizing the reputational and market advantages of demonstrating **strong environmental credentials.** Customers and stakeholders now expect companies to take tangible steps towards reducing emissions, and this social pressure is pushing firms to innovate and adopt greener practices. Additionally, being a leader in sustainability can offer competitive advantages in mature markets, as one interviewee explained.

Lastly, there is a growing **intrinsic motivation** within the field to reduce carbon emissions. Beyond regulatory requirements, some are driven by an understanding of the global importance of reducing CO_2 emissions. This recognition of the environmental challenges fuels a broader commitment to cleaner practices, reinforcing the alignment of regulatory, economic, and social factors in the decarbonization journey.

BALANCING ENVIRONMENTAL RESPONSIBILITY WITH ECONOMIC PRESSURE

The challenge of **balancing environmental responsibility with economic pressures** is a recurring theme in the maritime industry.

While some stakeholders focus primarily on technological development, others are working at the intersection of environmental, economic, and societal factors. The approach to this balance varies depending on the specific role, but the overall objective is clear: achieving sustainability without compromising economic viability.

One expert described their framework as centered around three quantitative axes: environmental, economic, and societal impacts. For them, **none of these dimensions can exist in isolation.** A sustainable option that is not economically viable will never be adopted, and conversely, purely economic solutions lacking environmental or social benefits are insufficient. This expert stressed the difficulty of optimizing all three factors simultaneously, but highlighted the importance of continuously asking how to quantify and integrate these elements to ensure a balanced approach.

Others view their primary role as promoting environmental improvements and assisting the industry in achieving decarbonization. For these experts, the **drive to enhance safety and protect the environment** is the key focus. Their efforts align with the broader decarbonization goals of the industry, which inherently involve economic pressures but are predominantly motivated by a commitment to environmental responsibility.

For some researchers, the focus is less on directly balancing environmental and economic pressures and more on **preparing the technological groundwork for future adoption.** One interviewee mentioned that their research is geared toward developing new technologies, assuming there will eventually be an economic case for their use. They focus on ensuring these technologies provide value for money. While economic pressures do not drive their research, they work closely with industry partners to ensure that their technologies are both viable and cost-effective, recognizing that the financial aspect is crucial to widespread adoption.

One expert noted that their organization takes pride in having strategies that not only meet current regulations but are also flexible enough to adapt to future, **more stringent compliance requirements.** By prioritizing both values and regulatory alignment, they are able to navigate the balance between environmental responsibility and economic feasibility more effectively.

Some interviewees expressed the view that balancing these factors is not a major concern in their work. They see environmental and economic considerations as going hand in hand, **without significant tension** between the two. This reflects the perspective that, in some areas of the industry, sustainability and economic viability are naturally aligned, and progress in one area can benefit the other.

However, the challenge of **predicting and managing costs** is not overlooked. One interviewee who focuses primarily on technical solutions mentioned that while the economic aspect was initially not a priority in their research, the shift toward decarbonization has necessitated a deeper look into the financial implications. They acknowledged the significant investments required to implement new technologies and highlighted the difficulty of accurately predicting costs. In decarbonization efforts, the cost factor has become as important as the technical performance of solutions, and understanding where the necessary investments will come from is a crucial part of the puzzle.

OBSTACLES IN DECARBONIZATION

The maritime field faces **numerous challenges** in its journey toward decarbonization, ranging from fuel availability and energy infrastructure to technological readiness and regulatory pressures.

Despite the diversity of these obstacles, there is a shared recognition that overcoming them will require a combination of innovative solutions, collaboration, and policy support.

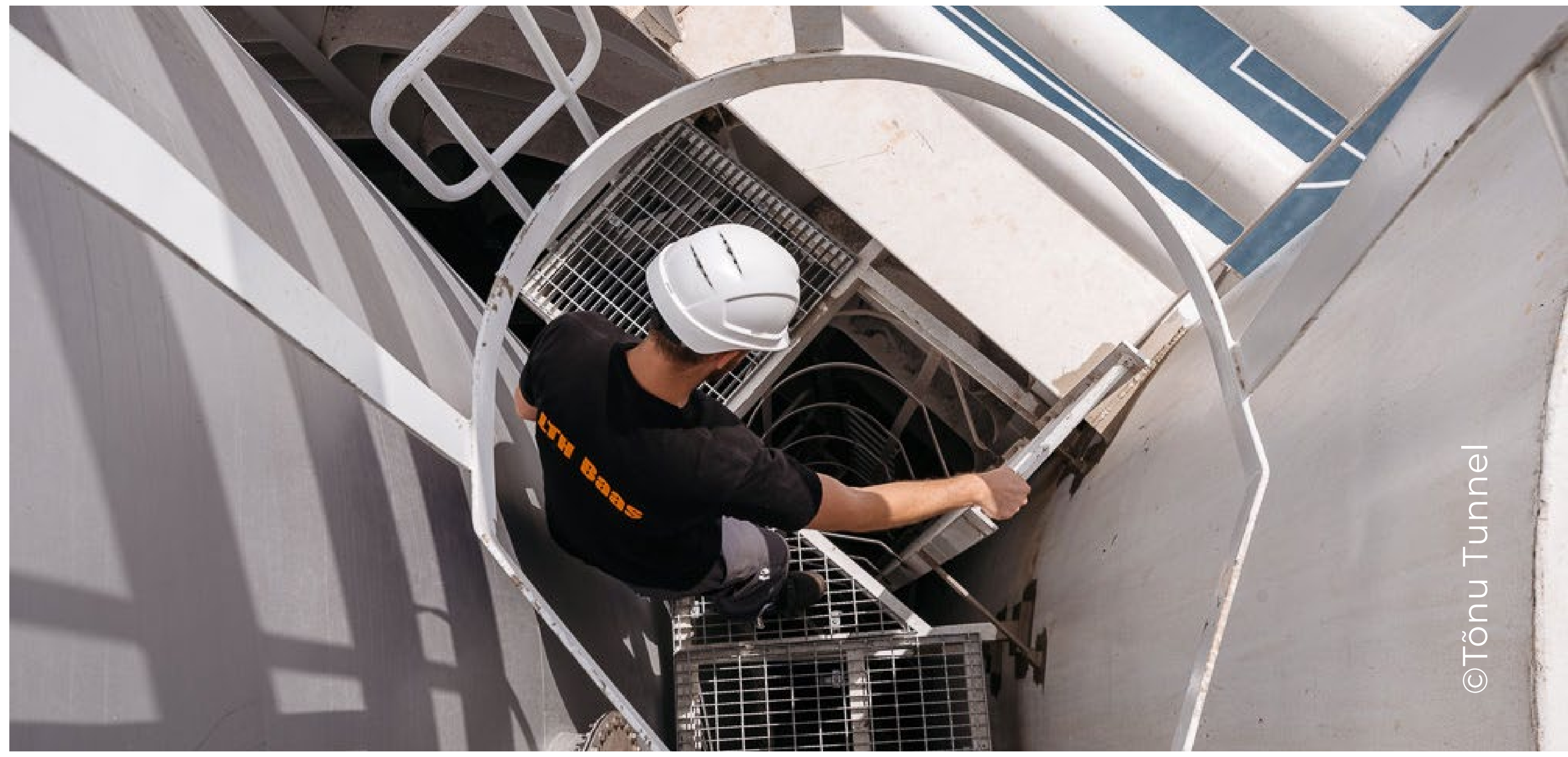
One of the most significant obstacles identified by both interviewed and surveyed experts is the **availability and price of alternative fuels.** Current options like methanol and ammonia are being explored as potential solutions, but their widespread adoption is hindered by the limited availability of green versions of these fuels. While methanol and ammonia are widely produced, their production processes are often carbon-intensive, resulting in a larger overall carbon footprint than traditional diesel fuel. To make a meaningful impact, there is a need for e-methanol, e-ammonia, or biodiesel. However, the production costs for these fuels remain high, and supply is limited. Furthermore, these fuels have lower energy densities, which means that for long-distance voyages, ships would need to be completely redesigned to accommodate the necessary fuel storage, as one interviewed expert pointed out.

Another challenge lies in the **lack of scalable alternatives** for deep-sea shipping, which involves significantly greater energy demands than coastal or short-sea shipping. While smaller vessels like ferries have more manageable energy requirements, deep-sea vessels face pronounced obstacles due to the massive amounts of energy involved. To address this, the experts interviewed propose using a diverse range of energy solutions across different segments of the shipping industry. These could include wind-assisted propulsion, batteries, and various forms of alternative fuel, but no single solution will fit all scenarios.

Technological readiness is also a key barrier as pointed out by interviewees. Many technologies needed for decarbonization are not yet fully developed or commercially viable. Moreover, the infrastructure required to support these technologies, such as charging facilities in ports, is lacking. Both interviewed and surveyed experts highlighted resistance to change within the industry as an obstacle. This resistance often stems from high investment costs and limited funding. For instance, ports are hesitant to invest in costly charging facilities without government backing, while governments may be unwilling to take on the financial responsibility. To break this deadlock, interviewees suggest that more collaborative research projects funded by the EU and local governments are essential. Pilot projects can demonstrate the viability of new technologies and encourage broader adoption by showcasing their potential.

The **regulatory landscape** also poses challenges. Current regulations are pushing the industry toward decarbonization, but there are no universally applicable and clear solutions that meet the new standards as mentioned by both interviewed and surveyed experts. Interviewees point out that more comprehensive financial support mechanisms, such as low-interest loans and targeted taxation incentives, are needed to help shipyards and operators comply with these regulations and meet decarbonization targets.

Some interviewed experts mentioned that another proposed solution lies in the **use of fuel cells,** a promising technology being explored through numerous projects in the marine sector. Fuel cells, along with other emerging technologies, could help the industry achieve its decarbonization goals. However, the challenge remains whether these technologies can deliver the same performance and reliability as existing systems. The maritime sector is traditionally conservative, with a preference for technologies that are proven and familiar. The shift to new energy systems may impact business operations, especially if these technologies require more space or have lower energy densities, potentially affecting cargo capacity or passenger numbers.

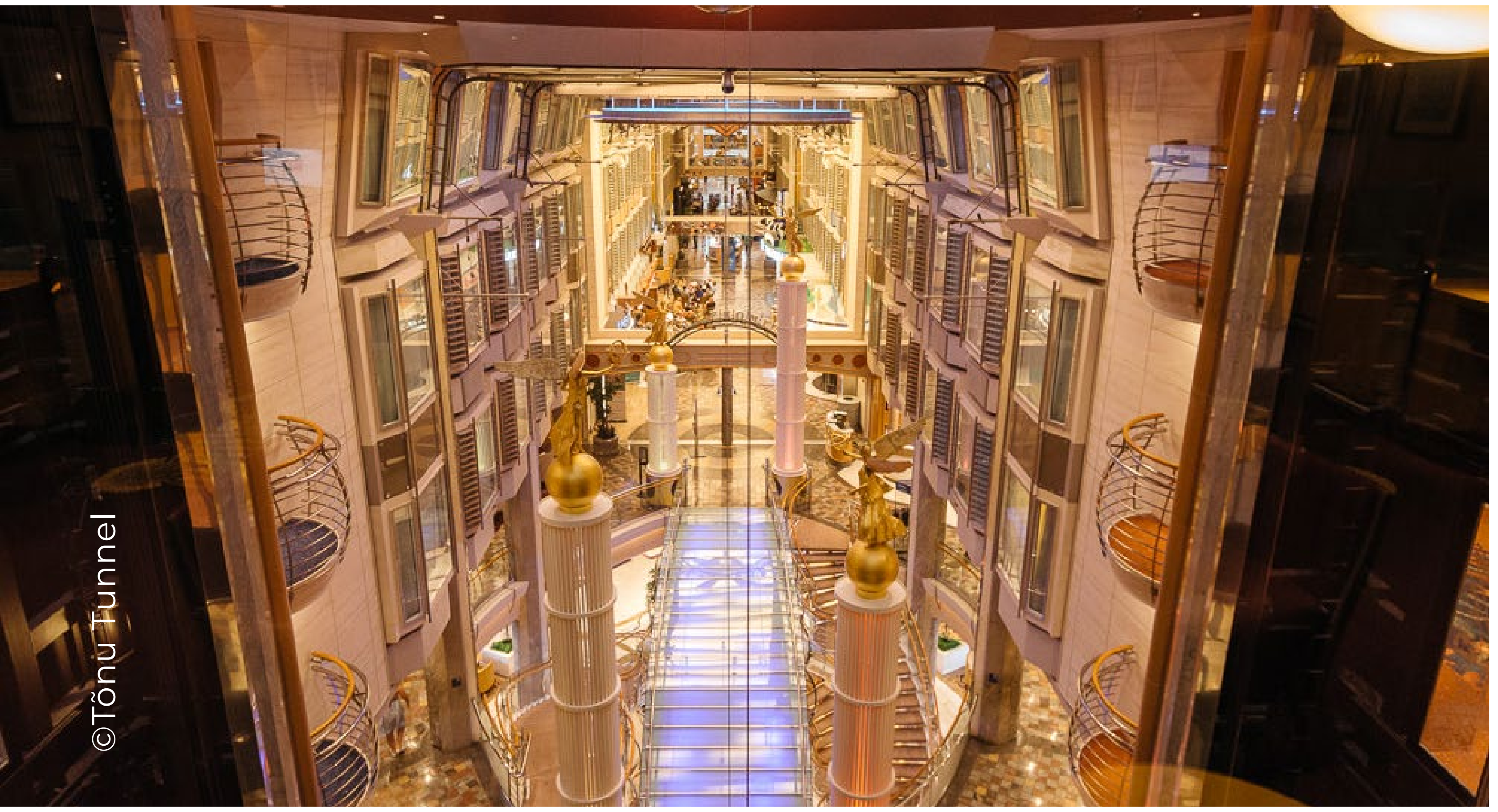


A more systemic challenge is the need for a **holistic approach to integrating** various decarbonization solutions. While there are numerous individual technologies in development - ranging from alternative fuels to energy storage solutions - the maritime sector lacks a comprehensive understanding of how these technologies interact on board vessels and within port infrastructures. Experts say that system-level analysis is crucial for redesigning and optimizing next-generation ships and port facilities. This approach will allow for the coordination of energy systems across ships and ports, enabling more seamless integration of renewable energy technologies.

As the experts see it, the solutions for decarbonizing the maritime sector can be broadly categorized into **three key areas.** First, propulsion technologies that can replace traditional engines, such as those powered by alternative fuels or renewable energy sources. Second, energy management systems on board, which focus on flexibility, particularly through energy storage solutions. Finally, information technology systems that enable the monitoring and management of energy systems on board ships, ensuring efficient operation and coordination across the vessel's energy network.

FUTURE DIRECTIONS AND STRATEGIC CONSIDERATIONS

The maritime industry is expected to see a significant increase in interest and focus on **R&D** in the coming years stated by interviewees and survey participants. Some interviewed experts predict an upward trend driven by initiatives to enhance ship and fuel efficiency and advance zero-emission technologies. As the targets for emissions reduction approach, the pressure to decarbonize will intensify, leading to more initiatives and resources being funneled into these areas. One interviewee compared the current state of the maritime industry to the automotive industry's shift towards electric vehicles two decades ago, highlighting the potential for once-unlikely technologies, like battery-powered vessels, to become mainstream. Fuel cells and the adaptation of ships to use alternative fuels are expected to be one area of development. However, one interviewee noted that some technologies that are still in development may never become practical solutions. They added that it is important to identify which technologies have real potential and distinguish them from those that are unlikely to succeed. Overall, there is unanimous agreement that research into digitalization and digitalization itself will only grow in importance as the industry adapts to global sustainability goals.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Once again, the maritime sector is exploring a wide range of solutions to achieve decarbonization, as **no single approach will suffice** across all vessel types and operational conditions. Interviewed experts emphasize that alternative fuels such as ammonia, hydrogen, and emerging technologies such as fuel cells hold some promise, though they acknowledge that these technologies are still in the early stages of adoption. Incremental gains across multiple areas, such as propulsion, energy storage, and heat recovery systems, could have a cumulative impact. There is also significant potential in combining different technologies to maximize efficiency and reduce emissions. Experts believe that while some technologies are not so realistic, innovations are being realized step by step through lab-based experimentation and incremental real-world testing. Other exciting developments according to interviewees include autonomous shipping, where vessels can be remotely controlled or operated with reduced crew from shore. This technology could increase efficiency and reduce costs, although it has safety and risk considerations that must be addressed through rigorous testing.

There is widespread agreement that more comprehensive and structured **data collection** is needed. This would allow for better decisions regarding fuel types, propulsion systems, and energy management, helping to prioritize which technologies to adopt for specific types of vessels. For instance, collecting detailed data on navigation cycles and power demands would enable researchers to assess the viability of alternative fuels for different ship types. However, the maritime industry has traditionally been slow to embrace digitalization due to its legacy systems and conservative culture, making the shift to a data-driven approach more challenging.

Despite the challenges, some see positive trends. The growing use of digital tools in ship design, maintenance, and operations has led to increased efficiency and better fuel consumption, though there remains an issue of **data overload** for operators. While the technology is promising, the capability to process and analyze the data is still lacking, especially when it comes to

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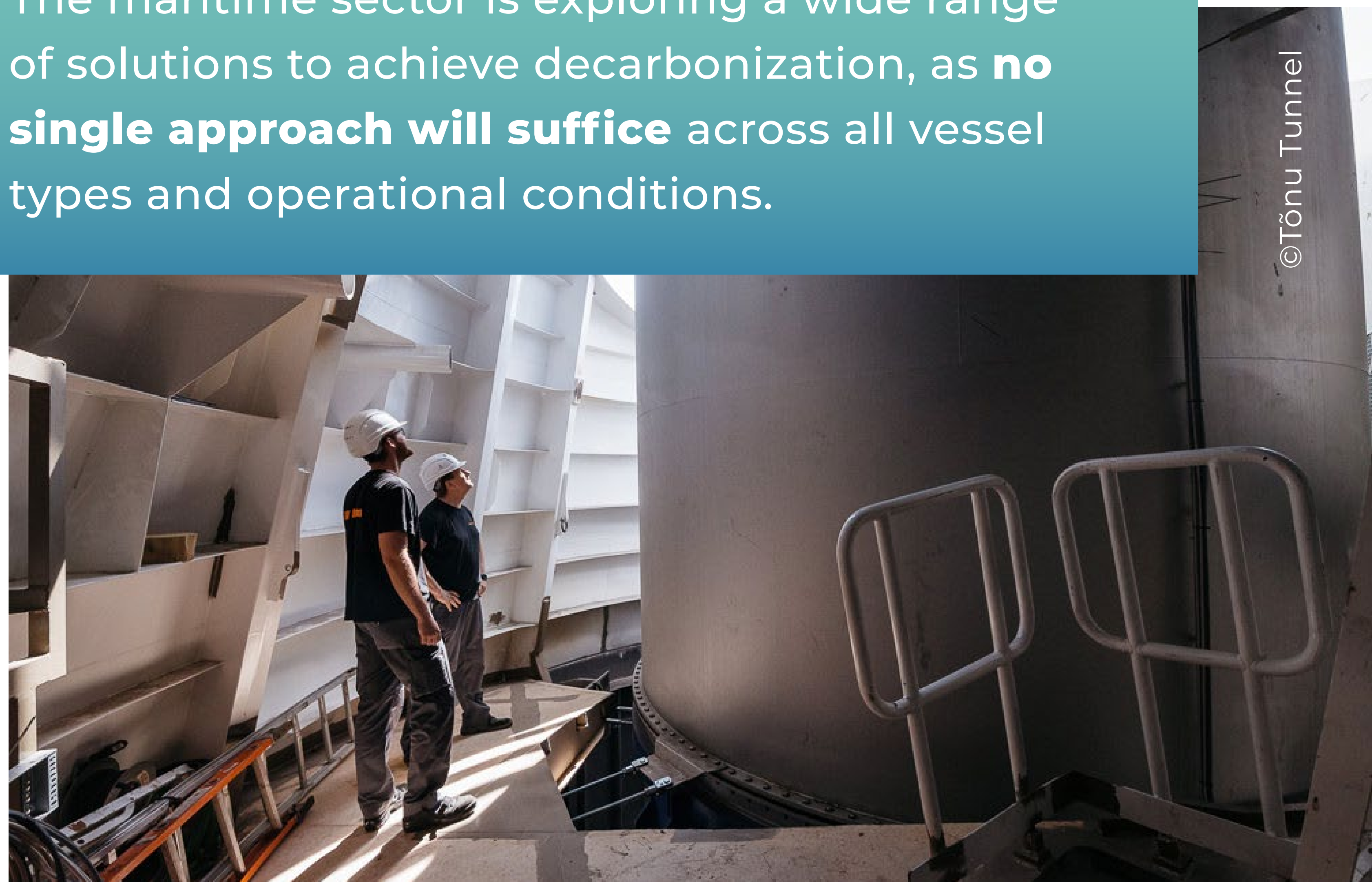
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integrating diverse data sets and applying them for decarbonization goals. Additionally, a lack of reliable cost data on new fuels and technologies, such as fuel cells and storage systems, poses a significant obstacle to progress.

Digitalization is seen as one of the key drivers in the maritime industry's efforts toward decarbonization stated by both interviewed and surveyed experts, enabling more efficient operations and providing valuable data for decision-making. One interviewed expert described digitalization as a "package of solutions" that can reduce emissions without requiring significant physical changes to vessels. However, the availability and management of data remain contentious issues. Ownership of data is not well-defined, and data is often fragmented, unstructured, or difficult to access, hindering its full potential. While some believe that digital technologies have made progress, some interviewed experts argue that the industry has yet to fully realize the transformative potential that data offers, particularly when compared to other sectors like aviation.

Another field that was mentioned among survey respondents where an increase in focus and investments is expected is **cyber security,** which involves practices, technologies and policies to protect shipping infrastructure from cyber threats and attacks. Some survey respondents acknowledge that digitalization introduces cyber-security risks, making the maritime industry increasingly vulnerable to cyber-attacks.

Beyond technical innovations, the importance of **non-technical solutions** was highlighted, such as hiring new employees to facilitate decarbonization and promoting gender equality in the maritime workforce. A more balanced workforce can improve innovation and collaboration while inspiring the next generation to pursue careers in maritime engineering and technology. Finding employees is generally not a challenge in the maritime industry, although this can vary depending on the specific role.

At the same time, **attracting students and employees** to the maritime sector presents varying challenges, depending on the level of education and the specific roles involved. For undergraduate students, the field of net-zero energy systems and sustainability is appealing, making it relatively easy to attract interest. However, at the master's and PhD levels, many students are drawn to industry opportunities that offer more attractive financial opportunities, making it harder to retain them in academia. Students are difficult to attract to academic maritime careers due to the uncertainty of academic paths. One interviewee pointed out that the area of ship design tends to attract a healthy number of students, but there is a significant shortage of students interested in ship operations, despite the high demand in the job market. The industry's pull is strong, often drawing graduates away from research careers, making it difficult to find new academic researchers.

COLLABORATION

Collaboration is a key aspect of the maritime industry, with most organizations **actively working with external partners** such as universities, technology providers, and industry associations. Many interviewees reported extensive partnerships across Europe, involving shipowners, harbor authorities, energy operators, and academic institutions. Finding partners is generally not difficult, as there is a shared interest in addressing challenges and developing co-created solutions. However, alignment of interests and complementarity between partners is crucial for successful collaboration. In some cases, company politics or internal policies can hinder partnerships. It was also pointed out that valuable partners may already be fully committed to other projects.

For some, the challenge lies not in finding partners but in **securing funding or fulfilling complex requirements** for collaborative projects. Long-standing relationships with big shipyards or industry partners can make collaboration easier, but establishing mutual understanding and setting clear project objectives can be difficult at the start of a new partnership. Both interviewed and surveyed experts state that while collaboration is seen as essential and widely practiced, the most significant barriers are often related to aligning goals, securing funding, and navigating administrative requirements rather than finding willing partners.

The maritime sector is exploring a wide range of solutions to achieve decarbonization.


SAILING PAST BARRIERS
Tackling hurdles in
maritime energy innovation

As already mentioned, the maritime industry faces significant challenges in adopting dynamic on-demand heat energy systems, largely due to high upfront costs, technical complexities in retrofitting, and resistance to innovation.

These barriers are compounded by the industry's traditionally conservative approach to new technologies, making widespread adoption of advanced energy solutions a slow and cautious process.

HIGH UPFRONT COSTS OF NEW TECHNOLOGIES

One of the primary obstacles for integrating dynamic heat energy systems is the **substantial initial investment required.** Retrofitting existing ships or installing these systems on new vessels involves considerable costs, including hardware for heat recovery systems, thermal energy storage, and advanced control systems. Additionally, expenses related to shipyard labor, system integration, and downtime during installation further escalate the financial burden. For large vessels like cruise ships and container ships, these costs can be prohibitive, especially for shipowners with older fleets who may not see immediate financial returns.

Smaller shipping companies or those operating on tight profit margins are **particularly vulnerable** to these financial challenges. While the potential long-term benefits, such as fuel savings and regulatory compliance, are significant, the initial investment often outweighs the immediate advantages, leading to reluctance in adopting these technologies. The maritime industry is generally slow to invest in large-scale upgrades unless there are clear, short-term returns on investment (ROI).

To overcome this financial barrier, **several strategies** can be considered. Financial incentives such as government subsidies, tax breaks, or grants under programs like Horizon Europe or national green energy initiatives could make these technologies more accessible. Additionally, innovative financing models, such as leasing options or performance-based financing—where shipowners pay for the system through the fuel savings it generates over time—can reduce the perceived financial risk. Demonstrating short-term ROI through pilot projects on various types of vessels can also help build confidence in the technology and encourage broader industry adoption.

TECHNICAL CHALLENGES IN RETROFITTING AND SYSTEM INTEGRATION

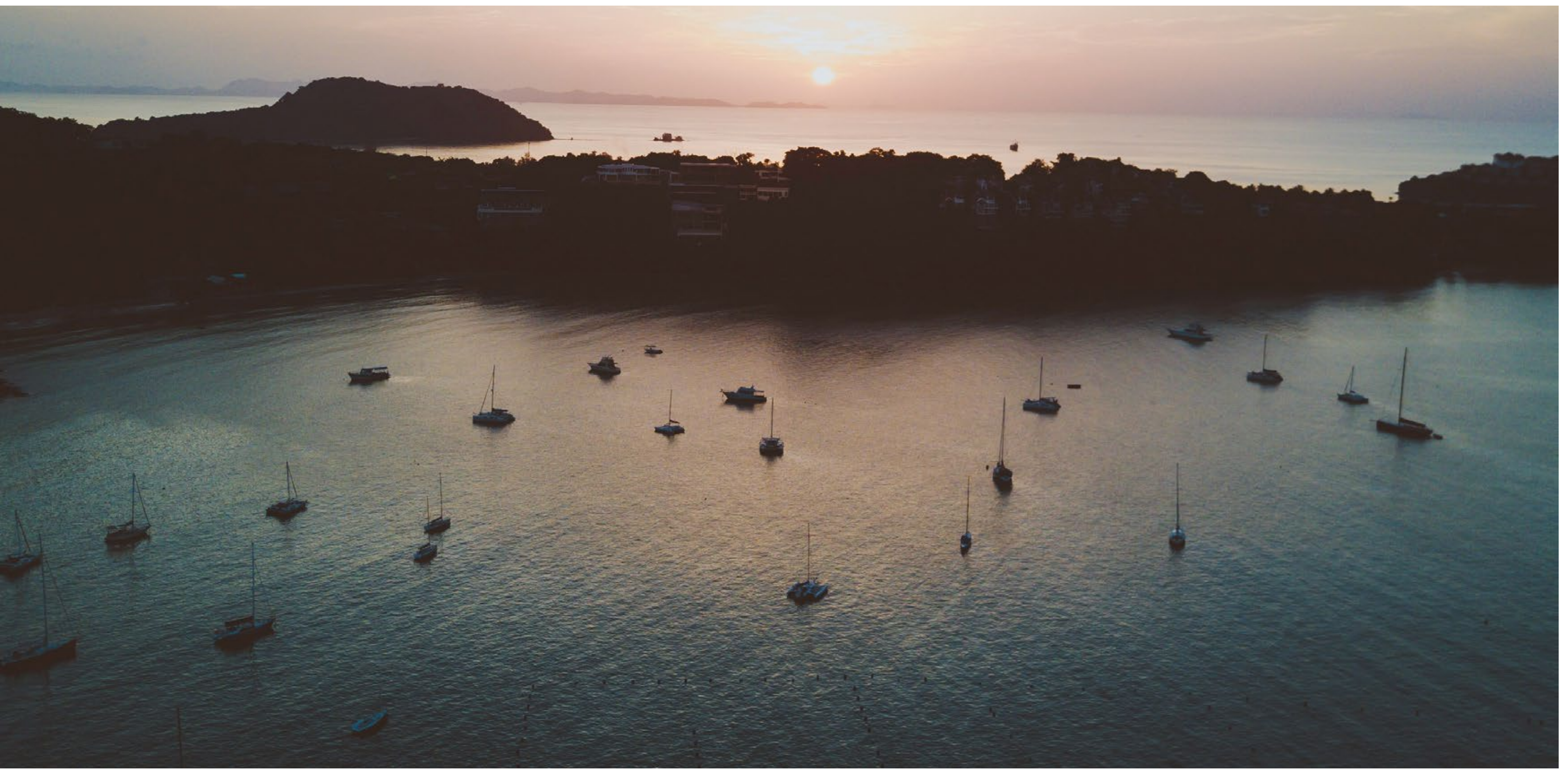
The technical complexity of retrofitting existing ships with dynamic heat energy systems poses another significant barrier. Many operational vessels were not designed with modern energy-efficient technologies in mind, making integration difficult. Key technical challenges include space constraints, system compatibility, and minimizing operational disruptions during installation.

Space constraints. Older ships often have limited space to accommodate new energy management systems, such as thermal energy storage or advanced heat exchangers. Installing new technology may require extensive modifications to the ship's layout, increasing costs and extending downtime.

System compatibility. Ships operate with a variety of machinery and equipment, much of which may not be compatible with modern energy optimization solutions. Retrofitting new technologies often involves integrating them with existing propulsion, electrical, and HVAC systems. This can be particularly challenging if the ship is equipped with outdated or non-standard equipment, making the process more complex and costly.

Minimizing downtime. Downtime during retrofits translates directly into lost revenue for shipping companies. The time required for installation is a critical concern, especially for vessels on tight schedules, such as cargo ships that operate on fixed global trade routes. Developing efficient installation processes and minimizing retrofitting time will be crucial in making these upgrades more appealing to shipowners.

To address these technical challenges, the development of modular and scalable systems can be a game-changer. Modular systems that can be customized to fit the specific constraints of each ship reduce the need for extensive modifications and speed up the installation process. Collaborating with experienced shipyards and marine engineering firms to develop streamlined installation procedures will also help minimize downtime and make retrofitting projects more technically and financially viable.



RESISTANCE TO INNOVATION AND CONSERVATIVE INDUSTRY ADOPTION

The maritime industry is known for its conservative approach to adopting new technologies, driven by a combination of operational risk aversion and financial uncertainty. Shipowners and operators often prioritize short-term cost savings over long-term investments in innovative technologies, especially when the benefits are not immediately apparent or are contingent on external factors like fluctuating fuel prices or evolving regulations.

Risk aversion. The maritime sector operates in a high-stakes environment, where operational failures can have severe financial and environmental consequences. Shipowners are understandably cautious about adopting new, unproven technologies that might not perform as expected in real-world conditions. This risk aversion is heightened by the lack of widespread adoption of energy-efficient systems, which makes early adopters more hesitant to take on the potential financial and operational risks associated with new heat energy solutions.

Uncertain regulatory landscape. While there is a clear push for decarbonization, some shipowners remain uncertain about the pace and direction of future regulations. Although organizations like the IMO have set clear targets, specific policies and enforcement mechanisms can vary by region and are subject to change. This uncertainty can deter shipowners from investing in energy-efficient technologies if they are unsure whether the investment will be necessary or provide a competitive advantage in the near future. There is also concern that future regulations might render the current technology obsolete or insufficient for compliance.

Operational disruption. Beyond financial concerns, shipowners worry that integrating new technologies might disrupt ongoing operations. Ships operate on tight schedules, and any technological adoption that risks mechanical failures, unexpected maintenance, or requires extensive operational training can create resistance. Moreover, ship crews often have limited experience with advanced energy technologies, creating a knowledge gap that may make shipowners hesitant to invest in systems that demand significant training or technical expertise.

To overcome this resistance, **pilot projects and demonstration initiatives** to the likes of HEMOS are essential. These projects can showcase the reliability, effectiveness, and ROI of the proposed heat energy system under real-world conditions, reducing perceived risk. Offering comprehensive training and support services to ensure that ship crews are fully equipped to operate and maintain the new systems can further alleviate concerns about operational disruptions.

Moreover, highlighting the system's compliance capabilities and its ability to future-proof ships against evolving emissions standards will help shipowners see its long-term value. Shipowners are more likely to adopt new technologies when they understand how these systems can facilitate compliance with upcoming regulations and reduce operational risks.

GOING FORWARD

To accelerate the development and deployment of new energy solutions in the maritime industry, there are numerous opportunities for strategic partnerships and collaborations. These partnerships can help overcome technical challenges, access new markets, and create synergies between complementary technologies.

Shipbuilders and shipyards. Collaborating with shipbuilders and shipyards would allow new solutions to be integrated into newbuilds from the design phase, ensuring seamless installation and operation.

Marine engineering firms. Partnering with established marine engineering firms could accelerate the adoption of new solutions by leveraging their extensive experience, market presence, and customer base.

Technology providers and startups. Collaborating with technology providers or startups focused on renewable energy, digitalization, or AI could enhance solutions' capabilities and position it at the cutting edge of innovation.

Regulatory bodies and research institutions. Collaborating with regulatory bodies such as the IMO, the EU, or national maritime authorities would ensure that the new solutions is aligned with evolving standards and can serve as a reference model for future regulations.

NAVIGATING A GREENER FUTURE

Conclusions

Based on literature review, stakeholder survey and expert interviews, this market study set out to analyze the state of the maritime industry along with its changing trends, barriers and drivers, regulations and market specifics. The main findings are presented as follows.

STATE OF THE MARITIME INDUSTRY

Decarbonization in the maritime sector is shaped by a **multifaceted relationship** between regulatory pressure, economic motives, and technological advancements. While regulations provide the essential framework and motivation, economic drivers and technological innovation are critical to ensuring that the industry can meet these challenges effectively and sustainably.

Balancing **environmental responsibility** with **economic pressures** is a complex challenge in the maritime sector. While some focus on developing cost-effective technologies or aligning with regulatory frameworks, others take a broader approach, integrating environmental, economic, and societal factors. Overall, the need for innovation that delivers value for money remains a critical consideration, as does the recognition that investments are required to realize decarbonization goals.

The maritime sector's decarbonization voyage faces **several interconnected obstacles,** from fuel availability and infrastructure development to regulatory compliance and technological readiness. However, through a combination of collaborative research, diverse technological solutions, and financial support, there is potential to overcome these challenges and move the industry toward a more sustainable future.

The maritime industry is expected to see **growing interest** in research and development, digitalization, and alternative fuels, driven by efforts to improve fuel efficiency and meet zero-emission targets. While areas like fuel cells and alternative fuels show promise, it is crucial to distinguish between viable technologies and those that may not succeed as the industry adapts to global sustainability goals.

Digitalization is starting to have an impact on the maritime sector, but the availability and quality of data need to improve to fully support decarbonization efforts. More structured data collection, better processing capabilities, and open access will be critical to maximizing the potential of digital technologies in the sector.

Collaboration is considered essential in the maritime industry, with most organizations actively partnering with universities, technology providers, and industry associations to tackle shared challenges. While finding partners is generally easy, the main obstacles are aligning goals, securing funding, and meeting administrative requirements.

HEMOS OFFER

Despite the growing focus on energy efficiency in the maritime industry, several unmet needs remain that current technologies do not fully address. The on-demand heat energy system proposed by HEMOS is uniquely positioned to fill these gaps and offer solutions that go beyond traditional approaches.

Real-time flexibility and adaptability. Many existing heat energy systems are static and operate at fixed capacities, making them less efficient during periods of fluctuating energy demand. The maritime industry needs systems that can adapt dynamically to changes in energy consumption, such as varying engine loads, weather conditions, and onboard activity. The proposed system's ability to adjust in real-time to optimize heat distribution addresses this need, providing significant efficiency gains that existing systems cannot achieve.

Retrofitting capabilities. Retrofitting is becoming increasingly important as shipowners seek to upgrade their vessels to meet new environmental standards without building entirely new ships. However, many existing energy optimization systems are difficult to retrofit due to their complexity or the space constraints on older vessels. The proposed system's modular and adaptable design makes it ideal for retrofitting, allowing shipowners to easily integrate it into their existing ships without extensive modifications. This capability fills a critical gap in the market for retrofitting solutions that can meet both regulatory and operational demands.

Holistic energy management. The maritime industry currently lacks integrated systems that holistically manage all aspects of a ship's energy consumption. While many systems focus on specific areas, such as waste heat recovery or electrical power optimization, the proposed system offers a more comprehensive solution that manages heat energy in conjunction with other onboard energy systems. This holistic approach ensures that all energy flows - whether from heat, propulsion, or auxiliary systems — are optimized together, offering greater overall efficiency and performance improvements compared to piecemeal solutions.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