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Technology and economic perspective of hydrogen as a green fuel on ship

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Abstract

The maritime industry is currently navigating a critical juncture with the imperative goals of de-carbonization and achieving zero carbon emissions, driven by increasingly stringent environmental regulations. As the world grapples with the escalating depletion of fossil fuels, the industry is compelled to explore alternative energy sources. Green hydrogen, produced through electrolysis and devoid of carbon emissions, emerges as a promising solution for the maritime sector's sustainable future. Despite the potential benefits, the development of hydrogen as a viable marine fuel faces numerous technical and economic challenges. This article provides a thorough examination of the technical and economic aspects of hydrogen's development, offering insights that can inform evaluations, propose solutions, and catalyze new research initiatives. By addressing these challenges, the maritime industry can pave the way for the widespread adoption of hydrogen technology, contributing significantly to the sector's commitment to environmental sustainability. This comprehensive analysis aims to facilitate in-formed decision-making, foster innovation, and accelerate the integration of hydrogen as a clean and efficient fuel for ships.

Keywords

Hydrogen, Green fuel, Ship

Introduction

In global economic development, the maritime and shipping industry plays a crucial role. The flow and transportation of goods, as well as the mobility of people from one place to another, lead to a significant increase in energy demand. Energy is one of the many fundamental needs that govern all structures of human life on Earth. Naturally, energy demand is closely linked to population and economic growth. The world's population and economy continue to grow, coupled with advancements in industry and transportation, resulting in a significant increase in energy demand (Figure 1) [1].

As mentioned [2], [3] the human population has increased sixfold while energy consumption has reached 80 times. Our dependence on fossil energy has reached its

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peak, leading to a gap between fuel availability and the level of fuel consumption needs [4], [5]. This is certainly a concerning issue, aside from the non-renewable nature of fossil fuels, which means they can be depleted. The impact of increasing global emissions, particularly greenhouse gases, will have significant consequences for the sustainability of life on Earth [6]–[8]. The effects of greenhouse gases manifest in the form of increased global warming and global climate change.

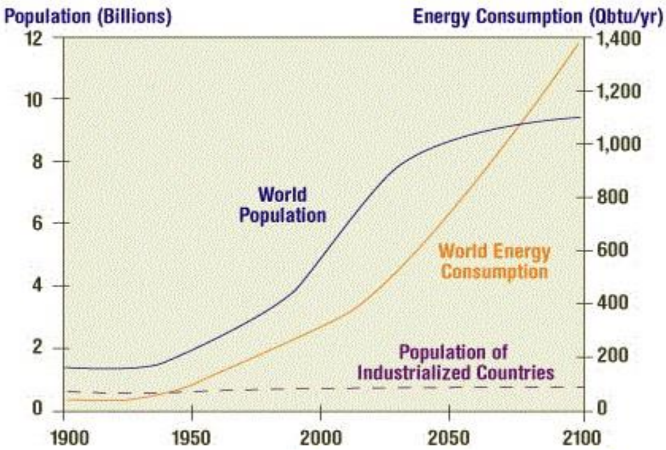

Figure 1. Population & energy consumption growth

In the maritime sector, as a response and effort to mitigate greenhouse gases, significant decarbonization efforts are underway towards achieving zero carbon emissions by 2050 [9]–[11]. Based on data [12]–[14] it is stated that in 2018, global shipping emissions accounted for 2.9% of global emissions caused by human activities, a trend that is projected to increase to 130% by 2050 if left uncontrolled. Data from 2021 indicates that sea transportation contributes 3 - 4% of total CO2 emissions. Significant steps have been taken through the International Maritime Organization (IMO) via various regulations and policies as concrete measures in the commitment to reduce greenhouse gas emissions towards zero carbon emissions by 2050 [13], [15]. One of the efforts involves implementing measures to provide environmentally friendly alternative fuels for ships.

The use of hydrogen is beginning to attract the attention of various groups as an alternative to reduce greenhouse gas emissions [16], [17]. Hydrogen is significantly different from fossil fuel energy in general, where combustion exhaust gas produces CO_2, while hydrogen actually produces water as a by-product. This makes hydrogen a projection of future energy [17]–[20]. Statements from [21], [22] suggest that the use of hydrogen can reduce carbon emissions by 20% in the form of fuel cells

This article will discuss technological and economic perspectives regarding the projections for the future use of hydrogen in the shipping sector. Through reviews conducted in many journals, we will technically discuss hydrogen production and storage technology as a basis for planning infrastructure that supports its operations and usage on ships. In terms of economic overview, we will explain the changes that have arisen after the conversion from fossil fuels to hydrogen and the global view on this matter. Through reviews conducted in many journals.

Method

The initial stage involves grouping articles based on keywords, namely hydrogen production technology, hydrogen storage design, technology for converting fossil fuels into hydrogen, economic impacts after the application of hydrogen, as well as economic reviews related to preparations and global impacts after the application of hydrogen in transportation in general and shipping in particular. The information obtained from the journal review will then be used as a reference for writing technological and economic perspectives on the discourse of using hydrogen fuel for shipping.

Results and discussion

Hydrogen production process

In a statement made by [23] There are almost a hundred hydrogen production technologies. To facilitate the process of classifying hydrogen based on its origin of production and the characteristics of each type of hydrogen, a hydrogen taxonomy was created with color coding, as stated in Table 1 [24].

Table 1. Hydrogen taxonomy based on emission potential

Color Code	Method	Feed Stock	Emission	Maturity Level	Literature
Green H_2	Electrolysis	Water	Low	9 - 10	[25]–[28]
Gray H_2	Steam Reform	NG	High	10	[24], [29], [30]
Blue H_2	Steam Reform	NG	Low	10	[31]–[34]
Brown H_2	Gasification	Coal	High	10	[35]
Turquoise H_2	Pyrolis Thermal	NG	Low	8 - 10	[36], [37]

As the name suggests, green hydrogen is obtained through an environmentally friendly process where water electrolysis utilizes electricity from renewable energy sources [25], [26]. The electrochemical separation process of water into oxygen and hydrogen is a commonly used method that leaves no carbon footprint at all [27], [28]. In contrast to gray hydrogen, this type of hydrogen is produced from fossil fuels, namely natural gas, through steam reforming which generates CO_2 exhaust gas that enhances the greenhouse effect. In its statement [24] In the production of 1 ton of hydrogen, it will produce around 10 tons of CO_2 or 10 times as much. Although currently reforming methane into hydrogen has relatively affordable production costs, namely around €1.5/kg or €0.045/kWh, this will be abandoned along with the development of economic scale and the application of renewable energy [29], [30]. Unlike blue hydrogen, additional applications in the form of carbon capture and storage make emissions more controlled compared to gray hydrogen, although this statement [31], the level of carbon emissions produced by blue hydrogen is only 9 - 12% lower than gray hydrogen, this is not surprising due to the use of natural gas in carbon capture. What is surprising is that the greenhouse gas footprint of blue hydrogen is 20% greater than that of burning natural gas or coal and 60% greater than that of burning diesel fuel. Meanwhile, hydrogen production originating from the coal gasification process or more commonly known as brown hydrogen is stated to be the least environmentally friendly method due to the high CO_2 emissions produced in the range of 18 - 20 times more than the amount of hydrogen produced. Turquoise hydrogen [24], [36], [37] is produced through pyrolysis of methane from natural gas, This thermal decomposition method breaks down methane into hydrogen and carbon molecules at temperatures ranging from 600 to 1200 – 1400 °C. However, this high-temperature process is not very effective in reducing the CO_2 emissions produced, thus resulting in emissions not lower than those from methane reforming processes. It is crucial to utilize renewable energy in high-temperature reactor operations, ensure long-term binding or storage of solid carbon, and implement conditions that support CO_2 neutrality.

From Table 2 can be obtained that electrolysis is a method used to produce hydrogen by passing a direct current through an electrolyzer, which drives electrochemistry based on the principle of oxidation-reduction, thus breaking water into hydrogen and oxygen [39]. Power plants can utilize fossil fuels or renewable energy such as solar or wind power. As mentioned by [41] there are three models of electrolysis: low-temperature electrolysis, high-pressure electrolysis, and high-temperature steam electrolysis. According to [47] water thermolysis in the hydrogen production process requires heating at high temperatures, necessitating efficient reactor performance and power. Photolysis, on the other hand, requires light penetration into water, posing a challenge in designing the optimal reactor [43]. Hydrogen can also be obtained through hydrocarbon pyrolysis, partial oxidation, auto thermal processes, or steam reforming using natural gas or other fossil fuels [48], [51], [52]. Additionally, biomass can serve as a material for hydrogen production through processes such as bio-photolysis, dark fermentation, photo-fermentation, or biomass gasification and pyrolysis [44]–[46]. However, the production process from biomass is less reliable due to its slow and low yields. Moreover, biomass conditioning requires specific attention to stages of collection, transfer, and processing, which need to consider certain spatial and size constraints not necessarily proportional to the production capacity.

Table 2. Efficiency of hydrogen production method

Process	Feed Stock	Technology	Efficiency	References
Electrolysis	Water	AEM	62-82	[19][38][39]
	Brine	PEM	67-84	[40][41]
Photolysis	Water, alga	Photosynthesis	1,6-5	[42][43]
Biolysis	Microorganism	Dark ferment	60-80	[44]
	Fermentive bacterias	Hydrolysis	-	[45]
	Biomass, water	Aqua reform	35-55	[46]
	CO+water	Bio shift ref	-	[45]
Thermolysis	Water	Water thermo	20-55	[47]
	Biomass no O_2	Pyrolysis	35-50	[48]
	Biomass	Gasification	35-50	[49][50]
	Coal	Gasification	74-85	[35]
	Fuels	Steam reform	60-85	[51][24]
	Methane + CO_2	Auto-thermal	60-75	[52]

Discourse on hydrogen storage

The most important aspect that requires attention in the utilization of hydrogen, besides its production, is the issue of storage and transportation. Security and efficiency requirements are absolute prerequisites to ensure that hydrogen can be utilized anywhere and anytime [51]. According to [53] in its pure form, hydrogen is characterized by low volumetric energy density and high gravimetric energy density. However, in practice, hydrogen storage is closely associated with the medium used. In its application as a transportation fuel, for instance, gravimetric density is crucial, where the hydrogen storage system must be tailored to the size of the user's vehicle without adding extra load and ensuring efficiency in vehicle operation. As mentioned by [53] generally, there are three common approaches to hydrogen storage, namely physical storage in the form of compressed gas and cryogenic liquid hydrogen, as well as material-based or solid-state storage. Storage in compressed gas and liquid methods is the most widely utilized compared to the third method, which is still in the research and development stage. As a form of liquid hydrogen, the challenges faced by the industry are more significant compared to others, including when compared to LNG handling, thus limiting the number of people able to transport liquid hydrogen on a large scale (Table 3) [53], [54].

Table 3. Storage hydrogen method

Storage Method	Advantage	Weakness	References
Compressed gases	The technology has been widely embraced and firmly established, with a rapid handling and filling process.	It experiences energy losses of approximately 15%, is less secure and susceptible to leaks, and its distribution involves high-pressure systems.	[3], [54], [55]
Liquid Hydrogen	Effective compression, high density and efficiency, operates at low pressure, and offers lower storage costs compared to alternative methods.	Storage needs low temperature or high pressure, 30% energy losses, boil off in days and need cooling syst	[53], [54], [56]
Solid-State	Only a minimal storage volume is required to accommodate a substantial amount of hydrogen, with the potential for high density at moderate temperature and pressure.	Specific weight & volume of storage	[57], [58]

Economic aspect of hydrogen as alternative fuel on ship

According to [59] from an economic perspective, there are four cost categories that can be used to evaluate the feasibility of implementing hydrogen in the shipping sector. The four cost categories are as follows at Table 4.

From an economic perspective, there are several considerations in the implementation of hydrogen in the shipping sector, particularly, and transportation or other industries in general. According to [60][29] the cost of hydrogen production varies depending on the method used. The cost of hydrogen production is a primary economic consideration before other factors such as intervention costs to advance the use of hydrogen in the transportation and industrial sectors, technical target development costs, costs to guide research and development (R&D), costs of identifying legal and regulatory barriers and surveying safety codes and standards, costs of increasing global collaboration focus, and infrastructure costs that support hydrogen applications.

Table 4. Breakdown of hydrogen implementation costs on ships

Category	The Definition	Items
Capital Cost	One-time costs of starting business	Ship hull weight, engine output power, number of azimuthal pods as part of the propulsion system, cost of hydrogen cargo, fuel tanks and ship engines.
Annual Cost	Variations and fluctuation of routine expenses	Fuel prices and crew costs
Emission Cost	Emission taxes	Assumed no emission taxes
Investment	Additional cost required to prepare and run the project	Design, research & develop tanks and ship hull materials, manufacturing, engineering & supervision, consulting, contingencies & science technology.

Conclusion

In general, hydrogen can be proposed as an alternative fuel for ships, with green hydrogen emerging as a possible discourse at this time due to its lowest emission potential and easily obtainable raw materials. However, there are still long-standing challenges ahead, especially concerning the supporting systems related to hydrogen handling and conversion that need to be addressed for ships to be converted into hydrogen-powered vessels. Nonetheless, even though hydrogen is not the sole alternative solution, research indicates significant potential regarding the future of hydrogen energy.

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