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Low-Carbon Development of Green Ships and Related Strategies

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Abstract: In recent years, environmental pollution caused by shipping has garnered significant attention from the international community. International conventions and related documents for regulating environmental pollution and reducing emissions from ships have been promulgated successively, and the associated standards and regulations have become increasingly stringent. Green ships have become inevitable in shipbuilding and shipping industries. Herein, the initial International Maritime Organization strategy for reducing greenhouse gas emissions from ships is first analyzed; subsequently, the development status of green ships in Norway, Japan, and the United Kingdom is presented. We summarize the advantages of these countries in terms of policy guidance, technical direction, and international cooperation, and propose some suggestions while considering the development status of green ships in China. China should strengthen its government leadership to formulate green ship development plans at the national and industrial levels, realize technical breakthroughs to accelerate the market application of alternative fuels for ships, and encourage international cooperation while enhancing core competitiveness.
Keywords: green ship; International Maritime Organization; carbon emission reduction; development trend

1 Introduction

Since the 21st century, environmental problems caused by the world's economic growth have become increasingly severe. With more attention being focused on environmental pollution and protection by the international community, requirements of low-carbon and environmental friendliness have become stricter for all industries. A series of new international conventions, regulations, and standards have been promulgated successively, including the *United Nations Framework Convention on Climate Change* for comprehensively reducing greenhouse gas (GHG) emissions and preventing global warming, as well as the framework by the *Paris Agreement* for global climate actions. The World Meteorological Organization *Statement on the State of the Global Climate* in 2019 confirmed that global warming and its chain reactions have progressed, rendering it difficult to achieve the targets of the *Paris Agreement*. António Guterres, the Secretary-General of the United States, remarked, "We need to reduce gas emissions by 45% from 2008 levels by 2030 and reach net zero emissions by 2025. For that, we need political will and urgent actions to set a different path [1]."

Approximately 90% of global trade is by sea, and environmental pollution caused by shipping has garnered significant attention from the international community. Various mandatory regulations to prevent ships from pollution emissions have been formulated and promulgated by the International Maritime Organization (IMO). In this context, the concept of environmental protection through the development of green ships has emerged and has been gradually accepted by the shipping industry. The development of green ships and the exact definition of "green ship" have begun to be discussed and investigated comprehensively in academia. In China, the following definition

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by the China Classification Society is widely recognized: "A green ship utilizes relatively advanced technology (green technology) to economically meet its predetermined functions and performance during its life cycle, while saving resources and energies, reducing or eliminating environmental pollution, and offering protection for operators and users [2]." Although the academic community has yet to reach a consensus pertaining to the definition of "green ship," it supports the fact that a green ship should embody the core principles of environmental protection and energy saving, be supported by the development of advanced technology and new energy fuels, and aim to reduce or eliminate environmental pollution.

To enhance the competitiveness of the shipbuilding industry, the world's major shipbuilding countries have formulated development plans and launched technical research pertaining to green ships. Since the 1990s, China has begun to investigate green ship technology and realized progress in the development of energy-efficient ships and hull construction. To better fulfill its international commitments in energy conservation and accelerate its transition from a major power to a dominant power in shipbuilding, China should exploit the opportunities during the critical development period of green ships to design a layout for realizing the market-oriented operation of green ships. This paper discusses methods to improve the performance of ships and facilitate the market-oriented application of green ships in China through carbon emission reduction, based on the analysis of IMO's carbon emission reduction strategy and the development of green ships in other countries.

2 IMO's carbon emission reduction strategy

The IMO has been committed to promoting GHG emission reduction in the shipping industry and has identified the reduction of carbon emissions from shipping as its primary activity. In 2011, to promote the international shipping sector and achieve the target of emission reduction, the IMO established the energy efficiency design index (EEDI) as an important measure to supervise the low-carbon emission process of shipping and shipbuilding industries. In April 2018, the IMO adopted the *Initial Greenhouse Gas Strategy*, which comprehensively addresses the actions of the shipping industry in response to climate change from the perspective of vision, emission reduction efforts, guiding principles, emission reduction measures, and effects at different stages (Fig. 1) [3,4]. This strategy is not only the first GHG emission reduction strategy formulated by the international shipping industry in response to climate change, but also a milestone in IMO's negotiation for GHG emission reduction in the shipping industry [5].

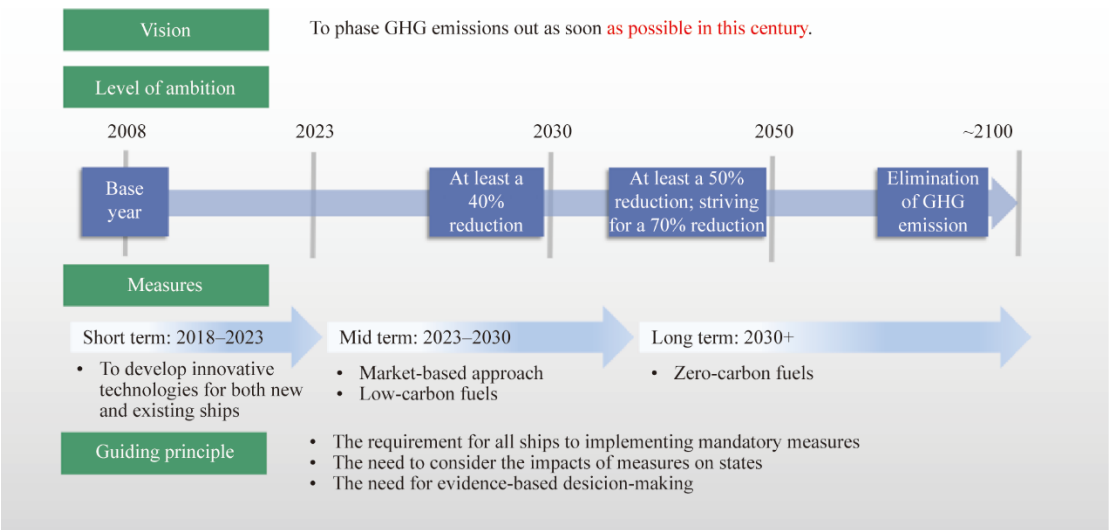

Fig. 1. Initial IMO strategy on reduction of GHG emission from ships.

The strategy incorporates quantitative carbon intensity and GHG reduction targets for the international shipping sector, including (1) at least a 40% reduction in CO_2 emission per product shipping by 2030 and activities to achieve a 70% reduction by 2050, both compared with 2008 levels; (2) at least a 50% reduction in annual GHG emissions by 2050 compared with the 2008 level; (3) measures that are distinguished as either short-, mid-, or long-term to eliminate GHG emissions from the international shipping sector the soonest possible. This includes short-term measures from 2018 to 2013 to develop technical and operational energy efficiency measures for both new and existing ships, as well as to initiate research and development (R&D) activities addressing innovative technologies including alternative fuels; mid-term measures from 2023 to 2030 to implement programs for the effective uptake

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of alternative low-carbon and zero-carbon fuels, as well as to encourage technical cooperation and capacity-building activities; long-term measures beginning from 2030 to pursue the development and provision of zero-carbon fuels, as well as to encourage and facilitate the adoption of possible new/innovative emission reduction mechanisms.

The Marine Environment Protection Committee (MEPC) acknowledges that developing globally available new energy sources that are safe for ships can be a specific barrier to the implementation of possible measures. For instance, to prepare for the effective uptake of alternative fuels, robust lifecycle GHG/carbon intensity guidelines for alternative fuels must be formulated. The *International Code of Safety for Ships using Gases or Other Low-Flashpoint Fuels* has provided mandatory provisions for ships using liquefied natural gases (LNG), but not for ships using hydrogen or other fuels. The MEPC states that it can assist in efforts for promoting low-carbon technologies by facilitating public–private partnerships and information exchange to accelerate the transition to low-carbon and zero-carbon fuel usage in ships.

The IMO's initial strategy for carbon emission reduction in the shipping industry will be formally transformed into the final strategy in 2023 after balancing the interests of all parties. Changes in relevant international regulations determine the shipping industry's development direction. This will significantly affect the formulation of China's energy-saving and emission-reduction policies; hence, the phased goals and measures for energy-saving and emission reduction in the shipping industry must be adjusted accordingly. International regulations and emerging technologies will become important factors affecting the future clean and low-carbon development of the shipping industry. With the establishment of the final IMO expected rules and standards for environmental protection, new opportunities for investment in ships and shipping are expected.

3 Development plans of green ships in other countries and inspirations

Under the pressure of a series of strict environmental protection conventions and standards issued by international organizations, the European Union, Japan, and other countries have formulated national plans and measures for green ships to accelerate the R&D of new energy, new technology, and new materials in the field of green ships. These actions will enable the shipbuilding and shipping industries of these countries to satisfy the requirements of international environmental protection conventions the soonest possible and offer competitive advantages in the international market [6].

3.1 Norway

As a world leader in green transition for all shipping segments, the Norwegian government's ambition is to reduce emissions from domestic shipping and fishing vessels by half by 2030 and promote the development of zero- and low-emission solutions for all vessel categories by legislation, financial advantages, close cooperation between the authorities and the business sector, quotas, green public procurement, and incentive schemes to facilitate the low-carbon transition of the shipping industry [7].

Related legislation and development plans have been introduced in Norway. Norway is a driving force for developing a good international framework to achieve a climate-friendly and environmentally sound shipping industry. The *Ship Safety and Security Act* includes environmental safety and a series of provisions pertaining to environment-related requirements involving the construction, equipment, and operation of ships. The *International Convention for the Prevention of Pollution from Ships*, which regulates matters such as air pollution and noxious and harmful substance emissions caused by shipping, has been implemented in Norwegian law. The *Pollution Control Act* expands its effect by regulating GHG emissions from shipping.

Environmental requirements have been developed for public procurement processes. The government will promote the inclusion of requirements for zero- and low-emission solutions in future procurement processes of ferries and high-speed vessels. Norway's public procurement legislation states that public agencies must perform procurement processes that reduce harmful environmental effects and promote climate-friendly solutions. The government encourages the public sector to use its procurement practices to stimulate demand for products manufactured using low-emission technology. The government will ensure the inclusion of requirements relating to zero-emission transport in public procurement processes to generate opportunities and provide incentives for developing zero-emission vessels.

Incentives for supporting the purchase and registration of green ships have been introduced. The Norwegian government has formulated a long-term subsidy and tax incentive plan for the purchase of environmentally friendly ships. In the revised national budget for 2019, the government has proposed a specific allocation to promote the introduction of low- and zero-emission solutions for high-speed passenger vessels and provide support for counties

that wish to acquire climate-friendly high-speed vessels. While promoting the implementation of environmental measures for the existing fleet under the Norwegian flag, the government also introduced incentives (such as better services and lower fees) to encourage owners to register zero- and low-emission ships in Norwegian registers to enhance the competitiveness of the Norwegian shipping industry internationally.

The development plans for green ships were formulated by the Norwegian government in collaboration with relevant enterprises. The government acknowledges that ship owners, cargo owners, and the public sector must collaborate to develop green ships. When formulating the development plan, the government will initiate a dialog with relevant industry partners to discuss the possibility of drafting a letter of intent concerning the green renewal of cargo fleet. Grants from companies for developing technologies and building charging infrastructure are encouraged. For example, Enova, a wholly state-owned company under the Royal Norwegian Ministry of Petroleum and Energy, has allocated NOK 1.5 million to projects involving different types of vessels, used for the installation of batteries or charging facilities of green ships.

A biofuel quota obligation for sustainable biodiesel and biogas production has been established. The Norwegian government believes that increasing the use of biodiesel and biogas may be vital to achieving the aim of halving emissions from domestic shipping by 2030. The Storting has asked the government to propose a sustainable biofuel quota obligation for shipping. The Ministry of Climate and Environment has requested the Norwegian Environment Agency, in cooperation with the Norwegian Maritime Authority, to review the possibility and consequences of introducing a quota obligation for sustainable biodiesel and biogas for shipping. The government supports the production, research, and development of biogas based on feedstock such as biological residues and waste, with joint efforts from R&D institutes such as Innovation Norway and the Research Council of Norway as well as relevant companies.

3.2 Japan

As one of the major power in the global shipping and shipbuilding sectors, Japan is committed to introducing ultra-low and zero-emission ships by 2030, which is expected to achieve nearly or more than 90% reduction in GHG emissions compared with the 2008 level (hereinafter “zero emission ships”). In this regard, Japan is accelerating the research, development, and demonstration of new technologies, while simultaneously developing plans to incentivize the adoption of zero-emission ships, as well as global supply chains and relevant infrastructure for low-/zero-carbon alternative fuels to solve issues such as high initial costs in the promotion and application of green ships, insufficient endurance capacity, and delayed construction of related supporting facilities.

Japan is developing alternative clean fuels to promote the development of green ships. Two major possibilities of fuel shift exist in international shipping: one is the expanded use of biomethane or carbon-recycled methane via the infrastructure of LNG fuels, which can be used as a transitional, alternative fuel to solve problems related to CO_2 emissions; the other is the increased use of hydrogen and ammonia fuels, which generate no CO_2 when burned without any ignitors, in addition to the continuous use of LNG fuels [4].

To fully introduce alternative fuels and relevant technologies for shipping by 2028, Japan has established key pilot projects and technologies in recent years. First, pilot projects for dual-fuel combustion engines using conventional fuels and either hydrogen or ammonia fuels will be conducted to apply such engines to small coastal ships by 2026, and then to large ocean-going ships with the increased sophistication of relevant technologies. Second, the use of LNG fuels and carbon-recycled methane fuels will be encouraged by establishing plans to minimize methane slip. Third, the performance of the onboard CO_2 capturing system will be enhanced by improving the CO_2 capture rate as well as reducing the size, cost, and necessary power. Finally, the demand for large ocean-going ships with long-term endurance will be fulfilled by increasing the energy density of batteries and improving battery propulsion systems.

In terms of practice, Japan has established the Shipping Zero Emission Project (hereinafter “the project”), in which the concept designs for zero-emission ships to be introduced by 2028 were created, including those for hydrogen-fueled, ammonia-fueled, onboard CO_2-capturing, and super-efficient LNG-fueled ships, to investigate the possibilities for container ships and bulk carriers. By developing the concept designs of these four types of zero-emission ships, possibilities as well as challenges in introducing zero-emission ships from technical and other perspectives were identified. For instance, while developing the concept design of 20 000 TEU container ships or 80 000 DWT bulk carriers, the following technical issues to be resolved in introducing liquified hydrogen-fueled ships were identified: the development of hydrogen-fueled engines and fuel systems, the upsizing of fuel tanks and thermal protection systems, and plans to prevent hydrogen leakage. Nippon Kaji Kyokai has attempted to improve

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and enhance the performance of green ships by optimizing ship types, reducing hull friction, improving propulsion efficiency, and increasing waste heat recycling rate and operating efficiency [6], and progress has been realized.

3.3 The United Kingdom (UK)

The UK believes that the decade of 2020–2030 is the most significant decade in terms of implementing actions to transition the shipping industry to zero emissions by 2050. According to the IMO's Initial GHG Strategy, the decade of 2020–2030 is the most significant decade in terms of R&D based on scaling and commercialization. According to the UK government, zero-emission vessels (ZEVs) must be operated by 2030, and anyone planning to finance, design, or build a ship in the 2020s must consider switching it to a non-fossil fuel ship later in its operational life [8]. To ensure that the decarbonization of the shipping industry is achieved by 2040, the UK developed the following transition pathways: To identify the requirement to develop ZEVs in a low-carbon pathway by 2050; to perform an industrial feasibility assessment of developing ZEVs; to clarify the gap between in-service vessels and ZEVs; to compare different decarbonization schemes; to clarify the driving factors in the transition to ZEVs; and to design a low-carbon action plan to develop ZEVs comprehensively.

To promote the application of ZEVs, the UK has expended significant effort in terms of policy, the public sphere, standards, and rules. Supportive shipping policies entering the decade of 2020–2030 that enable the cost-effective decarbonization of shipping are likely to affect the sector significantly. The standards of ZEVs are likely to become increasingly rigorous over time, which will create a relatively fair competition, reduce the competitive gap between ZEVs and conventional fossil-fueled vessels, and increase the utilization of ZEVs. In terms of the development and commercialization of ZEVs, the UK emphasizes the collaboration with advanced industry enterprises both locally and internationally, including energy developers and fuel technology companies.

Lloyd's Register of Shipping assesses the barriers of each zero-carbon fuel and proposed solution based on an analysis of the implications of zero-carbon fuel technologies. Zero-carbon fuels are defined as fuels that have extremely low CO_2 emissions and can potentially become zero or net zero CO_2 emissions. It is speculated that zero-carbon fuels will need to be available and produced primarily from renewable electricity, bio-energy, and/or fossil fuels with carbon capture and storage. Lloyd's Register of Shipping has assessed each technology to determine the implications for bunkering, storage, processing, conversion, and propulsion, and believes that some barriers exist for each zero-carbon fuel. Industry entities, regulatory agencies, and non-governmental organizations are required to collaborate to resolve issues pertaining to the formulation of bunkering procedures and quality standards, storage systems for new fuel energy, and the required supporting infrastructure on land. [9]

To fulfill the market demand, Lloyd's Register of Shipping demonstrated the elements and viability of ZEVs. By calculating the lifetime protability and cost implications for all possible combinations of seven ZEV technologies (Table 1) across five ship types (bulk carrier, container ship, tanker, cruise, and RoPax) and under different regulatory and economic scenarios, the following question was answered: "Which ZEV technologies are the most viable for delivering vessels that can match the capabilities of today's conventional ships?" [10] A survey of stakeholders in the shipping industry revealed that the majority of ship owners agreed that the reliability and scalability of technologies is more important than the cost, whereas zero-emission vessels should not increase vessel costs by more than 10%. Subsequently, Lloyd's Register of Shipping calculated the cost implications of building and operating ZEVs and concluded that none of the zero-emission options (including advanced biofuels) in their current specifications completely satisfied the ship owner requirements. With the significant investment in R&D and the improvement in technologies, the cost of technology and equipment will gradually decrease during the transition to zero-emission shipping; however, but the operating cost will still hinder the marketization of ZEVs.

Table 1. The UK ZEV technology and machinery combinations.

No.	ZEV Technologies	Machinery combinations
1	Electric	Batteries/Electric motor
2	Hybrid hydrogen	Hydrogen storage/Batteries/Fuel cell/Electric Motor
3	Hydrogen fuel cell	Hydrogen storage/Fuel cell/Electric Motor
4	Hydrogen + Internal combustion engine	Hydrogen storage/Emergency HFO tank/Dual fuel internal combustion engine
5	Ammonia fuel cell	Ammonia storage/Reformer/Fuel cell/Electric motor
6	Ammonia + Internal combustion engine	Ammonia storage/Emergency HFO tank/Dual-fuel internal combustion engine
7	Biofuel	Biofuel tank/Internal combustion engine

3.4 Inspirations

To comply with the development of zero-emission efforts of the international shipping industry, the world's major maritime countries have increased their investment in the development of green ships by encouraging shipbuilding companies to accelerate the R&D of green ships and shipping companies.

First, in terms of guiding policy, these countries, according to IMO's aims of carbon emission reduction by 2030 and 2050, have formulated their national plans for mid- and long-term carbon emission reduction, such as the UK's *Maritime 2050*, Norway's *Government's Action Plan for Green Future in Shipping*, and Japan's *Roadmap to Zero Emissions from International Shipping*. Moreover, financial support and preferential taxes and fees have been offered to the shipping industry to promote market entities and industrial units, including colleges and institutes, to participate in the R&D and production of green ships.

Second, these countries focused on the R&D of green ship technologies in the shipbuilding industry and encouraged various R&D institutions and organizations to analyze the development trends and performance improvements of green ships to maintain their leadership in the shipping industry. For example, in Japan, the 80 000 DWT bulk carriers, 20 000 TEU container ships, and super-efficient LNG-fueled ships researched and developed by the NYK Group represent the first zero-emission ships.

Third, international cooperation was encouraged. Through cooperation with internationally advanced technology companies, general contractors, and manufacturers that design and develop key systems/modules, these countries aim to improve their international competitiveness and influence, while accumulating experience and training talents. For example, the European Union established the LeanShips Innovation Project, uniting 46 shipbuilding companies, equipment manufacturers, and research institutions in 13 countries to perform the R&D of eco-friendly shipping technology/various types of zero-emission ships and solve issues pertaining to alternative fuels, ship energy efficiency decision support systems, and rectification of sulfur emission control areas to reduce ship fuel consumption by 25%, carbon dioxide emissions by 25%, and emissions of SO_x, NO_x, and particulate matter to zero.

Throughout the current development of international green shipping, two aspects are primarily emphasized in green ship technology: the overall ship optimization and the decarbonization of ship power systems, supported by the construction and operation technologies of green ships. The overall optimization of vessels primarily focuses on optimizing the ship design, updating hull materials, reducing the ship ballast water, and reducing surface friction; the decarbonization of ship power systems is primarily developed through technologies pertaining to alternative fuels, including gas fuel technology, hybrid/electric propulsion systems, fuel cell technology, and engine waste heat recycling.

4 Current development and existing problems of green ships in China

In response to the new requirements of international conventions and the IMO for energy conservation and environmental protection in the shipping industry, China has realized achievements in the development of green ships. Relevant policies were issued to guide the low-carbon development of shipbuilding and shipping industries according to international industry standards and regulations. Moreover, to be consistent with international trends, China's research institutions and shipbuilding companies have realized breakthroughs in the R&D of alternative fuels and the construction of green ships. However, problems remain in the overall planning, concept design, and technological innovation of green ships in China.

4.1 Current development

Driven by efforts in energy conservation and emission reduction from the international shipping industry, China has issued relevant policies to guide the R&D and construction of green ships in shipbuilding and shipping industries. In October 2013, the Ministry of Transport of the People's Republic of China (PRC) issued the *Guiding Opinions on Promoting the Application of Liquefied Natural Gas in the Water Transport Industry* to promote the use of LNG for ship fuels to facilitate energy conservation and emission reduction in the shipping industry [11]. In June 2017, the Ministry of Science and Technology of the PRC, together with the Ministry of Transport of the PRC issued *the Special Plan for Technological Innovation in the Transport Sector During the Thirteenth Five-Year Plan*, which listed advanced ship propulsion technology, green ship design, and optimization technology as key research topics [12]. In August 2020, the Ministry of Transport of the PRC issued the *Guiding Opinions on Promoting the Construction of New Infrastructure in the Transport Sector* to encourage the use of clean energy such as LNG in ships [13].

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Moreover, China's shipbuilding companies and research institutions have begun to regard carbon emission reduction as an important indicator in the R&D and construction of green ships. Furthermore, they have realized some progress in low-carbon shipbuilding, low-carbon supporting equipment, emission reduction technology, and recycling of ship materials [14]. China's research on certain types of new energy and fuels has advanced internationally. For example, LNG and other alternative fuels have been widely used in non-gas vessels, such as the 3.2×10^5 DWT oil tanker equipped with the WinGD dual-fuel engine, which was developed by Shanghai Waigaoqiao Shipbuilding Co., Ltd. and satisfied third-stage requirements, with an EEDI lower than the baseline of 37.5%. It was approved by the American Bureau of Shipping (ABS) in 2018 [15]. The Dalian Shipbuilding Industry Group Co., Ltd. built the world's first 3.08×10^5 DWT ultralarge crude oil ship, Kaili, which was equipped with sail equipment for the China Merchants Group and filled the technical gap in the application of sail equipment in China [16]. Meanwhile, COSCO Shipping has successfully installed solar panels on the car carrier COSCO Ascendas, rendering it one of the world's leading solar ships using photovoltaic/grid-connection technology [17]. In addition, LNG-powered ultralarge container ships, bulk carriers, oil tankers, and ro-ro passenger ships as well as battery-powered three-fuel vehicle carriers have been constructed, some of which have been delivered. Furthermore, ships using alternative energy sources such as ethane, liquefied petroleum gas, methanol, and ammonia powered are being developed. The current status of green ships in China can satisfy the IMO's present requirements for environmental protection. However, China is still hindered by major challenges to fulfill higher requirements in the future, compared with other countries such as the European Union, Japan, and South Korea [18]. If China disregards the critical period from 2020 to 2030, it will lag behind other countries and be constrained by other countries in terms of green ship development.

4.2 Existing problems

4.2.1 Insufficient national planning for green ships

China's insufficient proactive and overall planning for the R&D of green ships, integration of efforts from enterprises, universities, and research institutions, as well as incentive sharing mechanisms among research institutions and enterprises has resulted in repetitive and low-quality investment and construction. This has significantly restricted the efficient and intensive development of green ships in China and will delay China's transition from a major power into a dominant power in shipbuilding. To comply with the trend of energy conservation and emission reduction in the international shipping industry, seize the leading advantage in green ship technology, and be vocal regarding the formulation of new international standards and regulations, China should perform actions urgently to formulate national and industrial plans for the development of green (zero-emission) ships and evaluate all types of alternative fuels throughout the industrial chain to accelerate the R&D progress of green ship technology and achieve the emission reduction targets of China.

4.2.2 China's independent ability in developing supporting equipment and technologies for green ships cannot satisfy market demand

The low-carbon development of the shipbuilding industry is significantly affected by the technical and environmental performances of the supporting equipment. In recent years, a new generation of energy-saving, emission-reducing, and low-noise power equipment, electromechanical devices, and environmental devices and materials for green ships has emerged successively, resulting in the mainstream trend of the world's energy-saving technology for ships and promoting the development of innovative technologies and industries pertaining to green ships [19]. However, China has not performed systematic studies regarding the key supporting technology for energy saving and emission reduction in ships. Investigations pertaining to high efficiency and energy saving, vibration and noise reduction, energy saving and emission reduction, and new materials have not been integrated into one, resulting in a weak capacity for realizing integrated innovations and difficulties in the efficient transformation from scientific results to productivity. The core technologies of some key supporting equipment for green ships, such as dual-fuel engines and membrane enclosure systems, still need to be imported from foreign patent owners. Furthermore, the zero-emission transition of the shipbuilding industry requires a large amount of investment from enterprises. The increase in operating costs may weaken the competitiveness of green ships and consequently reduce the participation of enterprises in the zero-emission transition. In the context of the Sino–US trade war and technology war, China must urgently identify approaches to realize breakthroughs in key supporting equipment and technology for green ships to improve China's independent development ability and construct a healthy industry chain of green ships.

4.2.3 Insufficient motivation for technological innovation and regulation formulation in green ships

Countries and regions such as Norway, Japan, and the UK have prioritized compact schedules and efficient R&D progress when formulating their action plans for zero-emission transition to strengthen their position in the world in regard to formulating relevant standards and regulations of international organizations. In terms of R&D, their emphasis is on new types of alternative fuels, optimization of hull design, and zero-emission propulsion systems. Although China has realized breakthroughs and innovations in some sectors, it has not yet reached the level of some leading countries. Currently, green ships in China are designed primarily based on the EEDI and international conventions, as well as specifications and standards. Furthermore, they are improved by the addition of energy-saving and emission-reducing equipment based on the framework of existing ships. This results in the lack of motivation for innovations in the concept design of green ships.

5 Recommendations and suggestions

As one of the major participants of the United Nations' action plans in response to climate change, China has proposed its carbon emission reduction goal by 2030, as announced by President Xi Jinping at the Paris Climate Change Conference in 2015. The development of green ships provides opportunities for China to fulfill its international emission reduction commitments and promote the transformation and upgrading of the shipbuilding industry. The decade from 2020 to 2030 is a critical period for accelerating breakthroughs in the development of green ships; therefore, China must exploit the opportunities during this period to realize the market-oriented and industrialized operation of green ships after 2030. China should formulate national and industrial plans for the overall development of green ships the soonest possible to reverse the situation of passively following, imitating, and importing rather than creating. Moreover, China should endeavor to realize breakthroughs in key technologies through domestic and foreign collaborations, based on the comprehensive analysis of the basic conditions of the R&D and production of green ships in China.

5.1 Strengthen government leadership by formulating national and industrial development plans for green ships

5.1.1 Provide guidance by creating national policies and plans, while promoting integration of various sources

The development of green ships provides an invaluable opportunity for China to enhance its international competitiveness in the shipbuilding industry and ensure its sustainable development. China should formulate national and industrial plans for green ships the soonest possible, which are both systematic and maneuverable, to emphasize the development of green ships. In addition, policies should be issued to guide and promote related companies and research institutions in China to integrate their forces and sources, reduce repetitive and low-quality investment, and accelerate breakthroughs in key technologies of green ships.

5.1.2 Introduce incentives to motivate enterprises to participate in technological innovation

The zero-emission transition of the shipbuilding industry relies on the planning, monitoring, intervention, and incentives from the government, such as charging carbon emissions and establishing infrastructure for alternative fuels. Incentives such as tax concessions and special subsidies can mobilize enterprises and ship owners to participate in the R&D, construction, and operation of green ships, as well as relieve the burden of increased costs caused by the zero-emission transition from enterprises. The regulation and guidance of the government together with the active participation of enterprises can accelerate the development of green ships and reduce shipping costs, thereby enabling a market-oriented application of green ships.

5.2 Accelerate market-oriented application of alternative fuels for green ships by promoting technological advances

5.2.1 Promote market-oriented application of LNG-fueled ships

The demand for low-carbon development promotes not only the transition from fossil fuels to new clean fuels, but also the transformation from diesel propulsion systems to hybrid and electric propulsion systems. China has realized breakthroughs in the development of LNG fuel and propulsion systems; however, it is still lagging in terms of the conditions for market-oriented operations owing to its insufficient infrastructure. Therefore, the ongoing and planned R&D projects should be integrated with alternative fuels to formulate the Key National Plan for Alternative Fuel and Technology for Ship Propulsion, and LNG should be used as a transitional fuel to facilitate the realization of carbon emission reduction targets, market-oriented applications, and infrastructure construction of hybrid

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propulsion systems.

5.2.2 Organize pilot application of hydrogen fuel ships

Because ammonia and hydrogen may become mainstream alternative fuels for ships carrying zero-carbon emissions in the future, China must promote its technological advances in the production, transportation, and storage of ammonia and hydrogen, as well as the layout of refueling stations. The pilot application of hydrogen fuel cells in the shipbuilding sector should be promoted gradually by establishing pilot projects in the Yangtze River and the Pearl River Economic Belt, followed by other regions of China. With the application and continuous improvement of LNG and hydrogen fuel technologies for ship propulsion, the iterative effect of industrial development will be realized.

5.3 Lead development of international shipping industry while encouraging open cooperation and improving core competitiveness

5.3.1 Exploit advantages of domestic and foreign sources under open cooperation

The realization of the United Nations' strategic goals for energy saving and emission reduction relies on the joint efforts and mutual cooperation of all countries. The internationalized shipbuilding industry is currently dominated by a few countries, such as the European Union and Japan. Therefore, an important method to accelerate the industrialized development of green ships and the realization of China's international commitments is to promote open cooperation and mutual exchange. To achieve the effective development of green ships not only requires cooperation among departments in the shipping industry, but also the application of multiple disciplines, such as new materials and new energy. Therefore, open cooperation must be established to integrate the advantages and resources both inside and outside the industry to solve key problems in the development of green ships.

5.3.2 Improve competitiveness of China's shipbuilding industry through multiple forms of cooperation

According to the 21st Century Maritime Silk Road initiative, advanced technologies and high-level professionals should be introduced by establishing international joint R&D programs, international scientific and technology cooperation programs, and joint talent training projects. In addition, some topics remain to be discussed, such as scientific and technological cooperation in related fields, China's advantages in carbon emission technology that strengthen its position in the formulation of international standards, and balanced emphasis on both the internal circulation (self-sufficiency) and external circulation (internationalization) of green ships.

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