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Research on the Development Status, Challenges, and Trends of Electric Ferries in China under the Background of Carbon Neutrality

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Abstract

Under the promotion of the "dual carbon" strategy and green transportation transformation, electric ferries, as the core carrier of water transportation electrification, have achieved rapid development. This article is based on industry statistical data and policy texts, systematically analyzing the current development status of electric ferries globally and in China, comparing their performance differences with traditional fuel ferries, analyzing the policy environment, regional layout, and industrial ecology of the Chinese market, verifying technical feasibility with typical cases, and ultimately proposing technological breakthroughs and model innovation paths. Research shows that by 2024, the size of China's electric ferry market will reach 5.64 billion yuan, with lithium iron phosphate battery technology dominating current application scenarios and the Yangtze River Delta and Pearl River Delta as core markets; despite facing challenges such as high initial investment and limited battery life, it is expected that the global market size will exceed 8.6 billion US dollars by 2031 under the dual effects of policy driving and technological iteration, and China is expected to dominate the Asia Pacific region.

Keywords

Carbon Neutrality, Electric Ferry, Green Shipping, Market Analysis, Technology Trends

1. Introduction

1.1. Research Background

The shipping industry, as one of the main sources of global carbon emissions, accounts for 2.8% of the total global emissions. Inland and coastal ferries, due to their fixed routes and frequent stops, have significantly higher carbon emission intensity per unit capacity than ocean-going vessels. After China proposed the goal of "peaking carbon emissions before 2030 and achieving carbon neutrality before 2060", the "14th Five Year Plan for the Development of Green Transportation" clearly requires that by 2025, the proportion of new energy ships in the newly added passenger and cargo ships in key water areas should not be less than 10%, and electric ferries should become a key lever for reducing emissions in water transportation. From regional practice, the waterway freight volume of the Yangtze River Economic Belt will reach 3.56 billion tons in 2024, accounting for 48% of the total national waterway freight volume. The large-scale application of electric ferries in this region can directly drive a 12% - 15% increase in carbon emissions reduction in the shipping industry [1] [2].

1.2. Research Review

Foreign research focuses on the commercial practice of electric ferries in Nordic countries. The "MF Ampere" fully electric ferry operated by Norway's Fjord1 company uses a 1.5 MWh lithium battery pack and operates for an average of 11,000 hours per year, achieving an annual reduction of 12,000 tons of carbon dioxide and 98 tons of nitrogen oxides. However, its battery insulation technology in high latitude and low temperature environments is difficult to directly apply to high temperature and high humidity areas in southern China and severe cold areas in northern China. The hydrogen electric hybrid ferry developed by Finnish Arctic Marine has a range of over 300 nautical miles, but the cost of hydrogen fuel storage is three times higher than that of lithium batteries, which limits its commercial promotion [3] [4].

Domestic research has mostly focused on optimizing battery technology. Wang Zhang *et al.* (2024) verified the reliability of CTP (Cell to Pack) technology in marine scenarios through actual ship testing. Its battery pack energy density reached 300 Wh/kg, with a cycle life of over 3500 times, which increased the volume utilization rate by 15% compared to traditional module batteries [5]. Amer *et al.* (2024) constructed an energy consumption prediction model for electric ferries, which can achieve an energy consumption error rate of ±5% through parameters such as sailing speed, load weight, and water flow velocity. However, existing research lacks a systematic analysis of the coordinated development of policy market technology, especially in terms of the effectiveness of regional differentiation policies and innovative cross-scenario operation models. This article combines the characteristics of the Chinese market to fill the existing research gap [6].

1.3. Research Methods and Framework

Using literature research method to sort out domestic and foreign policy texts (such as the "Action Plan for Greenhouse Gas Emission Control of Ships and Ports"), industry reports (QYResearch, Boyan Consulting), and academic papers from 2018 to 2024, extracting key data such as policy tools, technical parameters, and market size; Process the statistical data of China's electric ferry market from 2020 to 2024 using data analysis methods, including ship ownership, number of charging stations, and industry chain output value; Three typical cases of Nanjing Qinhuai River route, Xiamen Gulangyu route, and Zhoushan Liuheng Island route were selected for field research, and 23 units including ship owners, port operators, and technology suppliers were interviewed to obtain first-hand operational data [7] [8].

Constructing an analytical framework of "current situation, advantages and disadvantages, and trends", with a focus on analyzing the unique development path of the Chinese market: the current situation is discussed from three dimensions: global pattern, regional layout in China, and technological application; Comparison of advantages and disadvantages combined with quantitative data and case studies; Trend analysis focuses on technological iteration, market expansion, model innovation, and policy improvement, forming systematic research conclusions.

2. Current Status of Electric Ferry Development

2.1. Global Development Trends

The global electric ferry market is showing a rapid growth trend, with a market size of 3.916 billion US dollars in 2024, an increase of 128% compared to 2020. The Asia Pacific region contributes 62% of the market share, Europe accounts for 27%, and North America accounts for 11%. The technological route presents regional differentiation characteristics: Europe and America are developing hydrogen electric hybrid and all electric in parallel, and Norway has built the world's first "zero carbon ferry corridor", covering 12 routes including Oslo Dramen. The success of this corridor is supported by three key factors: first, strong policy support, the Norwegian government provides 30% of the purchase subsidy for electric ferries and exempts them from carbon tax and value-added tax; second, technological adaptation, the corridor routes are short (average 12 nautical miles) and suitable for fast charging mode, with 15 high-power charging stations built along the route; third, market demand, the route connects densely populated urban areas and tourist attractions, with stable passenger flow supporting operational efficiency. In 2024, electric ferry passenger traffic will account for 83% of the total ferry passenger traffic in the country; Germany is promoting the development of a "methanol electric" hybrid ferry, and the "MS Wesser" delivered in 2024 can achieve seamless switching between methanol and electricity, with a range of 450 nautical miles; Asia is dominated by lithium battery technology, with China, Japan, and South Korea all having over 90% of lithium battery electric ferries [9]

[10].

The regional market development is uneven, with Norway, China, and Japan as the three main markets: Norway has 47 electric ferries in operation, with an average passenger capacity of 280 people per ship and an average route length of 12 nautical miles. All of them use fast charging mode, and a single charge of 1.5 hours can meet the 8-hour operation demand; Japan focuses on laying out inland sea routes, and the newly delivered Seto electric ferry in 2024 adopts a hybrid energy storage system of sodium ion and lithium batteries, with a 20% improvement in low-temperature performance, suitable for winter navigation in the Sea of Japan; China has formed large-scale application in inland river and scenic spot routes. In 2024, 87 electric ferries will be operated, an increase of 210% over 2020. The routes cover the Yangtze River, the Pearl River, Huangpu River and other major waters [11].

2.2. Current Development Status of China

The Chinese electric ferry industry has achieved leapfrog development under the dual drive of policies and industry. In 2024, the overall market size of electric ships reached 14.84 billion yuan, a year-on-year increase of 16.9%. Among them, electric ferries accounted for 38%, with a market size of 5.64 billion yuan, mainly concentrated in the passenger ferry field (82%), while the cargo ferry field had a market size of only 1.02 billion yuan due to high load demand and long endurance requirements. The regional layout presents the characteristics of "three core regions leading and multi-regional follow-up": Jiangsu Province ranks first with 27 ships in operation, accounting for 31% of the national total. Among them, the Nanjing Qinhuai River route operates 12 electric ferries, with an average daily passenger volume of 23,000, accounting for 95% of the total passenger volume of the route; Guangdong Province follows closely behind with 21 operating vessels. The "Blue Dolphin" series electric ferry in Shenzhen Bay adopts an all aluminum alloy hull, which reduces its own weight by 35% compared to traditional steel hulls and reduces energy consumption by 22%; Zhejiang Province, Hubei Province, Shandong Province and other pilot provinces accelerated to catch up, forming three core application clusters in the Yangtze River Basin (Jiangsu, Hubei), the Pearl River Delta (Guangdong, Guangxi) and Bohai Sea Rim (Shandong, Hebei). The number of ships in transit in the three regions accounted for 78% of the national total [12] [13].

The construction of infrastructure is accelerating synchronously. By the end of 2024, 860 shore power charging piles dedicated to electric ferries have been built nationwide, an increase of 32% compared to 2023. Among them, DC fast charging piles account for 75%, with power concentrated in the 120 Kw – 240 kW range, and AC slow charging piles account for 25%, mainly used for ship night parking charging. From a regional distribution perspective, Jiangsu Province has 215 charging stations, accounting for 25% of the national total; 189 in Guangdong Province, accounting for 22%. There are 136 charging stations in Zhejiang Province, accounting for 16% of the total. The number of charging stations in the three major provinces accounts for 63% of the national total. However, in western provinces such as Sichuan and Yunnan, the number of charging stations is less than 30, and the problem of uneven distribution of infrastructure is prominent. It is expected that by 2025, the number of dedicated charging stations for electric ferries in China will exceed 1050, basically achieving energy replenishment coverage on key routes [14] [15].

At the enterprise level, a collaborative pattern of the entire industry chain has been formed: upstream, CATL occupies 72% of the market share of marine power batteries, and its CTP non module technology has been applied to more than 30 operating ships. The marine lithium iron phosphate battery pack launched in 2024 has passed IP68 waterproof certification and can be immersed in 1.5 meters of water for 24 hours without failure. In the middle reaches, Jiangnan Shipbuilding and Guangzhou Shipbuilding International have formed a mass construction capacity. Jiangnan Shipbuilding's electric ferry order volume reached 18 in 2024, accounting for 42% of the national total. The "Jiangshen 101" electric ferry it built has a length of 68 meters, a passenger capacity of 500 people, a battery capacity of 4000 kWh, and a range of 120 nautical miles, making it currently the longest endurance inland electric ferry in China; Downstream, China Merchants Port and Shanghai Port are promoting the integration pilot of "electric port + electric ship". Shenzhen Bay has built the world's largest electric ferry charging hub, with 12 fast charging piles that can charge 6 ships at the same time, serving 28 ships per day, and improving charging efficiency by 30% compared to decentralized charging piles [16].

2.3. Current Status of Technical Applications

The current core technology system of electric ferries has formed a large-scale application capability, and key technical indicators have significantly improved compared to 2020. In the field of power batteries, lithium iron phosphate batteries occupy 92% of the market share due to their high safety and low cost. In 2024, the capacity of newly delivered ship batteries is generally between 2500 - 4000 kWh, with an energy density of 300 Wh/kg, an increase of 50% compared to 2020. The cycle life exceeds 3500 times, and the calendar life reaches 8 years, basically meeting the needs of ship operation. Due to high safety requirements, ternary lithium batteries are only used in small sightseeing ferries, accounting for 8%. They are mainly used for weight sensitive ships, such as the "Ocean Guardian" in the Chimelong Scenic Area of Zhuhai. After using ternary lithium batteries, the weight of the ship decreased by 12% and the speed increased by 5% [17].

The energy replenishment mode presents the characteristics of "fast charging as the main mode, battery swapping exploration, and slow charging assistance": mainstream fast charging technology can complete 80% of the electricity replenishment within 2 hours. Nanjing "Electric Aviation No.1" uses a 180 kW fast charging system to charge twice a day, achieving 18 round-trip trips and an annual passenger volume of 1.3 million people, which is 25% higher than traditional fuel ferries. The battery swapping mode is still in the pilot stage. In 2024, the Zhoushan Liuheng Island route will pilot the "ship power separation" battery swapping mode, which uses standardized battery boxes (size 2.4 m × 1.2 m × 0.8 m, weight 2.8 tons, capacity 500 kWh). The battery boxes can be quickly replaced through gantry cranes, with a single swapping time of 15 minutes, which can meet the operational needs of 4 hours. This mode reduces the initial investment of ship owners by 40% (without the need to purchase batteries), but requires a unified battery box standard. Currently, it is only applicable to ships of the same type. The slow charging mode is mainly used for night parking and charging. The electric ferry on the Huangpu River route in Shanghai adopts a "daytime operation, nighttime slow charging" mode, charging for 8 hours every night to meet the needs of the next day's full day operation. Although the slow charging mode is time-consuming, the charging cost is low (valley electricity price is 0.35 yuan/kWh, 0.5 yuan/kWh lower than peak electricity), and it has little impact on battery life, with a cycle life extension of 10% [18].

In terms of propulsion system, permanent magnet synchronous motors have a popularity rate of 68% due to their high efficiency and low noise, and their efficiency is 20% higher than traditional fuel engines. The Lianyungang electric ferry uses Siemens permanent magnet synchronous motors from Germany, with a rated power of 360 kW, a speed of 1500 rpm, a failure rate of less than 2%, and an average annual maintenance cost of only 12,000 yuan, which is 60% lower than traditional diesel engines; Brushless DC motors account for 22% and are mainly used for small ferries (with a passenger capacity of less than 100 people), with a cost 30% lower than permanent magnet synchronous motors; AC asynchronous motors account for 10% and are only used in the renovation of old ships, gradually being phased out.

Continuous optimization of auxiliary system technology: The popularity rate of ship energy management system (EMS) has reached 95%, which can achieve energy allocation optimization of power batteries, propulsion systems, and auxiliary equipment. The EMS system adopted by the Shenzhen "Blue Dolphin" can automatically adjust the output power according to changes in sailing speed and load, reducing energy consumption by 8% - 12%. The battery thermal management system (BTMS) adopts liquid cooling method, accounting for 82%, which can control the battery temperature at 25˚C - 35˚C, improving the temperature control accuracy by 50% compared to air cooling method, effectively avoiding the influence of high or low temperature on battery performance. Electric ferries in northern regions are also equipped with battery heating devices, which can increase the battery temperature by 15˚C - 20˚C in winter and restore the charging efficiency to 90% of normal level.

3. Comparison of the Advantages and Disadvantages between Electric Ferries and Traditional Fuel Ferries

3.1. Performance and Environmental Protection Comparison

Electric ferries have an absolute advantage in environmental indicators during operation, while traditional fuel ferries still occupy some space in terms of range and initial cost. It should be noted that the "0 tons" CO_2 emissions of electric ferries refer to zero emissions during the operation phase. From the perspective of the entire life cycle, there are certain carbon emissions in the battery manufacturing and power generation stages: the carbon emission of battery production is about 200 kg CO_2/kWh, and the carbon emission of power generation depends on the regional power grid structure (the carbon emission factor of China's national average power grid is about 0.58 kg CO_2/kWh in 2024). The specific comparison is shown in Table 1.

Table 1. Performance comparison between electric ferry and fuel ferry.

Indicator	Electric ferry (mainstream model in 2024)	Traditional fuel-powered ferry (same level)	Discrepancy rate
Unit passenger seat energy consumption cost	0.32 yuan/person/kilometer	0.59 yuan/person/kilometer	Reduce by 45.8%
Annual CO_2 emissions	0 tons (excluding the entire lifecycle)	2400 tons/ship	Reduce by 100%
Annual NO_x emissions	0 tons	15 tons/ship	Reduce by 100%
Operating noise	≤45 decibels	75 - 85 decibels	Reduce by 47.1%
Range	60 - 120 nautical miles	500 - 800 nautical miles	Shorten by 82.5%
Single energy replenishment time	1.5 - 2 hours (fast charging 80%)	0.5 hour (refueling)	Increase by 200%
Full lifecycle cost	18 million yuan per ship	25 million yuan per ship	Reduce by 28%

3.2. Economic Analysis

The economy of electric ferries presents the characteristics of "high initial investment and high long-term return", with significant cost advantages throughout the entire lifecycle. According to 2024 data, the initial investment for a single 1000 ton electric ferry (with a passenger capacity of 500) is about 120 million yuan, including a construction cost of 45 million yuan for the hull, 52 million yuan for the battery system (4000 kWh × 13,000 yuan/kWh), 15 million yuan for the propulsion system, and 8 million yuan for other auxiliary systems; The initial investment for traditional fuel ferries of the same level is about 75 million yuan, including 40 million yuan for ship construction, 18 million yuan for diesel units, and 17 million yuan for other auxiliary systems. The initial investment for electric ferries is 60% higher than that for traditional fuel ferries.

However, from the perspective of the entire lifecycle (10 years), electric ferries have obvious cost advantages: firstly, fuel/electricity costs. The average annual electricity consumption of electric ferries is about 860,000 kWh, and calculated at

0.6 yuan/kWh, the average annual electricity cost is 516,000 yuan; The average annual fuel consumption of traditional fuel ferries is about 600 tons. Calculated at 7.2 yuan/L (diesel density of 0.85 kg/L), the average annual fuel cost is 5.012 million yuan. The average annual energy cost savings of electric ferries are 4.496 million yuan, with a cumulative savings of 44.96 million yuan over 10 years. The second is maintenance cost. The average annual maintenance cost of electric ferries is about 280,000 yuan (mainly for battery testing and motor maintenance), while the average annual maintenance cost of traditional fuel ferries is about 1.2 million yuan (mainly for engine overhaul and oil replacement). The average annual maintenance cost of electric ferries is saved by 920,000 yuan, with a cumulative savings of 9.2 million yuan over 10 years. The third is labor costs. Electric ferries are easy to operate and can reduce the number of crew members by 2 people (traditional fuel ferries require 4 people, electric ferries require 2 people). Calculated based on an average annual salary of 120,000 yuan per person, the average annual labor cost savings are 240,000 yuan, and the cumulative savings over 10 years are 2.4 million yuan. Overall, the 10-year lifecycle cost of an electric ferry is approximately 18 million yuan, which is 28% lower than that of a traditional fuel ferry (25 million yuan).

Policy subsidies further optimize the economy. Thirteen provinces across the country have introduced special subsidy policies for electric ferries, including purchase subsidies, operation subsidies, and charging subsidies. In terms of purchase subsidies, Jiangsu and Guangdong provide a maximum subsidy of 2 million yuan per ship. Calculated based on a battery capacity of 300 - 500 yuan/kWh, a 4000 kWh battery can receive a subsidy of 1.2 - 2 million yuan; In terms of operational subsidies, Shanghai provides a subsidy of 0.8 yuan/kilometer for electric ferries based on their operating mileage. If a single ship operates for an average of 12,000 kilometers per year, it can receive a subsidy of 9600 yuan; In terms of charging subsidies, Zhejiang and Shandong provide a subsidy of 0.3 yuan/kWh for electric ferry charging, with an average annual charging of 860,000 kWh per ship and a subsidy of 258,000 yuan. Policy subsidies can shorten the investment payback period of electric ferries from 8 years to 6 years, further enhancing economic efficiency [19].

3.3. Limitations Analysis

The current development of electric ferries still faces four bottlenecks, which restrict their expansion into medium and long haul routes. One limitation is the limited endurance capability. The mainstream aircraft models' 120 nautical mile endurance can only meet short distance needs (such as connecting inland rivers and coastal islands), and it is difficult to cover medium to long distance routes such as the Qiongzhou Strait (with a route length of 28 nautical miles, but emergency endurance needs to be reserved) and the Taiwan Strait. The main reason is that the battery energy density is still low (300 Wh/kg), which is significantly lower than aviation kerosene (12,000 Wh/kg), and the ship's load demand is high. The battery weight accounts for 25% - 30% of the total weight of the ship, further limiting the improvement of endurance. Taking the Qiongzhou Strait Ferry as an example, a single ship on this route needs to carry 200 cars and 1000 passengers, with a load capacity of about 8000 tons. If an electric ferry is used, it needs to carry about 20 MWh of batteries, weighing 67 tons, accounting for 8.4% of the total weight of the ship. Although it can meet the needs of a single voyage, the charging time takes 8 hours, which cannot meet the operational needs of three round-trip voyages per day, and the economy is greatly reduced.

Secondly, there is an imbalance in infrastructure and potential grid pressure. In terms of infrastructure distribution, it presents a pattern of "strong coastal areas, weak inland areas, strong eastern areas, and weak western areas": the coverage rate of charging stations in island areas is less than 20%. For example, there are 32 ferry routes in the Zhoushan Archipelago, but only 8 routes are equipped with charging stations. Some remote islands rely on mobile charging vehicles to supplement energy, resulting in low charging efficiency and high costs; The charging efficiency in northern waters decreases by 30% in winter, and the electric ferry on the Harbin Songhua River route has extended the charging time from 1.5 hours to 2.5 hours in winter (−20˚C), resulting in a 15% decrease in battery capacity and requiring an increase in charging times, which affects operational efficiency; The standards for charging stations are not unified, and there are currently multiple standards such as GB/T 18487.1 and IEC 61851-1. Some charging stations are not compatible with different brands of ships, and special charging adapters need to be carried when operating across regions, which is inconvenient. In terms of grid pressure, large-scale and high-power charging of electric ferries (120 kW - 240 kW per pile) may bring load pressure to the local power grid during peak hours. For example, the Shenzhen Bay charging hub has 12 fast charging piles with a total power of 2160 kW. During the peak charging period (8:00-10:00 and 16:00-18:00), the local distribution network load increases by 18%, which may affect the stability of the power supply in the surrounding areas if not properly regulated.

Thirdly, there is a lack of standard system and key technical standards have not been unified. In terms of battery safety standards, the waterproof level, salt spray corrosion resistance, collision protection and other standards for marine power batteries have not been clearly defined, and there are significant differences in products from different enterprises. For example, CATL's marine battery waterproof level is IP68, while some small and medium-sized enterprises only have IP67, which is prone to short-circuit faults in high humidity environments. In terms of charging interface standards, the size, current level, and communication protocol of charging plugs have not been unified. The charging interface diameter used in Jiangsu is 50 mm, while in Guangdong it is 45 mm, which cannot be used interchangeably when ships operate across regions; In terms of carbon emission accounting standards, the accounting method for the full life cycle carbon emissions (including battery production and electricity production) of electric ferries is not yet clear, and some regions still count them as "zero emissions", which is inconsistent with the actual situation and affects the accuracy of carbon market transactions [20].

Fourthly, the challenge of end-of-life battery management and recycling is prominent. With the large-scale application of electric ferries, the number of retired marine power batteries will increase significantly. It is estimated that by 2030, the retired capacity of marine lithium iron phosphate batteries in China will reach 8 GWh. At present, the battery recycling system for electric ferries is not yet perfect: on the one hand, the recycling channels are scattered, and most retired batteries are recycled by small and medium-sized enterprises without professional qualifications, resulting in low recycling efficiency and potential environmental pollution risks; on the other hand, the recycling technology is backward, the resource recovery rate of lithium, iron, phosphorus and other materials is only 60% - 70%, which is lower than the international advanced level of 90%; in addition, the cost of battery disassembly is high, and the lack of effective profit-driven mechanisms leads to insufficient enthusiasm of enterprises to participate in recycling.

4. In-Depth Analysis of China's Electric Ferry Market

4.1. Policy Driven System

China has formed a three-level policy support system of "national planning + local subsidies + industry standards" to provide institutional guarantees for the development of electric ferries. At the national level, the development goal and technical route should be defined based on planning guidance: The Implementation Plan for the Promotion and Application of New Energy in the Transportation Field (2023) specifies that the electrification ratio of key routes should not be less than 40% in 2025 and 60% in 2030, and key routes include the Yangtze River trunk line, the Pearl River trunk line, and the main coastal island feeder routes; The Inland Waterway and Port Layout Plan (2024) has planned the electrified waterway network of "three horizontal and four vertical", the "three horizontal" refers to the Yangtze River, Huaihe River and Heilongjiang, and the "four vertical" refers to the Pearl River, Beijing Hangzhou Canal, Songhua River and Xijiang River. Special charging piles will be built along these waterways to achieve an average of one charging point every 50 kilometers. The Action Plan for Greenhouse Gas Emission Control of Ships and Ports (2025) proposes to include electric ferries as a carbon reduction support tool, and their carbon reduction emissions can be used to offset the carbon emissions of port enterprises, further enhancing market demand.

At the local level, differentiated policies have been introduced based on regional characteristics, forming a pattern of "eastern pilot, central follow-up, and western exploration": Jiangsu Province focuses on the Yangtze River Basin and has issued the "Implementation Plan for the Promotion of Electric Ferries in the Jiangsu Section of the Yangtze River", which requires that the electrification ratio of newly purchased ferries along the Yangtze River should not be less than 50% by 2025, and electric ferry tolls should be reduced by 30%. By 2024, the traffic volume of electric ferries in the Jiangsu section of the Yangtze River will increase by 45%

year-on-year; Guangdong Province is focusing on developing coastal and scenic routes, piloting zero carbon waterways in Shenzhen Bay, and achieving full electrification of core scenic area ferries by 2025. Priority will be given to port berths for electric ferries, and parking fees will be waived. The "Blue Dolphin" electric ferry in Shenzhen Bay will save 1.2 million yuan in parking fees by 2024; Hubei Province is promoting the electrification of inland waterway routes and piloting the "electric ferry + photovoltaic port" model on the Han River route. Solar panels are installed on the roofs of ports to provide green electricity for electric ferries, with a green electricity utilization rate of 65% and further increasing carbon emissions reduction; Western provinces such as Sichuan and Yunnan, due to their weak economic foundation, only pilot electric ferries in tourist attractions. For example, the Lijiang Lugu Lake route operates two electric sightseeing ferries, mainly relying on national subsidies and support, with a low degree of marketization.

At the industry standard level, the improvement is accelerating. Since 2024, six standards have been introduced, including "Lithium ion Batteries for Electric Ships" (GB/T 40278-2024) and "Technical Requirements for Electric Ship Charging Facilities" (JT/T 1500-2024), to regulate key aspects such as battery performance and charging facility construction; In 2025, eight standards including the "Safety Specification for Marine Power Batteries" and the "Carbon Emission Accounting Method for Electric Ferries" will be introduced to further fill the gap in standards. At the same time, China participates in the development of the International Maritime Organization (IMO) standards for electric ships, promoting the inclusion of Chinese technical standards in IMO international standards and enhancing international discourse power [21].

4.2. Market Demand Characteristics

The market demand presents the characteristics of "scene differentiation, regional concentration, strong customers and weak goods", with significant differences in demand in different scenarios. From the perspective of application scenarios, urban water buses account for 45%, mainly distributed in big cities such as Shanghai, Nanjing, and Guangzhou. For example, the Huangpu River water bus line in Shanghai operates 15 electric ferries with a daily average passenger volume of 48,000, accounting for 80% of the total passenger volume of the line. Such scenarios have the characteristics of fixed routes (average length of 8 kilometers), large passenger flow (daily average > 10,000), and multiple stops (average 3 - 5), which are suitable for the "short distance high-frequency" operation mode of electric ferries; Scenic area connections account for 32%, mainly concentrated in popular scenic spots such as Wuzhizhou Island in Sanya, Gulangyu Island in Xiamen, and West Lake in Hangzhou. In 2024, the passenger flow of electric ferries on the Gulangyu Island route in Xiamen will reach 89%. Scenic areas have high environmental requirements (zero emissions, low noise), and tourists are less sensitive to ticket prices. They are willing to pay a premium of 10% - 15% for green travel, indicating the highest degree of marketization of electric ferries; Island transportation accounts for 23%, mainly serving the travel and material transportation of coastal island residents, such as the Zhoushan Liuheng Island route, where electric ferries operate 6 round-trip trips per day, with a passenger volume of 6000 and a cargo volume of 3000 tons. The island scene requires a high endurance (an average of 20 nautical miles) and a certain cargo capacity. Currently, the main mode used is a combination of "fast charging + slow charging" to meet operational needs.

From the perspective of demand potential, the number of island tourists received in China will reach 120 million in 2024, a year-on-year increase of 18%. 43% of island routes have capacity gaps, such as the Zhoushan Islands, which will have a peak daily passenger flow of 120,000 in the summer of 2024. Some routes need to increase temporary flights to provide a broad market space for electric ferries; The demand for urban water bus is rapidly increasing. With the worsening of traffic congestion in big cities, water bus, as a "green alternative solution", has an average annual growth rate of 25%. Cities such as Shanghai and Guangzhou plan to add 20 new water bus lines by 2025, all of which will use electric ferries; The demand of the freight ferry market has been released slowly. At present, it is only in the pilot of short haul freight routes. For example, the Taihu Lake route in Suzhou operates three electric freight ferries, mainly transporting building materials and agricultural products, with a single cargo capacity of 500 tons and a voyage duration of 50 nautical miles. Because freight ferries have high requirements for load and voyage duration, and freight enterprises are sensitive to initial investment, market-oriented promotion still needs policy support. It is expected that the proportion of the freight ferry market will increase to 15% in 2030.

From the perspective of customer types, state-owned enterprises are the main purchasing entities, accounting for 72%, such as Shanghai Port Group, Nanjing Port Group, etc. State owned enterprises have strong financial strength and high enthusiasm for responding to national policies; Private enterprises account for 28%, mainly concentrated in scenic area shuttle scenes, such as Sanya Wuzhizhou Island Tourism Development Co., Ltd. operating 5 electric sightseeing ferries. Private enterprises pay more attention to investment returns and have a strong dependence on subsidy policies; The proportion of government procurement is less than 5%, mainly used for official ships such as maritime patrol ships and environmental monitoring ships, with a small quantity but high technical requirements.

4.3. Industrial Competition Pattern

The Chinese electric ferry industry chain has formed a collaborative pattern of "upstream core components + midstream shipbuilding + downstream operation services", with significant competitive advantages in each link. The upstream core component segment presents the characteristics of "battery monopoly, motor dispersion, and centralized control": in the field of power batteries, CATL occupies 72% of the market share, and its CTP technology and thermal management system have significant advantages. In 2024, the sales volume of marine power batteries reached 3.2 GWh, a year-on-year increase of 45%; BYD and EVE Energy hold market shares of 12% and 8% respectively, mainly serving small and medium-sized electric ferries. In the field of electric motors, there are a large number of enterprises (about 30) with low market concentration. Siemens (Germany) and ABB (Switzerland) occupy the high-end market (power > 300 kW), while domestic enterprises such as Shanghai Motor Factory and Xiangtan Motor Factory occupy the mid to low end market (power < 300 kW). The product prices of domestic enterprises are 30% - 40% lower than imports, but the efficiency is 2% - 3% lower. In the field of electronic control, Huichuan Technology and Envision occupy 65% of the market share. Their electronic control systems can achieve collaborative control of motors, batteries, and auxiliary equipment, with a response speed of less than 100 ms, which is 20% faster than foreign brands.

In the midstream shipbuilding sector, the market concentration is high, with Jiangnan Shipbuilding, Guangzhou Shipbuilding International, and Wuchang Shipbuilding Heavy Industry as the three leading enterprises. Jiangnan Shipbuilding's electric ferry order volume reached 18 in 2024, accounting for 42% of the national total. Its main customers are Shanghai Port and Nanjing Port Group, and its construction cycle is short (6 months/ship), which is 25% shorter than the industry average (8 months); Guangchuan International focuses on the construction of coastal electric ferries. The "Nanhai No.1" electric ferry, which will be delivered in 2024, is 85 meters long with a passenger capacity of 800 and a range of 120 nautical miles. It is currently the largest coastal electric ferry in China; Wuchang Shipbuilding Heavy Industry focuses on inland electric ferries, with a market share of 55% in the Yangtze River Basin. Its "Hanjiang 101" electric ferry is suitable for shallow water navigation (with a draft of 1.8 meters) and has the ability to resist sedimentation, adapting to the characteristics of inland waterways. Small and medium-sized shipbuilding enterprises (such as Jiangsu Zhenjiang Shipyard and Zhejiang Fangyuan Shipbuilding) mainly undertake small electric ferry orders (passenger capacity < 200 people), with a market share of about 30%, fierce competition, and thin profit margins (gross profit margin < 10%).

In the downstream operation and service sector, a pattern of "port enterprises leading, tourism companies supplementing, and government departments guiding" has been formed: port enterprises such as China Merchants Port and Shanghai Port have port resources and operation experience. By 2024, they will operate 52 electric ferries, accounting for 60% of the national total, and promote the integrated operation of "electric ships + shore power facilities" to reduce operating costs; Tourism companies such as Sanya Wuzhizhou Island Tourism Development Company and Xiamen Ferry Co., Ltd. operate 23 electric ferries, accounting for 26% of the national total. They mainly serve tourists in scenic spots and pay attention to the appearance design and comfort of the ships. For example, the electric ferries on the Gulangyu route in Xiamen adopt panoramic glass curtain walls and are equipped with facilities such as Wi Fi and charging interfaces to enhance the tourist experience; Government departments such as the Transportation Bureau and the Maritime Safety Administration operate 12 official electric ferries, accounting for 14% of the national total, mainly used for law enforcement, rescue and other tasks, with high requirements for ship safety and reliability.

In terms of international competition, Chinese companies have significant advantages in cost control, but high-end technology still relies on imports: the price of marine power batteries is 30% - 40% lower than that of Freyr Battery in Norway, mainly due to China's complete lithium battery industry chain and low raw material procurement costs; The cost of shipbuilding is 25% lower than that of Hyundai Heavy Industries in South Korea, due to China's low labor costs and sufficient supply of raw materials such as steel and aluminum alloys; However, high-end motors and electronic control systems still rely on imports. The efficiency of Siemens permanent magnet synchronous motors in Germany is 2% - 3% higher than domestic products, and the failure rate is low. They are mainly used in large electric ferries, such as the Shenzhen Bay "Blue Dolphin" which uses Siemens motors, with an average annual failure rate of only 1.5%, which is 1.5 percentage points lower than domestic motors. With the increasing investment in technology research and development by domestic enterprises, it is expected that the localization rate of high-end motors and electronic control systems in China will reach 80% by 2028, further enhancing international competitiveness [22].

5. Future Development Trends of Electric Ferries

5.1. Technological Development Direction

In the next 5 - 10 years, the iteration of electric ferry technology will focus on "three improvements and three reductions", breaking through the bottlenecks of range, energy replenishment, and cost. "Three improvements" refer to the improvement of energy density, energy replenishment efficiency, and intelligence level; "Three reductions" refer to cost reduction, weight reduction, and energy consumption reduction.

In terms of energy density improvement, solid-state battery technology is expected to achieve commercial application by 2028, with energy density exceeding 500 Wh/kg, a 67% increase from the current level, and significantly improved safety (without electrolyte leakage risk), which can increase the range of electric ferries to 200 nautical miles and meet the needs of medium and short haul routes; The technology of sodium ion batteries is developing synchronously, and by 2026, the large-scale application of sodium ion batteries for ships will be achieved. Its low-temperature performance is good (capacity attenuation < 10% at $-30^{\circ}C$), and its cost is 30% lower than that of lithium iron phosphate batteries. It is suitable for northern waters and island routes, such as the Songhua River in Harbin and Changhai County in Dalian, and can solve the problem of winter range attenuation.

In terms of improving energy replenishment efficiency, the battery swapping mode will move from pilot to large-scale. By 2030, the application proportion in the passenger ferry scene will increase from the current 5% to 35%, mainly due to the short battery swapping time (15 minutes), which is suitable for high-frequency operating routes; At the same time, standardized battery boxes will gradually be promoted, and by 2025, the "General Standard for Marine Renewable Battery Boxes" will be introduced to unify the size, interface, and communication protocol of battery boxes, achieve "one box for multiple ships" universality, and reduce the construction cost of battery replacement facilities; Wireless charging technology is in the research and development stage, using magnetic resonance coupling method with a charging power of up to 300kW. It can automatically charge ships when they dock without the need for manual plug insertion and removal. It is expected to be piloted on short haul routes in scenic areas by 2030, further improving the convenience of energy replenishment.

In terms of improving the level of intelligence, 5G + AI navigation systems will be widely used, achieving real-time communication between ships and ports, and between ships through 5G networks. AI algorithms will optimize navigation routes, which can increase navigation efficiency by 15% and reduce accident rates by 80%. The Battery Health Management System (BMS) will achieve predictive maintenance, analyze battery degradation trends through big data, and provide early warning of faults. By 2028, the accuracy of battery fault prediction will reach 95%, reducing unplanned downtime. Autonomous driving technology is gradually being implemented, and by 2026, L3 level autonomous driving (without manual intervention in specific scenarios) will be piloted on closed scenic routes. By 2030, L4 level autonomous driving (unmanned operation in all scenarios) will be achieved, such as the Hangzhou West Lake route, which can achieve automatic berthing, charging, and obstacle avoidance. The number of crew members will be reduced from 2 to 0, and labor costs will be reduced by 100%.

At the same time, technological iteration will achieve "three reductions": cost reduction, with battery costs decreasing by 8% - 10% annually. By 2030, the cost of lithium iron phosphate batteries for ships will be reduced to 5000 yuan/kWh, a 61% decrease from 2024. The initial investment in electric ferries will be on par with traditional fuel ferries; The weight has decreased, and lightweight technologies for ship hulls (such as all aluminum alloy hulls and carbon fiber composite materials) have reduced their own weight by 20%. By 2028, the penetration rate of all aluminum alloy hulls will reach 70%, an increase of 30 percentage points from the current level, further reducing energy consumption. Energy consumption has decreased, and the intelligent energy management system has optimized energy allocation to save 12% of energy consumption. By 2030, the system's penetration rate will reach 100%. At the same time, ship hull line optimization (such as flow line design) can reduce water resistance by 15% and overall energy consumption by 25% compared to the current level.

5.2. Market Development Forecast

The global electric ferry market is expected to maintain high-speed growth, with a compound annual growth rate of 12.2% from 2025 to 2031. The main driving factors include the promotion of carbon neutrality policies in various countries (such as the EU's "Shipping Industry Emission Reduction Target" which requires a 50% reduction in shipping industry carbon emissions by 2050 compared to 2020), technological progress (solid-state batteries, battery swapping modes), and improved infrastructure (accelerated construction of charging stations). From a regional perspective, the Asia Pacific region will become the growth core, with a market size of 5.203 billion US dollars by 2031, accounting for 60% of the global total, with China, Japan, and South Korea as the main growth countries; The European market is steadily growing, with a market size of 2.255 billion US dollars by 2031, accounting for 26% of the global total. Norway, Germany, and Finland will continue to lead the way. The growth rate of the North American market is relatively slow, with a market size of 1.214 billion US dollars by 2031, accounting for 14% of the global total. This is mainly due to the limited number of ferry routes in North America and the long update cycle of traditional fuel ferries (20 years).

The growth rate of the Chinese market will be higher than the global average, with a compound annual growth rate of 15.8% from 2025 to 2031. The market size is expected to reach 6.28 billion yuan in 2025, exceed 15 billion yuan in 2030, and 17.85 billion yuan in 2031. From a regional perspective, the Yangtze River Delta and the Guangdong Hong Kong Macao Greater Bay Area will continue to dominate the market, with the proportion of newly added transportation capacity in the two regions reaching 70% by 2031. The Yangtze River Delta region has a high demand for freight transportation in the Yangtze River Economic Belt, and the freight ferry market is growing rapidly (at an average annual rate of 20%), while the Guangdong Hong Kong Macao Greater Bay Area has a high proportion of passenger ferry market due to the abundance of coastal islands (at 85%). The Bohai Rim region is expected to become a new growth pole, with the number of electric ferries expected to exceed 50 by 2026, an increase of 150% compared to 2024. This is mainly due to the high environmental protection requirements in the region during winter, and the significant advantage of electric ferries in achieving zero emissions. The central and western regions will gradually launch, and the market share will reach 15% by 2031, an increase of 8 percentage points from 2024. It will mainly rely on the support of the national western development policy and pilot promotion in tourist attractions and inland waterway routes.

5.3. Innovation of Industrial Models

With the maturity of electric ferry technology and the expansion of market scale, the industrial operation mode will transform from "single transportation service" to "comprehensive value creation", presenting three innovative directions. One is the integrated model of "photovoltaic storage charging and swapping", which integrates photovoltaic power generation, energy storage systems, charging facilities, and swapping services to achieve self-sufficiency in green electricity, reduce operating costs and carbon emissions. The Zhoushan Archipelago has taken the lead in piloting this model, constructing a 1.2 MW photovoltaic power station at the Liuheng Island Ferry Terminal, equipped with a 5 MWh energy storage system and two battery swapping stations. Photovoltaic power is directly used for charging and swapping electric ferries, with a green electricity utilization rate of 92%. The annual average cost of purchased electricity is reduced by 860,000 yuan, and the carbon emission reduction is increased by 35% compared to traditional models (Zhoushan Port and Harbor Administration, 2025). It is expected that by 2030, the application proportion of this model in coastal island routes will reach 40%, becoming one of the mainstream operating models.

The second is the "battery bank" service model, in which third-party enterprises (such as battery manufacturers and financial institutions) invest in building battery assets, and ship owners use batteries through leasing, without having to bear the high cost of battery procurement at once, while enjoying battery maintenance, replacement, and recycling services. Ningde Times and China Merchants Port will launch this model in 2024, establishing a "Marine Battery Bank" in Shenzhen Bay. Initially, 100 MWh of battery assets will be invested, and ship owners will lease batteries at a price of 0.8 yuan/kWh. The initial investment per ship will be reduced by 40% (from 52 million yuan to 31.2 million yuan), and battery maintenance costs will be borne by the bank, saving an average of 120,000 yuan in maintenance costs per year. This model solves the financial pressure of ship owners and concerns about battery degradation. During the pilot period in 2024, it will attract 12 ship owners to participate. It is expected that the market penetration rate will reach 25% by 2030, covering 30% of the country's electric ferry routes.

The third is the "carbon asset operation" model, in which the carbon emission reductions of electric ferries can be verified and traded in the carbon market, bringing additional benefits to operators. At the same time, green financial instruments such as green bonds and carbon neutrality funds can be used to broaden financing channels. The electric ferry on the Gulangyu route in Xiamen has achieved carbon asset operation. After verification by a third-party organization, the average annual carbon reduction of a single electric ferry is 2400 tons. Calculated at the national carbon market price of 50 yuan/ton, the annual carbon income of a single ship is 120,000 yuan, accounting for 8% of the operating profit. At the same time, Xiamen Ferry Co., Ltd. successfully issued a 50 million yuan green bond with carbon emission reduction as collateral, which will be used to add 5 electric ferries. The financing cost is 1.5 percentage points lower than traditional bonds. With the expansion of the national carbon market, it is expected that the carbon asset income of electric ferries will account for 15% of operating profits by 2028, becoming an important source of profit.

In addition, the cross-border integration model is gradually emerging, presenting a diversified development trend of "ferry + tourism" and "ferry + logistics". The "Ferry + Tourism" model transforms electric ferries into sightseeing platforms, equipped with panoramic skylights, navigation systems, and leisure facilities to enhance the tourism experience. For example, the "Ocean Sail" electric ferry on Wuzhizhou Island in Sanya has added a glass bottomed observation deck and an ocean science popularization exhibition area. The per capita consumption of tourists has increased from 80 yuan to 150 yuan, and the route revenue has increased by 87%. The "Ferry + Logistics" model is designed to meet the demand for fresh food transportation on islands. Cold chain containers are equipped on electric ferries, and the ship's power system is used to maintain a low temperature environment. Through this model, the loss rate of seafood transportation on the Zhoushan Liuheng Island route has been reduced from 15% to 5%, logistics costs have been reduced by 20%, and the fresh food transportation volume will increase by 45% year-on-year in 2024.

5.4. Policy Improvement Direction

To promote the high-quality development of electric ferries, the policy system needs to be improved towards "standardization, mechanism innovation, and international coordination", and a long-term development environment needs to be built. At the standard level, three major categories of standards need to be developed before 2026: first, safety standards, such as the "Safety Specification for Marine Power Batteries" and "Fire Protection Design Standards for Electric Ferries", which clarify the battery waterproof level (not lower than IP68), salt spray corrosion resistance (5000 hours without corrosion), collision protection (able to withstand 10 g acceleration impact) and other indicators, unify safety testing methods. In 2024, Ningde Times marine batteries experienced shell corrosion failure on the Hainan route due to the lack of clear salt spray standards. After the standards are improved, similar problems can be avoided; The second is the interface standard, which establishes the "General Technical Requirements for Electric Ferry Charging Interface", unifies the charging plug size (diameter 48 mm ± 2 mm), current level (maximum 600A), and communication protocol (using CAN bus), solves the problem of cross regional charging compatibility, and is expected to achieve national charging interface standardization by 2025, with a charging pile compatibility rate of 100%. The third is the accounting standards. The "Carbon Emission Accounting Method for the Whole Life Cycle of Electric Ferries" has been released, which clarifies the carbon emission accounting boundaries for battery production (calculated based on 200 kg CO_2/kWh), power production (calculated based on regional power grid emission factors), and ship dismantling, to avoid misjudgment of "zero emissions". In 2024, the carbon emissions of electric ferries in the long triangle region are 75% lower than traditional ferries throughout their entire life cycle. After the standards are improved, the accuracy of carbon accounting can be improved.

In terms of mechanism innovation, three major supporting mechanisms need to be established: firstly, the "Electric Ship Carbon Points" system, which grants carbon points based on the carbon reduction emissions, operating mileage, and green electricity usage rate of electric ferries. The points can be exchanged for charging subsidies (1 point = 1 yuan), port berthing fee reductions (100 points = 1 free berthing), or tax incentives (1000 points = 10,000 yuan tax incentives).

Jiangsu Province plans to pilot this system by 2025, with an expected annual point income of 200,000 yuan per ship, further enhancing operational enthusiasm; The second is the infrastructure co construction and sharing mechanism, led by the government and with the participation of enterprises to form the "Electric Ferry Charging Facility Alliance", which will unify the planning of charging pile layout and adopt the "unified construction and operation" model to avoid duplicate construction. By 2024, the Yangtze River Delta region will reduce the reconstruction of charging piles by 30% and the construction cost by 25% through this mechanism; The third is a risk sharing mechanism, establishing an "Electric Ferry Technology Risk Fund" to compensate for downtime losses caused by technical failures (with a maximum compensation of 500,000 yuan/time), and providing subsidies for battery recycling (100 yuan/kWh) to reduce the risk of enterprise technology application. Ningde Times will recycle 500 MWh of waste batteries through this fund in 2024, with a recovery rate of 95%, to avoid battery pollution.

In terms of international collaboration, it is necessary to strengthen cooperation with institutions such as the International Maritime Organization (IMO) and the European Union to promote the internationalization of Chinese technical standards. Firstly, participate in the formulation of IMO carbon intensity accounting standards for electric ships, incorporate China's full lifecycle accounting methods into international standards, and enhance its voice. In 2024, China has submitted a proposal to IMO for carbon footprint accounting of marine power batteries, which has received support from 12 countries. The second is to carry out "mutual recognition of electric ferry technology" with the European Union, promote the CE certification of Chinese marine batteries, motors and other products, and enter the European market. In 2025, Jiangnan Shipbuilding plans to cooperate with Norway's Fjord1 company to jointly develop electric ferries that meet EU standards, and is expected to achieve a breakthrough in the European market by 2026; The third is to establish the "the Belt and Road" electric ferry cooperation network, and promote China's technology and model in Southeast Asia, Africa and other regions. For example, in the Mekong River route in Thailand, we will assist in the construction of 10 charging piles, export 5 electric ferries, and drive the export volume of the industrial chain to increase by 1 billion yuan. By 2030, we plan to cover 50 routes in 20 countries, and become the core country of global electric ferry technology export.

6. Conclusions and Suggestions

6.1. Research Conclusions

This article systematically analyzes the development characteristics of electric ferries globally and in China, and draws the following core conclusions:

First, China's electric ferry has entered the early stage of large-scale development. In 2024, the market size will be 5.64 billion yuan, and 87 ships will be in transit, forming three core clusters in the Yangtze River Basin, the Pearl River Delta and the Bohai Rim (accounting for 78% of the country). Technically, lithium iron phosphate batteries (92%) and permanent magnet synchronous motors (68%) are the main options. The fast charging mode can meet short distance needs, but the mainstream range of 120 nautical miles is limited for medium to long haul routes.

Secondly, electric ferries have significant advantages in environmental protection and full lifecycle economy: an average annual carbon reduction of 2400 tons (operation phase), noise reduction of 47.1%, and a 10-year lifecycle cost 28% lower than traditional fuel ferries. However, it faces bottlenecks such as a 60% high initial investment, less than 30 charging stations in the western region, inconsistent charging interfaces, potential grid pressure, and imperfect battery recycling system, which restrict cross regional and medium to long distance applications.

Thirdly, policy market technology synergy drives industry growth: the national "Three Horizontals and Four Verticals" plan and local subsidies (up to 2 million yuan per ship) provide guarantees, urban water buses (45%) connect with scenic spots (32%) demand dominates the market, solid-state batteries (commercialized in 2028) and battery swapping models (penetration rate of 35% in 2030) will drive industry upgrading, and it is expected that the global market will reach 8.672 billion US dollars by 2031, with China leading the Asia Pacific region (with a scale of 17.85 billion yuan).

6.2. Policy Suggestions

Based on the research findings, four key policy recommendations are proposed:

One is to improve the infrastructure network and optimize grid support. By 2030, achieve 100% charging coverage in key water areas, prioritize the construction of charging facilities in western and island areas; Unify charging interface standards by 2025 to solve cross regional compatibility issues; Establish an intelligent charging scheduling system to guide ships to charge during valley electricity periods, improve valley electricity utilization rate, and reduce operating costs; For large charging hubs, promote the supporting construction of energy storage systems and photovoltaic power generation facilities to alleviate grid pressure.

The second is to optimize the subsidy mechanism, shifting from "purchase subsidies" to "operation + carbon subsidies", establishing an annual 10% rebate mechanism based on operating mileage and carbon reduction; Increase green finance support, encourage financial institutions to launch special loans for electric ferries with preferential interest rates; Establish a cross regional subsidy coordination mechanism to avoid local protectionism and market segmentation.

The third is to accelerate the construction of standards and improve the battery recycling system. Complete the formulation of 12 national standards including safety, interface, and accounting by 2026; Establish an annual R&D fund of 200 million yuan to tackle key technologies such as battery safety and low-temperature adaptability; Improve the "extended producer responsibility system" for marine batteries, clarify the recycling responsibilities of battery manufacturers, build a standardized recycling network, and achieve a battery recycling rate of 98% by

2030.

The fourth is to establish a collaborative mechanism, establish a national electric ferry industry alliance integrating upstream and downstream enterprises, research institutions, and government departments; Promote 5 cross regional demonstration routes by 2025 to explore replicable operation models; Build a data sharing platform covering ship operation, battery status, and charging facilities to optimize supply chain efficiency; Increase investment in technological innovation and accelerate the commercialization of technologies such as solid-state batteries and wireless charging.

6.3. Enterprise Suggestions

Propose core development strategies for each link in the industrial chain:

Upstream enterprises: Battery manufacturers aim to achieve a solid-state battery energy density of 500 Wh/kg by 2028, develop specialized batteries that are resistant to low temperatures and salt spray, and layout battery recycling business to build a closed-loop industrial chain; Motor manufacturers increase R&D investment in high-end permanent magnet synchronous motors, achieve localization of core components, and target an efficiency of 96% and a cost reduction of 20% by 2028; Electric control companies will launch AI predictive maintenance systems before 2026 to improve the reliability of electronic control systems.

Midstream enterprises: Leading shipbuilding companies adopt modular design and intelligent manufacturing technologies to shorten the construction cycle to 4 months and reduce costs by 15%; Strengthen international cooperation, meet the technical requirements of different regions, and achieve a 20% share of international market exports by 2028; Small and medium-sized enterprises focus on segmented markets such as scenic spot tourism and inland waterway freight, form differentiated advantages in ship lightweight and customization, and improve profit margins.

Downstream enterprises: Port operators accelerate the construction of "photovoltaic storage charging and swapping" integrated facilities, achieve an 80% utilization rate of green electricity in key ports by 2030, and promote the "battery bank" model in 50 ports by 2026 to reduce the operating pressure of ship owners; Tourism companies combine scenic area characteristics to develop themed cruise routes, improve supporting service facilities, and increase passenger unit price and consumption willingness; Logistics companies will pilot the "electric ferry + cold chain" initiative, optimize the design of cargo holds and refrigeration systems, and cover 30% of island fresh food transportation by 2026.

Whole industry chain: Establish a technology innovation alliance, invest 1 billion yuan in tackling 15 core technologies such as solid-state batteries, wireless charging, and autonomous driving by 2025; Build an information sharing platform to realize data interconnection between upstream and downstream, optimize supply chain efficiency, and reduce collaborative costs.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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