

Opportunities and Challenges for the Application of Biomass Energy in the Maritime Industry

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Abstract As the global demand for sustainable energy continues to rise, the maritime industry, as a cornerstone of global trade, is increasingly scrutinized for its carbon emissions and environmental impact. Traditional fossil fuels, while meeting transportation demands, have also brought about issues such as greenhouse gas emissions and environmental degradation. Biomass energy, as a renewable and low-carbon alternative, has gradually attracted attention in the maritime industry. This review aims to delve into the opportunities and challenges of biomass energy application in the maritime sector. Firstly, it introduces the basic concept of biomass energy, analyzes its characteristics and advantages, emphasizing its potential in reducing carbon emissions and mitigating environmental impact. It then examines the existing challenges in the maritime industry. Subsequently, it explores in detail the application of biomass energy in maritime shipping, including its potential, feasibility, and current biomass energy maritime projects. This review focuses on the opportunities and challenges of biomass energy in the maritime sector, with special attention to technological limitations, cost-effectiveness, and sustainability issues. Finally, it summarizes the significance of biomass energy in achieving sustainable maritime transportation and underscores the key challenges that need to be overcome. It aims to provide valuable insights for future research and policy development. By thoroughly investigating the potential of biomass energy in the maritime industry, this review intends to promote more environmentally friendly, sustainable, and innovative developments in maritime shipping.

Keywords Biomass energy; Maritime industry; Sustainability; Carbon emissions; Environmental impact

With the increasing severity of global climate change, reducing greenhouse gas emissions and achieving sustainable energy supply has become a global priority. In this context, all walks of life are actively exploring the possibility of alternative energy sources to reduce dependence on traditional fossil fuels and thus reduce negative impacts on the environment. The shipping industry, as the key pillar of global trade, is also seeking sustainable energy solutions to address its challenges of carbon emissions and environmental sustainability.

The shipping industry has always been an important component of the global trade and logistics system, but it is also a relatively high carbon emitting industry. According to data from the International Maritime Organization (IMO), the shipping industry accounts for approximately 2% to 3% of global greenhouse gas emissions. With increasing concerns from the international community about climate change, reducing carbon emissions from the shipping industry has become a part of the global agenda. The IMO proposed an "initial strategy" in 2018 aimed at reducing greenhouse gas emissions from the global shipping industry. However, to achieve this goal, the shipping industry needs to take a series of innovative measures, including finding alternative energy sources.

Although renewable energy sources such as wind and solar energy are widely used in land transportation, their application in the shipping industry still faces many challenges. Traditional liquid fuels, such as heavy oil and diesel, remain the main source of energy for most commercial ships, but their use relies on limited fossil fuel resources and will lead to high carbon emissions.

Therefore, this study aims to explore the potential application of biomass energy in the maritime industry, as well as the opportunities and challenges faced in realizing this potential. Specifically, the study will examine the definition, characteristics, and advantages of biomass energy, analyze its application in other fields, evaluate the

potential and feasibility of biomass energy in the maritime industry, and also focus on technological innovation and sustainability issues.

The study introduces the basic concepts of biomass energy, including definition, classification, and characteristics. Subsequently, the current situation and challenges faced by the maritime industry will be introduced, highlighting the urgency of emission reduction. Additionally, the study explores the application potential and advantages of biomass energy in the maritime industry. On this basis, we will delve into the feasibility and applicability of biomass energy in the maritime industry, as well as existing biomass energy maritime projects and application opportunities. While biomass energy has opportunities in the shipping industry, there are also challenges that need to be emphasized in terms of technological innovation, cost-effectiveness, and sustainability. At the end of the review, the key points and findings are summarized, emphasizing the importance of biomass energy in achieving sustainable maritime transportation, aiming to provide a reference for future research and policy formulation.

1 Overview of Biomass Energy

Biomass energy is a renewable energy source that originates from biomass, such as plants, trees, crop residues, wood waste, and other organic materials. These biomass materials can be transformed into forms that can be used for energy production through various technologies including as liquid fuels, gases, electricity, and thermal energy. The widespread application of biomass energy not only helps to reduce dependence on limited fossil fuels, but also helps to reduce greenhouse gas emissions, thereby mitigating the impact of climate change.

1.1 Definition and classification

Biomass energy is a diverse source of energy, which can be divided into different categories based on its source, form, and use, mainly including biomass solid fuel, biomass liquid fuel, biomass gas fuel, biomass thermal energy, and biomass electricity. These forms of biomass energy have wide applications in different fields, and the sustainability and environmental characteristics of biomass energy make it a powerful choice to replace traditional energy. In the maritime industry, biomass energy is also considered a potential sustainable energy source, with the potential to reduce carbon emissions and improve environmental sustainability (Zhang et al., 2023).

Biomass solid fuels include solid biomass materials such as wood, straw, sawdust, and straw, which are commonly used in fields such as biomass boilers, biomass combustion power plants, and household heating; Biomass liquid fuels exist in liquid form, including biodiesel and bioethanol. It can be used to replace traditional petroleum fuels such as diesel and gasoline for transportation, power generation, and heating; Biomass gas is a combustible gas that includes biomass gas (Biogas) and biomass synthesis gas (Syngas). It is usually generated during the fermentation process of organic waste and can be used for power generation, heating, and fuel production; Biomass can be used for heating and industrial processes through combustion or direct heating, known as biomass thermal energy. This type of energy is widely used in fields such as heating, cooking, and drying; Biomass fuel can also be used for power generation, usually achieved through steam turbines or internal combustion generators in biomass power plants.

1.2 The characteristics and advantages of biomass energy

Biomass energy has unique characteristics and numerous advantages in the energy field, making it a remarkable alternative energy choice in the shipping industry. It can help reduce ship carbon emissions, improve the environmental sustainability of the shipping industry, and help meet international and domestic greenhouse gas emission reduction targets.

Firstly, renewability. Biomass energy comes from renewable biomass materials, such as plants and waste, and therefore has the potential for sustained supply. Compared to limited fossil fuels, biomass energy does not deplete and helps reduce the uncertainty of energy supply (Zabed et al., 2017). Secondly, carbon neutrality ability. The carbon dioxide released during the combustion process of biomass energy is almost equal to the amount of carbon dioxide absorbed by biomass materials during their growth process, thus possessing the potential for carbon neutrality. It helps to reduce greenhouse gas emissions and mitigate the impact of climate change. Thirdly, diversity. The sources of biomass energy are very diverse and can utilize a variety of plants, waste, and

agricultural residues. This diversity helps to reduce dependence on specific energy sources and improve the diversity of energy supply. Fourthly, innovation. Innovative technologies are constantly emerging in the field of biomass energy, such as efficient conversion of biomass waste, development of new biomass fuels, and integrated utilization of biomass energy. These technological innovations are expected to improve the production efficiency and economic feasibility of biomass energy. Fifth, locality. The production of biomass energy is usually carried out locally, as raw materials are usually produced nearby. It helps to promote local economic development and reduce dependence on long-distance energy transportation. Sixth, resource sustainability. The sustainability of biomass energy is closely related to the planting and management methods of plants. Adopting sustainable agricultural and forestry management practices helps ensure the sustainable supply of biomass resources.

1.3 Overview of the application of biomass energy in other fields

As a multifunctional renewable energy, biomass energy not only has broad application potential in the shipping industry, but also has made significant progress in other fields. The applications in these fields indicate that biomass energy has a wide range of applicability and potential, and can provide clean and sustainable energy solutions for different fields. In the shipping industry, drawing on the experience and technology of these fields is expected to promote the application of biomass energy, reduce carbon emissions, and achieve more sustainable shipping.

In the field of transportation, biomass energy has been widely used in road and railway transportation. Biodiesel and bioethanol are the most common biomass transportation fuels. They can be mixed with traditional fuels to reduce greenhouse gas emissions from vehicles and improve air quality. Biomass energy is also used for power generation, especially in local power plants and biomass power plants. Biomass energy can be converted into electricity through combustion, gasification, or fermentation. The use of the clean energy helps reduce dependence on fossil fuels (Wang and Wang, 2015). In terms of heating and cooling, biomass energy is widely used in household heating and industrial heating. Biomass boilers and biomass water heaters can use wood, straw, and other biomass as fuels to provide efficient heating services. Biomass energy is also used in industrial production to prepare products such as chemicals, pulp, and paper. Biomass as a raw material can replace fossil resources and reduce the environmental impact of the production process. Biomass waste and organic waste can also be converted into biomass energy, such as biogas, through anaerobic digestion processes. This method helps to reduce waste accumulation while generating usable clean energy. In addition, biomass energy is also being studied and applied in the aviation industry to reduce aircraft carbon emissions. Some test flight projects have successfully used biomass aviation fuel for flight (Liu et al., 2012).

2 Current Situation and Challenges of the Maritime Industry

The shipping industry is one of the largest logistics and trade transportation modes in the world, carrying the vast majority of international trade goods. According to the International Maritime Organization (IMO), approximately 80% of global trade is completed through sea transportation, which is crucial for the health and growth of the international economy. The maritime industry, as the core of the global trade and logistics system, provides a solid foundation for economic growth and human social development.

The shipping industry is a global mode of transportation. By sea freight, goods can quickly cross national borders and oceans, connecting markets and supply chains around the world. This global connectivity provides a solid foundation for the globalized economy, enabling products and resources to flow faster and farther. In recent years, global freight volume has steadily increased. This is partly attributed to the development of globalization, the increase in cross-border trade, and the rise of emerging markets. Especially in Asia, especially China, the continuous growth of export and import demand has driven the development of the maritime industry. With the continuous advancement of technology, the design and performance of ships have been significantly improved. Modern vessels such as large container ships, liquefied natural gas carriers, and ultra large oil tankers not only have large carrying capacity, but are also more environmentally friendly and energy-efficient. These advances contribute to improving the efficiency and sustainability of the shipping industry.

Although the shipping industry is crucial to the global economy, it also faces challenges in terms of environment and sustainability. The greenhouse gases and pollutants emitted by ships have raised environmental concerns, prompting the international community to take measures to reduce ship emissions. The global sulfur restrictions imposed by the IMO, which mandate the use of cleaner fuels, are an important measure. The current situation of the maritime industry is also influenced by port and logistics infrastructure. Various countries and regions are continuously investing in modern ports, terminals, and logistics centers to meet the growing demand for goods. The efficiency and capacity of these infrastructure are crucial for the health and growth of the shipping industry.

The shipping industry faces multiple challenges, including environmental, economic, and technological issues, which require finding sustainable solutions.

The shipping industry is one of the main sources of global greenhouse gas emissions, with emissions equivalent to the overall emissions of many countries. Especially the fuel consumption of large cargo ships has a significant impact on greenhouse gas emissions, which exacerbates the problem of climate change. The exhaust gas and wastewater generated by traditional fuel combustion also cause pollution to the marine environment, and have adverse effects on marine ecosystems and marine organisms (Figure 1) (Cao, 2011).



Figure 1 Marine vessel discharge (Photo by Bing)

In terms of economy, fluctuations in fuel prices have a significant impact on the economic situation of shipping companies, especially when prices rise. The volatility and instability of the global trade market also affect the operation and profitability of shipping companies.

The maritime industry also urgently needs to improve in terms of technology. Improving ship fuel efficiency is key to reducing greenhouse gas emissions. However, traditional fuel engines have relatively low efficiency and require the search for more energy-efficient and environmentally friendly alternatives. In addition, designing and building more environmentally friendly ships requires a significant investment in research and development, which poses challenges to the development of the industry. In order to support the application of biomass energy, it is necessary to establish corresponding fuel supply chains and infrastructure, including production, storage, and transportation (Chen, 2021).

Faced with the above challenges, biomass energy, as an alternative energy option, provides important opportunities for the maritime industry. By reducing greenhouse gas emissions, lowering fuel costs, improving environmental quality, and promoting technological innovation, biomass energy can help drive the shipping industry towards a more sustainable direction.

3 Application of Biomass Energy in the Maritime Industry

3.1 Potential and advantages

Biomass energy has significant potential and multiple advantages in the maritime industry, which can help reduce environmental impact and improve the predictability of operating costs. Biomass energy is extracted from biomass materials that can be continuously regenerated, such as wood, discarded crops, and vegetable oil. It makes biomass energy a sustainable form of energy. Besides, the use of biomass energy typically releases an amount of carbon dioxide equal to the amount absorbed during the growth of these biomass materials, thus having a potential carbon neutrality effect on global warming.

Compared with traditional petroleum fuels, biomass energy combustion produces lower emissions of sulfur and nitrogen oxides, which helps to improve air quality and reduce air pollution. Biomass energy can be obtained from various sources, including agricultural waste, forestry waste, biomass waste, and specially grown energy crops. The diversity reduces supply risk and helps ensure supply stability. Many biomass energy production technologies are already very mature and widely applied in other fields. It means that the maritime industry, which is shifting towards biomass energy, can fully utilize existing technology and experience.

Although the production and processing costs of biomass energy may vary depending on materials and technologies, relatively stable price trends can help shipping companies better manage and predict operating costs. In addition, the use of biomass energy may qualify for environmental subsidies, further reducing costs. With the increasing attention of the international community to environmental protection, some countries and international organizations have formulated regulations to limit greenhouse gas emissions. The use of biomass energy helps shipping companies comply with these regulations, reducing potential fines and reputational damage caused by environmental issues.

3.2 Feasibility and applicability

The application of biomass energy in the maritime industry not only has potential, but also needs to consider its feasibility and applicability. These two aspects are crucial for deciding whether to adopt biomass energy.

The technological applicability of biomass energy is a key factor in its application in the maritime industry. At present, various biomass energy technologies suitable for ships have been developed, including liquid biomass fuel and biomass gas fuel. These technologies have made significant progress in fuel supply, storage, and processing, providing feasible options for shipping companies.

The adaptability of ships is another key factor. Some ships have been retrofitted to adapt to the use of biomass energy. This may include modifications to the engine and fuel system to ensure that it can operate on the basis of biomass energy. Some newly built ships can be directly designed to use biomass energy in addition.

The feasibility of biomass energy supply chain is crucial. It includes ensuring sufficient biomass energy supply to meet the needs of shipping companies and establishing a stable supply system. Some countries and regions have established biomass energy supply infrastructure, providing reliable sources of supply for shipping companies (Jia et al., 2015).

The cost-effectiveness of using biomass energy is an important factor that shipping companies consider. Although the production and processing costs of biomass energy may vary, relatively stable price trends and possible environmental subsidies can help reduce operating costs and improve feasibility.

The use of biomass energy may bring environmental benefits, including reducing greenhouse gas emissions and improving air quality, which is very attractive for meeting international and domestic environmental regulations and improving the company's reputation.

3.3 The practice of biomass energy in the maritime industry

Although the application of biomass energy in the maritime industry is still in its relatively early stages, there have been some important projects and application opportunities that have emerged, laying the foundation for future development. These existing biomass energy maritime projects and application opportunities demonstrate the enormous potential of biomass energy in the maritime industry and provide feasible avenues for achieving more environmentally friendly shipping.

Some shipping companies have already used biomass natural gas as fuel for their ships. Biomass natural gas is a renewable, low-carbon fuel that is converted from organic waste such as agricultural and food waste. This measure aims to reduce greenhouse gas emissions from ships and provide shipping companies with more environmentally friendly energy options (Figure 2). On the other hand, some ships are already equipped with biomass energy generation equipment to meet electricity demand. These devices use various biomass resources,

such as sawdust, straw, and other organic waste, to convert them into electricity. This type of electricity can be used by ship equipment and systems, reducing reliance on traditional sources of electricity.



Figure 2 Transport ships relying on biofuels (Photo by Bing)

To support the application of biomass energy in the maritime industry, some countries and regions have established sustainable biomass supply chains, including the production, storage, transportation, and treatment of biomass energy. This sustainable supply chain provides stable and reliable biomass energy supply for shipping companies.

In addition, some international cooperation projects aim to promote the application of biomass energy in the global shipping industry. These projects typically involve multiple countries and organizations working together to address technological, policy, and market challenges to promote the feasibility and sustainability of biomass energy.

In the future, with the continuous innovation of technology, more opportunities will emerge. For example, the conversion technology, storage technology, and ship engine technology of biomass energy are expected to be improved, enhancing the efficiency and feasibility of biomass energy application in the maritime industry.

4 Opportunities and Challenges of Biomass Energy in the Maritime Industry

4.1 Development trends and opportunities

The application of biomass energy in the maritime industry is facing exciting development trends and broad opportunities. These development trends and opportunities highlight the prospects of biomass energy in the maritime industry.

With the continuous progress of science and technology, new biomass energy conversion technologies and ship engine technologies will continue to emerge. These innovations are expected to increase the energy density, efficiency, and reliability of biomass energy, reduce costs, and reduce environmental impacts. For example, efficient biomass gasification and synthesis gas technologies can provide more sustainable fuel options.

Global attention to sustainable biomass resources is constantly increasing. The government, enterprises, and social organizations are taking measures to ensure that the raw materials for biomass energy come from sustainable sources to avoid adverse effects on the natural environment. This will help provide a more sustainable biomass energy supply chain (Sulaiman et al., 2011).

With the increasing awareness of environmental protection and sustainability, the demand for more environmentally friendly transportation methods from shipping companies and consumers continues to grow.

Biomass energy, as a low-carbon and renewable fuel, has the potential to meet this demand. Therefore, the demand for biomass energy in the maritime market is expected to continue to increase.

Many countries and international organizations have formulated policies and regulations which includes setting tax reduction policies, emission reduction targets, and sustainable development goals to encourage and support the application of biomass energy in the maritime industry. Policy support helps to reduce the production and usage costs of biomass energy and improve its competitiveness. International cooperation projects and initiatives are expected to strengthen cooperation between different countries and regions in biomass energy shipping. And joint research, technological exchange, and resource sharing will help overcome common challenges and promote the global application of biomass energy.

4.2 Technical limitations and cost-effectiveness

Although biomass energy has enormous potential in the maritime industry, it also faces some technological limitations and cost-effectiveness challenges. Addressing these technological limitations and cost-effectiveness challenges requires continuous research and innovation. The government, industry, and research institutions can work together to promote technological development, resource management, and cost-benefit analysis to ensure the feasibility and sustainability of biomass energy in the maritime industry.

In terms of technology, the storage and transportation technology of biomass energy needs to be continuously improved. It includes developing more efficient storage methods to ensure the stability and availability of fuel during long-distance voyages. Furthermore, the engine technology of ships also needs to adapt to different types of biomass energy to ensure their full combustion and stable performance. The sustainability of biomass energy depends on the sustainable supply of raw materials. Ensuring the stable supply of raw materials and the sustainability of the production chain is a challenge that requires close cooperation to ensure sustainable procurement and resource management. Producing high-quality biomass energy requires efficient production technology which includes steps such as biomass harvesting, pretreatment, gasification or liquefaction. The maturity and efficiency of technology will affect production costs and energy quality (Liu and Feng, 2015).

In terms of cost-effectiveness, the production cost of biomass energy is usually higher, and compared to traditional petroleum fuels, its production and processing process requires more energy and resources. This leads to relatively high prices for biomass energy, which restricts its competitiveness in the market. In addition, retrofitting ship engines to adapt to biomass energy requires a certain amount of investment, including engine improvements, upgrading of combustion technology, and system adaptability changes. These modifications may result in higher initial costs, but can achieve energy-saving and environmental benefits in the long term. Although biomass energy is a low-carbon fuel, its production and collection process may have an impact on the environment and society, and managing and reducing these costs will require more resources and technological investment.

4.3 Sustainability and reliability issues

The sustainability and reliability of biomass energy in the shipping industry are important factors that determine its long-term success. These issues cover multiple aspects of biomass energy production, supply, transportation, and use.

The sustainability of biomass energy depends on effective resource management. Sustainable logging and biomass production are key to ensuring sustainable supply of raw materials. It is necessary to ensure that the collection of biomass resources does not lead to forest destruction or ecosystem degradation. The production of biomass energy usually requires a large amount of land. Therefore, it is necessary to ensure that land use is sustainable and does not lead to desertification or loss of competitive uses, such as food production. Moreover, biomass energy is considered a low-carbon energy source, but its carbon emissions during production and transportation still need attention. Sustainable production and supply chain management can reduce these emissions.

The quality and stability of biomass energy are crucial for engine performance. Ensuring the quality and chemical composition of each batch of biomass fuel is a challenge to ensure the reliable operation of the engine. The shipping industry requires reliable fuel supply to ensure the sustainability of long-distance voyages. Therefore, establishing a reliable biomass fuel supply chain and inventory is crucial. The technical reliability of ship engines is crucial for the use of biomass fuels. Ensuring that the engine can operate stably under various conditions and cope with the characteristics of biomass fuels is a challenge (Gentry et al., 2010).

Solving these problems requires cross departmental cooperation and technological innovation. Governments, industries, and research institutions can work together to develop sustainable production standards, resource management policies, and biomass energy quality standards to ensure the sustainability and reliability of biomass energy in the shipping industry. This will help achieve low-carbon, efficient, and environmentally friendly sea transportation.

5 Prospect

The role of biomass energy in sustainable maritime transportation is increasingly prominent. Its low-carbon characteristics, wide availability, and compatibility with traditional petroleum fuels make it an important factor in promoting carbon neutrality and environmental protection in the maritime industry. In the future, it is expected that biomass energy will be applied in more shipping companies and ships.

To ensure the sustainability of biomass energy, governments, industries, and research institutions need to work hard together. Developing sustainable standards for the production and procurement of biomass energy is a crucial step. In addition, promoting technological innovation and improving the production efficiency and quality of biomass energy are important aspects to ensure its sustainable application.

The application of biomass energy requires cross-border cooperation. The close collaboration between the government, shipping companies, energy producers, and research institutions will promote the widespread application of biomass energy in the shipping industry. Jointly addressing resource sustainability, quality standards, supply chain reliability, and technological challenges is a necessary condition for achieving this goal.

With increasing global attention to climate change and environmental issues, the prospects of biomass energy in sustainable shipping seem promising. Its potential lies in providing a low-carbon and renewable fuel option for the shipping industry, which is expected to drive the entire industry towards a more environmentally friendly and sustainable future.

This study reviews the opportunities and challenges of biomass energy in the maritime industry, emphasizing the importance of its sustainability and innovation. In the context of addressing climate change and environmental demands, biomass energy, as a potential alternative energy source, provides feasible solutions for the maritime industry. However, to realize its potential, challenges such as resource sustainability, technological innovation, and supply chain reliability must be addressed. Through cooperation and innovation, we can build more sustainable and environmentally friendly navigation for the future shipping industry.

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