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A review on applicability of hydrogen fuel cells in shipping for a sustainable future.

Una revisión sobre la aplicabilidad de las pilas de combustible de hidrógeno en el transporte marítimo para un futuro sostenible.

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ABSTRACT

From 2020, International Maritime Organisation (IMO) rules have banned ships from using fuels with a sulphur content above 0.5 percent, compared with 3.5 percent before, unless they are equipped to clean up sulphur emissions. This will be enforced by fines levied by the IMO's member states. One of the attempts being made by the shipping industry to reduce its environmental impact is to use Fuel Cell Technology to deliver power to the vessels. Fuel cells as clean power sources are very attractive for the maritime sector, which is committed to sustainability and reducing greenhouse gas and also atmospheric pollutant emissions from ships. Fuel cells operating on hydrogen fuel are an efficient, environmentally-friendly, zero emission, direct current (DC) power source already applied to heavy duty bus, truck, and train applications, and are now under development for marine applications. The only emissions from a fuel cell are water vapour and some heat [1].Renewable hydrogen, generated from solar, wind, hydroelectric, and geothermal sources is considered an ideal fuel for decarbonising society. It can be used for industrial purposes, power generation, heating, and as a transportation fuel. This paper aims to show how the Hydrogen fuel cell systems are one of the best options for ships to meet the future and present IMO environment requirements, along with the challenges and conveniences of using renewable hydrogen compared to traditional marine fuels including a feasibility study of a Hydrogen fuel cell powered ferry.

Keywords: IMO (International Maritime Organisation), sulphur emission, Fuel cells, sustainability, Greenhouse Gas, Hydrogen.

RESUMEN

A partir de 2020, las normas de la Organización Marítima Internacional (OMI) han prohibido a los barcos utilizar combustibles con un contenido de azufre superior al 0,5 %, en comparación con el 3,5 % anterior, a menos que estén equipados para limpiar las emisiones de azufre. Esto se hará cumplir mediante multas impuestas por los estados miembros de la OMI. Uno de los intentos que está haciendo la industria naviera para reducir su impacto ambiental es utilizar la tecnología de celdas de combustible para suministrar energía a los buques. Las pilas de combustible como fuentes de energía limpia resultan muy atractivas para el sector marítimo, que apuesta por la sostenibilidad y la reducción de las emisiones de gases de efecto invernadero y también contaminantes atmosféricos de los buques. Las celdas de combustible que funcionan con combustible de hidrógeno son una fuente de energía de corriente continua (CC) eficiente, respetuosa con el medio ambiente, de cero emisiones, que ya se aplica a aplicaciones de autobuses, camiones y trenes de servicio pesado, y ahora están en desarrollo para aplicaciones marinas. Las únicas emisiones de una celda de combustible son vapor de agua y algo de calor [1]. El hidrógeno renovable, generado a partir de fuentes solares, eólicas, hidroeléctricas y geotérmicas, se considera un combustible ideal para la descarbonización de la sociedad. Se puede utilizar para fines industriales, generación de energía, calefacción y como combustible para el transporte. Este documento tiene como objetivo mostrar cómo los sistemas de celdas de combustible de hidrógeno son una de las mejores opciones para que los barcos cumplan con los requisitos ambientales actuales y futuros de la OMI, junto con los desafíos y las ventajas de usar hidrógeno renovable en comparación con los combustibles marinos tradicionales, incluido un estudio de viabilidad de un Ferry propulsado por pilas de combustible de hidrógeno.

Palabras clave: IMO (Organización Marítima Internacional), emisión de azufre, Pilas de combustible, sostenibilidad, Gases de Efecto Invernadero, Hidrógeno.

INTRODUCTION

The Shipping industry plays an important role in economic development of maritime nations since more than 80% of world trade occurs through sea. The contribution of maritime sector to sustainable environment is also significant. The International Maritime Organization has adopted regulations to address the emission of pollutants from ships and has adopted mandatory energy-efficiency measures to reduce emissions of greenhouse gases (GHGs) from international shipping and finally phase them out as soon as possible in this century [10]. The initial IMO strategy targets a reduction in total GHG emissions from international shipping by at least 50% by 2050 compared to 2008 level [1]. The major marine fuels in use today such as Heavy Fuel oil and Marine Diesel oil are derived from fossil sources. The use of these fuels results in air pollution and greenhouse gas emissions (refer: figure: 1) [9], whereas the use of renewable and non-conventional fuels reduces the greenhouse gas emission by a significant amount.

	ICCT (million tons)		
	2013	2014	2015
CO_2 Emissions	910	930	932
SO_x Emissions	10.355	10.361	10.457
NO_x Emissions	18.426	18.398	19.062
PM Emissions	1.475	1.504	1.492

Fig 1: Shipping Emissions Inventory [9]

Renewable options can be used in ships of all sizes to provide primary, hybrid and/or auxiliary propulsion, as well as on-board and shore-side energy use. These clean energy solutions are being integrated through retrofits to the existing fleet or incorporated into new shipbuilding and design, with most applications deploying renewable energy as part of an integrated package of efficiency measures.

Potential renewable energy sources for shipping applications include wind (e.g., soft sails, fixed wings, rotors, kites and conventional wind turbines), solar photovoltaics, fuel cells, bio fuels, wave energy and the use of super capacitors charged with renewable [2].Among these sources, Hydrogen fuel cells have also been used as a clean energy technology for shipping. When compared to other renewable sources, Hydrogen fuel cells provide an inherently clean source of energy, with no adverse environmental impact during operation as the by-products are simply heat and water. Moreover, Hydrogen has the highest energy content of any common fuel by weight. High pressure gaseous and liquid hydrogen have around three times the gravimetric energy density (around 120MJ/kg) of diesel and LNG [2].

Hence, this paper explains the clear advantages of using fuel cells in ships and presents examples of ships which have successfully used fuel cell power systems along with the challenges of using renewable hydrogen compared to traditional marine fuels.

WORKING OF A HYDROGEN FUEL CELL

Fuel cells work by producing electricity like batteries, but they do not run down or need recharging. They produce electricity and heat as long as fuel is supplied. A fuel cell consists of two electrodes - a negative electrode (or anode) and a positive electrode (or cathode) -sandwiched around an electrolyte. A fuel, such as hydrogen, is fed to the anode, and air is fed to the cathode. In a hydrogen fuel cell, a catalyst at the anode separates hydrogen molecules into protons and electrons, which take different paths to the cathode. The electrons go through an external circuit, creating a flow of electricity. The protons migrate through the electrolyte to the cathode, where they unite with oxygen and the electrons to produce water and heat [3].

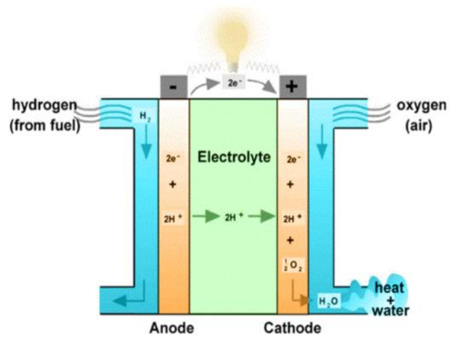

Fig 2: Basic working principle of Hydrogen Fuel cells [3]

ADVANTAGES OF USING HYDROGEN INSHIPPING

1. Hydrogen is a Renewable Energy Source and Abundant in Supply
2. Hydrogen is a rich source of energy for many reasons, the main being that it's abundant in supply. While it may take a lot of resources to harness it, no other energy source is as infinite as hydrogen. That essentially means that there is no possibility of it running out like other sources of energy.
3. There are Numerous Sources to Produce Hydrogen Locally
4. Hydrogen gas can be obtained from various sources such as water, biomass, methane, gasoline and coal. The factors like amounts of pollution, technical challenges, and energy requirements vary depending on method of production and the sources used.
5. Hydrogen is Practically a Clean Energy Source

When hydrogen is burnt to produce fuel, the by products are totally safe, which means they have no known side effects. Aeronautical companies actually use hydrogen as a source of drinking water. After hydrogen is utilized, it is normally converted to drinking water for astronauts on ship or space stations.

6. Hydrogen is Non-toxic

Hydrogen is a non-toxic substance that is rare for a fuel source. This means that it is friendly towards the environment and does not cause any harm or destruction to human health. This aspect makes it preferred compared to other sources of fuel like nuclear energy, natural gas, which are extremely hazardous or daunting to harness safely. It also allows hydrogen to be used in places where other forms of fuel may not be allowed [7].

7. Hydrogen is Far More Efficient Than Other Sources of energy

Hydrogen is an efficient energy type since it has the ability to convey a lot of energy for every kilogram of fuel (around 120MJ/kg) compared to marine diesel or LNG. This categorically means that an automobile that utilizes hydrogen energy will travel more miles than one with an equal amount of diesel. When coming to shipping, usage of hydrogen as fuel will offer merchant ships with higher cargo carrying capacity compared to any other energy source.

8. A Sustainable Production System

Electrolysis is a method by which electricity is used to produce hydrogen from water. Renewable sources such as solar, wind, geothermal and hydro energy can be used to power electrolysers. After the hydrogen is produced in an electrolyser, it can be used in a fuel cell to produce electricity to power ships. The by-products generated in the fuel cell process are water and heat. If fuel cells operate at high temperatures, the system can be set up as a co-generator, with the waste energy used for heating.

All the more in a paper issued by the ship classification society DNV GL, they have clearly stated Hydrogen as the cleanest fuel when compared to any other renewable source with the least CO_2 emission when it is produced from water (refer: fig: 3)[4].

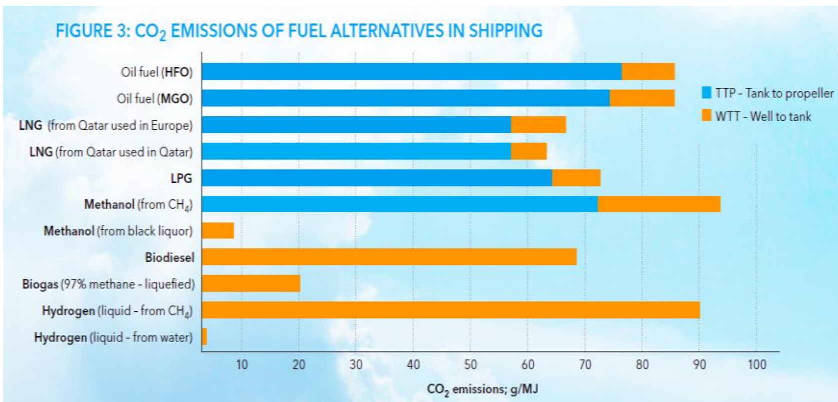

Fig 3:CO_2 Emission of Fuel Alternatives in Shipping [4]

APPLICABILITY OF HYDROGEN FUEL CELLS IN SHIPPING

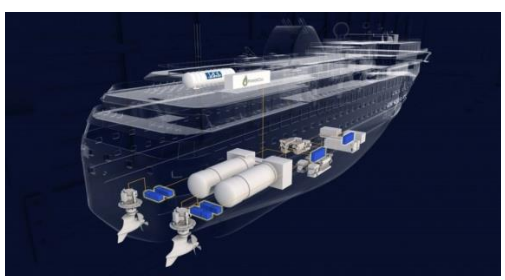

Fig 4*:* Illustration of hydrogen propulsion systems with integrated LH2 tank and fuel cells [11]

Hydrogen has the highest energy per mass of any fuel; however, its low ambient temperature density results in a low energy per unit volume, therefore requiring the development of advanced storage methods that have potential for higher energy density. In the fig 4 shown above, two integrated LH2 tanks are used to store hydrogen at cryogenic temperatures because the boiling point of hydrogen at one atmosphere pressure is −252.8°C.This is by far the most efficient way hydrogen fuel cells can be applied in ships.

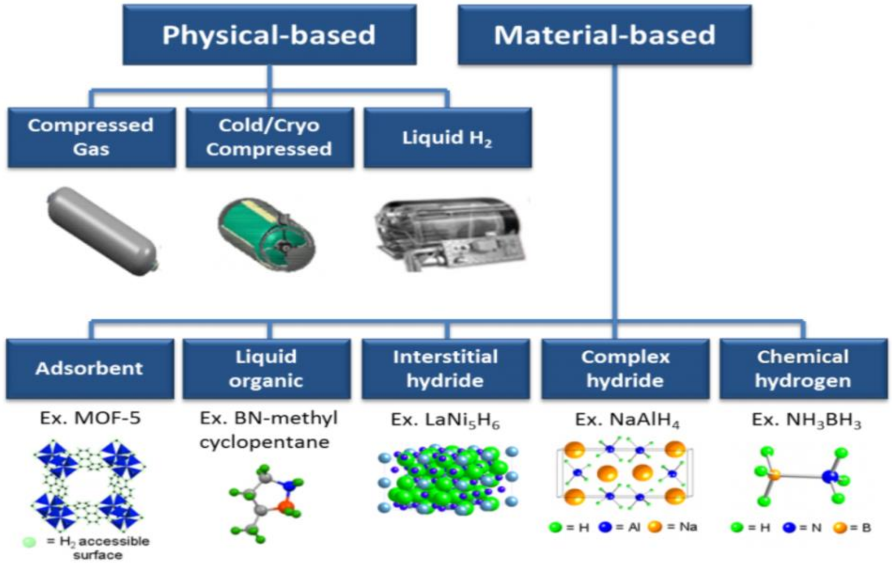

Fig 5: Different Hydrogen Storage Methods [12]

Hydrogen fuel cells can also be used to generate electricity onboard the vessels. Most of the merchant ships currently under operation use diesel generators to produce electricity, where chemical energy is converted into electricity via thermal and mechanical energy. In comparison, fuel cells convert chemical energy directly into electrical energy, thus omitting the indirect route via thermal energy in combustion engines. The absence of expansive, high temperature combustion reduces NOX formation, noise and vibrations, while high efficiencies can still be achieved [6].

There are also various examples where ships have used Hydrogen Fuel cells as its main propulsion source. In the FCS Alsterwasser, a 100-pax fuel-cell-powered passenger vessel based in Hamburg Port (Germany), as well as a number of other small ferries and river boats. In 2012, as part of the FellowSHIP project, a 330 kW fuel cell was successfully tested on board the offshore supply vessel, Viking Lady, operating for more than 7000 hours. This was the first fuel cell unit to operate on a merchant ship, with the electric efficiency estimated to be 44.5 % (when internal consumption was taken into account), with no NOx, SOx and particulate matter (PM) emissions detectable. In 2012, Germanischer Lloyd set out design concepts for a zero-emissions 1500 passenger “Scandlines” ferry and a 1000 TEU (twenty-foot equivalent unit) container feeder vessel with a 15-knot service speed and using hydrogen fuel cells [1].

The Australian-based Global Energy Ventures announced it is entering into a two-year project with Ballard Power Systems to design and develop a hydrogen fuel cell system for the company’s proposed large-scale ocean-going hydrogen transport ship. The Compressed H2 Ship (C-H2) is a concept design to transport up to 2,000 tons of compressed hydrogen at 250 bars. GEV projects that the C-H2 ship at scale will have a power requirement of 26MW. The company is also developing a design for a smaller pilot ship that would have a power requirement of under 10MW [5].

FEASIBILITY STUDY OF A ZERO-EMISSION HIGH-SPEED HYDROGEN FUEL CELL FERRY

Sandia National Laboratories, a multi-mission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, initiated a feasibility study for a high-speed passenger ferry powered by hydrogen fuel cells, called the San Francisco Bay Renewable Energy Electric vessel with Zero Emissions (SF-BREEZE). Sandia not only determined that such a vessel was feasible, the company also determined that by using renewable hydrogen, CO_2 emissions would be reduced by 75.6 percent, NO_x by 99.2 percent, and PM by 98.6 percent. But compared to a diesel-powered ferry, the cost of building a fuel-cell ferry would be about three times greater.

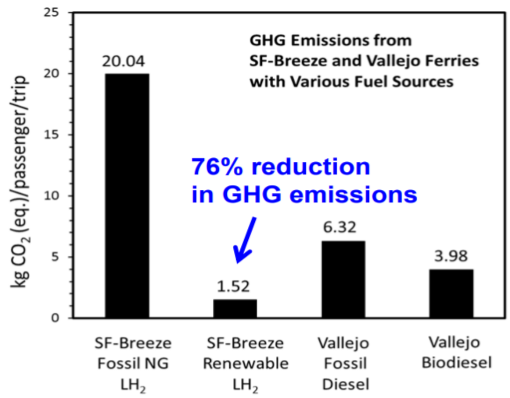

Fig 6: Co_2 Emission Comparison Using Different Fuel Sources [13]

All SF-Breeze emissions are due to LH 2 production path; the SF-Breeze is Zero Emissions at the point of use.

CHALLENGES OF USING HYDROGEN AS FUEL

1. Hydrogen Energy is Expensive

Electrolysis and steam reforming, the two main processes of hydrogen extraction, are extremely expensive [7]. This is one of the main reasons it is not massively used across the world. Today, hydrogen energy is mainly used to power most hybrid vehicles.

A lot of research and political will is required to discover cheap and sustainable ways to harness this form of energy. Until then, hydrogen will remain as an expensive gas used only by the rich.

2. Storage Complications

One of the properties of Hydrogen is that it has low density when compared to gasoline. This means that it has to be compressed to a liquid state and stored the same way at lower temperatures to guarantee its effectiveness and efficiency as an energy source. This reason also explains why hydrogen must at all times be stored and transported under high pressure, which is why transportation and common use is far from feasible [8].

3. Hydrogen is Not the Safest Source of Energy

Though hydrogen is non-toxic and environment friendly, hydrogen is a highly flammable and volatile substance that frequently makes headlines for its potential dangers. Compared to gas, hydrogen lacks smell, which makes any leak detection almost impossible. To detect leaks, one must install sensors.

4. Majority of the Hydrogen Production is Dependent on Fossil fuels

Hydrogen energy is renewable and has a minimal environmental impact, but its separation from oxygen requires other non-renewable sources such as coal, oil and natural gas. Fossil fuels are still needed to produce hydrogen fuel. But Renewable hydrogen, generated from solar, wind, hydroelectric, and geothermal sources is considered an ideal fuel for decarbonising society.

CONCLUSION

Although hydrogen puts forward a lot of challenges to overcome, it is still one of the most dependable and the cleanest fuel source for the shipping industry to meet the present and future IMO requirements without sacrificing the ship's overall cargo carrying capacity. But the full potential of this abundant element cannot be harnessed until more research and innovative technologies are brought forward to produce hydrogen in the cheapest and sustainable way possible. At present we do not have the technology to produce cheap and energy efficient hydrogen from renewable energy. But if enough innovation and research is put in the renewable energy area, there is no doubt that hydrogen could be our solution to achieve zero-emission in at least the transportation sector. Hence, hydrogen could become the best solution for the future of our energy requirements but this will require political will and investment to achieve. However, as the IMO regulations become more and more stringent hydrogen could be a key solution for global shipping.

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