

Research on the development strategy of electric ship replacement new business based on SWOT analysis

Yao Qin

1. College of Transportation, Chongqing Jiaotong University, Chongqing, 400074

Date of Submission: 01-04-2025

Date of Acceptance: 10-04-2025

ABSTRACT: Zero-emission battery-powered ships are considered to be an ideal technical solution for reducing emissions and saving energy in inland shipping. However, due to the range, the limitations of the onboard space, the initial investment and other factors, pure electric boats are not suitable for long-distance inland navigation. Therefore, as a new business mode, the power exchange mode has become one of the hot spots and trends in the development of electric ships, which can improve the charging efficiency of pure battery-powered ships and improve the range of pure battery-powered ships. This paper introduces the typical electric ship in China, and analyzes the advantages, disadvantages, opportunities and threats of the new business mode of electric ship by SWOT analysis. In response to these problems, suggestions are put forward to vigorously promote modular container batteries, modular container operation, establish and improve long-term service system and strengthen talent support, so as to promote the healthy development of new business forms of electric ship power replacement.

Keywords: Electric ship change electricity; SWOT analysis; Energy conservation and emission reduction.

I. INTRODUCTION

In September 2020, China solemnly announced at the 75th United Nations General Assembly that it will strive to achieve the goal of "peaking by 2030 and achieving neutrality by 2060"^[1]. Against the backdrop of the "dual carbon" strategy, vigorously promoting electric ships is an important development trend for the green and low-carbon transformation and development of China's inland shipping^[2]. Currently, most battery powered ships operate in battery charging mode. With the increase in the number of shipborne batteries and the increase in battery charging time, the operational efficiency of the ship will be greatly reduced. In addition, due to space and investment constraints, the number of battery packs installed on board is limited and cannot

meet the needs of long-distance navigation for inland vessels. Therefore, it is necessary to supply electrical energy during the operation of ships^[3]. The commercial model of battery exchange can effectively solve the above problems. Compared to direct charging mode, ships using charging method can quickly replenish energy without occupying the dock shoreline, which helps to improve the efficiency of dock operations.

II. CURRENT RESEARCH STATUS ABROAD

European electric barges have started mass deployment^[4]. At present, companies in countries such as Norway and the Netherlands have already put into use or planned to build small and medium-sized inland vessels powered by container mobile energy. The first inland cargo ship in the Netherlands to be powered by replaceable container batteries, the "Alfena," made its debut on September 6, 2021. The ship is powered by the ZESpacek container battery pack developed by Wasrtail. The Maersk Cape Town, with a capacity of 4500 TEU, is equipped with a 600kW · h marine battery energy storage system. This system was jointly developed by Maersk and Denmark's Trident Shipping System. The ship uses a 40 foot container that can provide backup energy under rapidly changing power loads to enhance the efficiency of the ship's generators. Rezvanianani established a battery life prediction and safety management method by analyzing the process, influencing factors, and measurement indicators of battery life decline, achieving monitoring of battery safety^[5]. Lisbon has provided fire risk control methods and extinguishing strategies for different types of battery fires^[6]. Zaghbi et al. analyzed the relationship between charging voltage, capacity, temperature, and battery life^[7].

III. CURRENT RESEARCH STATUS IN CHINA

People have proposed many measures to

achieve energy conservation and emission reduction^[8-9]. Among them, the most representative is the All Electric Ship (AES)^[10]. The range issue of electric vehicles (EVs) also exists in electric ships^[11]. The problem that battery powered ships need to solve is whether the remaining battery capacity can support the replacement and timely delivery of the ship during the next voyage. Zhang et al. proposed a joint optimization method for battery capacity and speed based on battery charging method for navigation environment^[12]. Shang et al. developed an AES operation using ESS and proposed a multi-objective joint power generation voyage scheduling model that simultaneously minimizes greenhouse gas emissions and fuel consumption. When fully electric ships dock, shore power is the main power source for providing all loads and charging for ESS, and the cost of shore power cannot be ignored^[13]. Wen et al. constructed a two-level joint scheduling optimization model for AES and integrated energy storage systems with the goal of reducing shore power costs^[14]. Research has found that costs can be minimized when ships arrive at ports during low price periods. Cai Xuwen, Tan Zusheng, and others proposed a set of calculation methods for the endurance and economic performance of fully battery powered ships by comparing the requirements of diesel engines and batteries for ship displacement and cargo hold capacity, as well as battery capacity requirements under different navigation conditions, construction costs, and operating costs. This method can to some extent solve some key problems encountered in the development of battery powered ships^[15]. Wei Wang used a mixed integer linear programming (MILP) model to solve for charging costs, charging costs, and fixed ship costs. Taking the Yangtze River water transportation network as an example, empirical analysis was conducted on this method, and calculations showed that the cost of using electrically driven ships is only 42.8% of that of conventional ships. The use of electric ships can reduce SOx by 80%, PM by 89.47%, and CO2 by 42.62%^[16]. Jiang Minhua and Xiao Ping analyzed the technical characteristics and energy conversion efficiency of various links such as hydrogen production, hydrogen storage, and hydrogen production, and comprehensively analyzed the possibility of hydrogen energy development and application from the aspects of energy endowment, power generation characteristics, and development trends. The research results show that hydrogen energy is unlikely to become an important pillar of China's future energy and power development, and "re electrification" is a more realistic technological approach^[17]. Gu et al. proposed a comprehensive range optimization and energy management model for using replaceable

container batteries to reduce the cost of charging them on land^[18]. Research has found that speed and battery replacement are synergistically optimized. However, Gu et al. did not consider the navigation environment that would have a significant impact on the navigation of inland vessels. In addition, setting the battery trading price at a fixed value is not conducive to the operation of ships and BSS.

In February 2022, Hubei's first 120 TEU electric container ship was officially put into operation; In October, the "Jiangyuan Baihe" 120 ton electric container ship, jointly developed by the Jiangsu Provincial Port and Shipping Department and the Provincial Port Authority, was officially launched on the Beijing Hangzhou Grand Canal; In November, a 105 TEU electric container ship was officially put into operation from Wuhu to Hefei, Anhui; China COSCO Shipping started construction on two new 700 TEU electric container ships in Yangzhou in December; The N997 pure electric container ship, powered by China Shipbuilding Industry Corporation's 712 Institute, successfully completed its trial voyage in Yangzhou in November 2023. It uses a box type mobile power bank for battery swapping and endurance, and is propelled by battery power throughout the entire voyage. It is China's first independently developed and built pure electric container ship with independent intellectual property rights.

In 2020, the total assets of electric ships in China reached 90% 0.5 billion yuan, an increase of 14.73% compared to 2019^[20], has broad development prospects, which has significant practical significance for improving port turnover efficiency and ship transportation efficiency. Below, we will analyze the advantages, disadvantages, opportunities, and threats of the new format of electric ship battery swapping

IV. SWOT ANALYSIS OF THE CURRENT SITUATION OF ELECTRIC SHIP BATTERY SWAPPING

4.1 ADVANTAGES

The "ship electric separation" battery swapping electric ship is purchased and leased through bare ship procurement and battery leasing. The ship owner purchases and holds the ship's power battery, and provides charging, allocation, transportation, lifting and other services. The end user purchases the service from it and pays the service fee. The battery swapping service mode is shown. In this mode, shipping companies do not need to invest in purchasing their own power batteries, they only need to purchase or manufacture ship hulls that meet the requirements of ship power batteries; The battery swapping service company is mainly responsible for the initial investment of the battery system and the

maintenance costs of related charging facilities.

4.1.1 COMPARED TO TRADITIONAL FUEL SHIPS, THE COST IS LOWER

The use of power batteries can significantly improve the energy utilization efficiency of ships, saving nearly 50% of energy consumption compared to conventional fuel powered ships. For example, the fuel cost of a 2000 ton container ship is 4500 yuan per 100 kilometers, while the cost of an electric ship is

only 2560 yuan, as shown in Table 1. In addition, fully electric ships can also utilize peak and valley electricity, as well as clean energy sources such as wind, solar, and water at night to achieve energy conservation and emission reduction. While saving energy, it can also save maintenance costs, crew wages, and other expenses, as shown in Table 2. In shipping innovation, electric ships are considered to be both cost-effective and environmentally friendly.

Table 1 Operating cost per 100 km for the same 2000 tonnage vessel

Power Type	unit price	Fuel consumption per 100 kilometers	100 kilometer operating cost
Diesel powered vessels	8 yuan/kg	600kg	4800 yuan
LNG fueled vessel	6 yuan/kg	660kg	3960 yuan
Pure electric ship	1 yuan/kw · h	2560	2560 yuan

Table 2 Analysis of average annual operating cost of electric ships

Electric vessel name	Annual electricity consumption/10000 kWh	Electricity unit price/(yuan · kWh)	Energy consumption cost of electric ship berthing/10000 yuan	Electric ship berthing manual operation and maintenance cost/10000 yuan	If using traditional ship fuel consumption/10000 L	Fuel unit price/(yuan · L)	Traditional ship fuel consumption costs/expenses	Traditional ship manual operation and maintenance costs/10000 yuan	Operation and maintenance cost difference/10000 yuan
Tiamu Lake Electric Ship	7.36	1	7.36	20.00	7.000	6.75	47.2500	47.37	-67
Zhongtian Electric Transport Ship	2.00	1	2.00	20.00	2.000	5.60	11.2000	41.92	-31
The Taihu Lake Electric Work Boat	1.53	1	1.53	0.06	0.936	6.00	5.6160	0.60	-5
Lianyungang electric tugboat	60.00	1	60.00	160.00	34.950	6.75	235.9125	223.00	-239
Nanjing pure electric dry bulk carrier	65.00	1	65.00	36.00	35.000	6.50	227.5000	90.00	-217

Compared with traditional fuel powered ships, the zero emission advantage is significant

At present, there are successful cases of pure electric ships in Wuhan, Guilin, Yichang, the Pearl River and other places. Among them, the "Yangtze River Glory" type battery in Wuhan has a capacity of 2931kw/h, which can reduce about 230 tons of CO2 per year; The power of the Wuhan Junlv battery pack is 2200kw. h, which can reduce 170 tons of CO2 per year; The total power of the battery of the "Three Gorges One" project in Yichang is 7500kw/h, which

can reduce 580 tons of CO2 emissions annually. Batteries do not produce greenhouse gases such as CO2 during discharge, and the final carbon emissions are transferred upstream to power generation. Compared with traditional manned fuel ships, electric ships are more environmentally friendly.

Compared to shore charging mode, battery swapping mode is safer, more efficient, and cost-effective

The traditional coastal charging operation not only affects the efficiency of the operation, but

also limits its promotion. Compared to electric vehicles, the high energy consumption and complex navigation environment of ships make the problem of range anxiety more prominent; In addition, due to the large volume of power batteries carried on ships, they need to wait for charging on board for a long time, which not only has a great impact on the normal operation of the ship, but also occupies precious shoreline resources, and is not suitable for the development of electric ships in the future ^[24].

1 Due to the fact that the purchase cost of power batteries does not need to be paid by the end user of the operating vessel, and the vessel itself does not require the installation of diesel engines, the standardization of electric vessel types can greatly reduce the initial construction costs of ship operating enterprises. In addition, centralized charging can also maximize peak and valley power utilization, thereby saving costs.

2 Mobile power batteries can adopt a unified slow charging mode, which can effectively solve the problem of rapid battery decay caused by fast charging.

3 Compared to charging methods, the battery swapping mode can complete the entire ship's battery swapping and lifting work within 20 minutes.

4 Charging service providers can provide unified and reasonable scheduling for customers' battery supply, ensuring long-term use by end users and maximizing battery utilization.

4.2 DISADVANTAGES

4.2.1 PRODUCT ASPECT

At present, the relevant standards for pure battery powered ships are scattered in international maritime conventions, inspection rules, classification society specifications, as well as ships and related industries, but have not yet formed a system ^[25]. At present, there is no unified standard for battery capacity, charging and swapping indicators, interfaces, etc. of container type mobile power supplies developed and manufactured by different manufacturers. There is also no unified standard for regular testing and maintenance, and product

compatibility issues may arise in the future. Therefore, further research and improvement are needed in the life cycle management, hierarchical utilization, and dismantling and recycling of power batteries. Charging and swapping are the core of the operation of electric ships, and currently research on the safety of this ship mainly focuses on evaluating its operating conditions and failure analysis. Therefore, it is of great significance to study the charging and swapping safety of ship power batteries ^[26].

4.2.2 MANAGEMENT ASPECTS

At present, there is no safety management system or corresponding regulations for the transportation, loading, construction, and operation of container type mobile power sources in ship use, shore based lifting, land transportation, and charging and storage of power exchange stations. The relationship between their land transportation, lifting and replacement, ship use, and the management of major hazard sources of dangerous goods in road and waterway transportation and ports still needs to be further clarified.

4.2.3 ECONOMIC ASPECTS

Due to the high production cost of batteries, it is difficult for ship owners to afford the high initial charging cost. At present, the price of iron cobalt lithium batteries in the ocean is about 2000 yuan/kw. h, which is a capacity of 1000 kw. h, close to two million yuan, equivalent to the cost of traditional 1000 ton inland ships. As shown in Table 3. During use, issues such as post maintenance, repair, and scrapping of batteries have also deterred many ship owners from using electric ships. At present, marine power batteries cannot be used as power batteries after their service life exceeds 3500 times, and the best condition is only 8 years. If not maintained in a timely manner, it will accelerate the aging and decline of batteries. This means that after a few years, ship owners will encounter the problem of replacing batteries. The longer the battery is used, the more obvious the aging problem of the battery will be ^[27-29]

Table 3 Electric ship construction cost analysis

Electric vessel name	Battery capacity/kWh	Type	Total battery cost/10000 yuan	Total construction cost/10000 yuan	Supporting shore power construction cost/10000 yuan	If using the construction cost of traditional ships/10000 yuan	Cost difference/10000 yuan
Tianmu Lake Electric	1000	Lithium Iron Phosphat	200	1000	100.0	800	300.0

Ship Zhongtian Electric Transport Ship	1500	Lithium Iron Phosphat e	300	466	100.0	350	216.0
The Taihu Lake Electric Work Boat	250	Lithium Iron Phosphat e	50	100	4.2	35	69.2
Lianyungan g electric tugboat	5000	Lithium Iron Phosphat e	1000	2000	900.0	1600	1300.0
Nanjing pure electric dry bulk carrier	2200	Lithium Iron Phosphat e	425	819	152.0	400	571.0

4.2.4 TECHNICAL ASPECTS

Currently, electric ships are mainly powered by lithium-ion batteries, and their individual range is limited. According to statistics, over 70% of safety accidents occur during charging and recharging, and the bottleneck of battery technology needs further research and development to be overcome.

4.3 OPPORTUNITIES

4.3.1 POLICY SUPPORT

In recent years, many local governments have been strengthening their support for industry. To promote the development of the electric ship industry, the country has introduced multiple supporting policies. For example, in 2022, the Ministry of Industry and Information Technology issued the "Implementation Opinions on Accelerating the Green and Intelligent Development of Inland River Ships", which requires the vigorous development of battery powered ships. Strengthen the integration and optimization of ship power batteries, battery management systems, and other aspects, conduct research on efficient and energy-saving motors, power grid networking, ship charging and swapping, etc., improve the capacity and safety of ship battery power devices, and promote their application in long-distance inland cargo ships, riverside cruise ships, lake ships, and other fields. Taking cargo ships as pilot projects, the development and application of standardized box type power conversion technology.

4.4 THREATS

4.4.1 TECHNICAL ROUTE COMPETITION

Green shipping and logistics carbon reduction technologies mainly involve improving energy efficiency and updating energy or fuel technologies. At present, in addition to traditional battery driven methods, there are also multiple energy sources

coexisting, such as LNG, methanol, biofuels, hydrogen, ammonia, etc. In the future, there may be a pattern dominated by a single energy source or multiple energy sources coexisting, which poses great challenges to China's electric ship industry.

4.4.2 POWER SUPPLY SHORTAGE

More than 20 provinces, cities, autonomous regions, and municipalities directly under the central government, including Jiangsu, Guangdong, Yunnan, Zhejiang, Shandong, Hunan, Liaoning, Jilin, and Heilongjiang, have successively implemented power restrictions. Many regions have issued orders such as "start three, stop four", "start two, stop five", "start one, stop six", and "start one, stop six". In the Northeast region, the impact of electricity restrictions is not limited to industrial and commercial consumers.

4.4.3 QUEUE CONGESTION

After the large-scale promotion of electric ships using the future battery swapping mode, due to the operational characteristics of the ships themselves, some ports may have a large number of ships concentrated at the port. However, due to the limited construction scale of charging and swapping stations as port supporting facilities, some busy ports may experience congestion of electric ship battery swapping queues.

V. DEVELOPMENT STRATEGY FOR NEW FORMATS OF ELECTRIC SHIP BATTERY SWAPPING

5.1 INTRODUCE INDUSTRY UNIFIED SHIP BATTERY SWAPPING OPERATION STANDARDS

At present, there is no unified standard or standard for port ship charging and swapping operations in China. From the current actual situation, China has not yet established a complete set of

standards for the identification of ship batteries, the construction conditions of charging stations, and the operation specifications for ship charging and swapping. The management style is relatively extensive, which is detrimental to the long-term healthy development of the industry. It is recommended that box type ship power sources certified by professional organizations (such as classification societies) can be disposed of in ports according to ship equipment. At the same time, a set of national unified ship charging station construction standards and ship charging and swapping operation procedures should be formulated to provide policy support for the industry.

5.2 VIGOROUSLY PROMOTE STANDARDIZED BATTERY SWAPPING OPERATION MODE

This article proposes a modular ship electric separation power battery operation mode, which does not configure a stationary battery pack on board, but loads it in a modular container. When the battery power is low, it is driven to the battery swapping station, then transported to the charging station, and finally filled before being transported to the swapping station. At the same time, due to the random power requirements of the charging and swapping station, the fully loaded battery can also be achieved through multiple charging stations. The schematic diagram of the operation mode is shown.

5.3 STRENGTHEN TECHNICAL AND TALENT SUPPORT

When developing new business models, existing technologies should be fully utilized, such as improving ship power and propulsion systems, optimizing speed, etc., to achieve the goal of significantly reducing greenhouse gas emissions. Considering the comprehensive characteristics of the cross industry implementation of the new form of battery swapping for electric ships, it is necessary to cultivate specialized talents, increase talents in fields such as electric container ships and charging and swapping stations, establish a technically capable and efficient talent team, and adapt to the development needs of the market. Strengthen cooperation and contact with relevant units, conduct joint research and study on technical difficulties and hot issues, establish professional technical teams, enhance technical strength, and strengthen the competitiveness of enterprises.

5.4 STRENGTHEN RISK PREVENTION

The revenue source of the new electric ship battery swapping mode is relatively single, and its profitability is affected by various factors. In order to cope with major issues such as tight power supply,

crowded battery swapping teams, and intensified market competition, it is necessary to predict market changes, formulate response plans in advance, and enhance prevention and control capabilities. Risk transfer methods can be used to reduce the risk level of engineering economic entities, such as using a wide range of risk transfer methods such as insurance or contract agreements.

5.5 INCREASE POLICY SUPPORT AND STRENGTHEN THE PROMOTION AND APPLICATION OF ACHIEVEMENTS

The battery swapping of electric ships is a systematic project that includes the planning and construction of charging stations, the construction of electric ships, investment in batteries, and the selection of power supply methods. According to the game theory model related to electric vehicles^[34], the construction of supporting infrastructure can fundamentally enhance the industrial foundation of the industry, but this process still needs to be led by the government, with high-level top-level planning, and jointly formulated by industry associations, research institutions, and relevant enterprises. By comprehensively applying policies such as environmental assessment, financial and tax subsidies, and industry support, electric ships along the Yangtze River will be charged. Develop a timely promotion list for innovative, representative, and exemplary achievements, and promote their application within the industry^[35].

5.6 Promote the new model of integrated development of port source, network, load and storage

In response to the current power and power redundancy issues in battery swapping ports, this article proposes to build a new line to increase supply, while maximizing the efficiency of port energy consumption and enhancing the output balance capability of the power system. In the port area, based on the actual situation, new energy such as wind power and photovoltaics will be developed to promote the integrated development of "source grid load storage". On this basis, the peak shaving and valley filling effect of the energy storage device is utilized to achieve effective matching of network, time, and space in time and space.

VI. CONCLUSION AND PROSPECT

This article conducts a comprehensive analysis of the development of the new business model of electric ship battery swapping based on the SWOT analysis method. The results show that the new format of electric ship battery swapping has multiple advantages, including low cost, zero emissions during operation, and greater safety,

savings, and efficiency. At the same time, there are also some disadvantages to the new format of electric ship battery swapping, such as the lack of a systematic standard for pure battery driven ships, obvious battery aging problems, and high battery swapping costs. With the support of national strategies such as "carbon peak, carbon neutrality," and "Yangtze River protection," the development of new forms of electric ship battery swapping has a favorable policy environment and market foundation. Based on this, this article proposes a series of development strategies, including the introduction of industry unified ship battery swapping operation standards, vigorously promoting standardized battery swapping operation models, and strengthening technical and talent support.

In summary, the new industry of electric ship battery swapping, as an emerging phenomenon, is still in its early stages of development. Although it faces some bottlenecks, it has enormous potential and broad prospects for development. In the future development, we should fully leverage our strengths, actively address our weaknesses, seize opportunities, and jointly promote the healthy and sustainable development of the new electric ship battery swapping industry.

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