Energy Conversion Technology of Fuel Cells on Ships to Mitigate Greenhouse Gas Emissions

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Abstract. Greenhouse gas emissions are something that contribute to climate change, which is getting hotter and causing concern for the condition of the earth. The shipping sector is a major cause of greenhouse gas emissions, accounting for 2.89% of anthropogenic greenhouse gas emissions and 919 million tonnes of CO2 emissions. This research aims to present different types of fuel cells that can be applied to different vessels. System Literature Review (SLR) is the method in this study to review the data sources obtained with a range of publications in 2019-2024. The result of this review is the acquisition of 2 types of fuel cells that can be used in 8 ships. The types of fuel cells are SOFC and PEMFC. Each fuel cell produces a high percentage of eficiency. Both fuel cells can be integrated into other technologies such as GT, ORC, SRC, and ICE. The companies that support the development of this fuel cell are KC, WHB, MCFC, PAFC, DEC, and LT. Therefore, fuel cells have high potential to mitigate greenhouse gas emissions due to marine transport.

1 Introduction

Greenhouse gas emissions are a significant contributor to climate change [1]. Their contribution to the environment has become a concern in this increasingly hot earth [2]. Greenhouse gas emissions are becoming more widespread each year, resulting in increased heat waves [3]. In addition, sea level and temperature are also negatively affected by these emissions [4]. This sector has actually been the subject of intense debate in recent years [5]. This is because a series of measures have been used such as greenhouse gas restrictions proposed by the Kyoto Protocol to the International Maritime Organisation (IMO) in 1997 and the implementation of policies drawing from the Energy Efficiency Design Index (EEDI) and Ship Energy Efficiency Management Plan (SEEMP) in 2011[5]. To date, the shipping sector still accounts for 2.89% of anthropogenic greenhouse gas emissions and 919 million tonnes of CO_2 emissions [6], which adversely affects the health of the marine environment.

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Given these conditions, one of the things that can be pursued is the development of energy conversion technologies [7]. This projection also supports the plan to reduce emissions by at least 34% by 2030, and no emissions before 2050 in line with the goals of the Paris Agreement [8]. This development should not be delayed at all given that the shipping sector is still the choice of global citizens for transport.

In particular, fuel cells can be a potential solution to reduce greenhouse gas emissions. Fuel cells are a proposed power source for ships that operate over long distances for long periods of time [9]. Fuel cells can directly convert electrochemical energy and chemical energy from certain compounds into clean and renewable electric power [10]. In addition, when compared to traditional marine diesel engines, fuel cells are able to produce good efficiency as a new power system in addition to fuel development planning for marine engines [11].

In this study, the researcher aims to present various types of fuel cells that can be applied to different vessels. Each type of fuel cells will be given an overview of the percentage of research results to review the effectiveness in its application. This is expected to be a consideration for marine industry players and policy makers to determine future targets given the urgency of handling greenhouse gas emissions today.

2 Methods

Researchers in this study used the Systematic Literature Review (SLR) method which was carried out without determining a specific place because the data source was obtained online. According to [12], Systematic Literature Review (SLR) is an analysis method for conducting case studies in a way that is adjusted to a certain phase-by-phase analysis. The SLR method uses three phases, namely the planning phase, the review phase, and reporting the results of the research as in Figure 1.

Fig. 1. Phases in the *Systematic Literature Review* Method [12].

The phases of this research are described as follows:

-Planning Phase

In this phase, the researcher developed a Research Question (RQ) to ensure systematic smooth running. The Research Question (RQ) was developed to provide a design of the method. This phase was conducted on 24 November 2023 which resulted in the following list of RQs:

a. RQ1: What are the types of vessels that *fuel cells* can be applied to?
b. RQ2: What are the types of *fuel cells* used as energy conversion technology?
c. RQ3: What is the energy efficiency percentage of *fuel cells* for greenhouse gas

mitigation?

-Review Phase

In the review phase, the research was conducted from 25 November to 05 December 2023. At first, a strategy was developed to identify research topics that would help in understanding the RQ. There were three stages in this phase, namely identifying keywords, determining data sources and the process of finding data sources. In this study, the keywords used were fuel cells, ships, and marine technology. Furthermore, the data source is determined by the publication year range which covers the years 2019-2024. These data were then searched in Google Scholar, Sciencedirect, IEEE, Linkspringer, and MDPI pages. Finally, the data visited by researchers were 250 articles.

Next, articles were selected based on the inclusion and exclusion criteria. This was done by reading the titles and abstracts to see if they met the criteria. The following table shows the inclusion and exclusion criteria used in this study (Table 1).

Table 1. Inclusion and exclusion criteria

Inclusion Criteria	**Exclusion Criteria**
This article focuses on the types of types of *fuel cells* to mitigate greenhouse gas emissions.	This article does not focus on types of *fuel cells* to mitigate greenhouse gas emissions
The article is able to answer at least two RQs.	The article was unable to answer at least two RQs.
Articles used are in English.	Articles used are not in English.

Articles that fit the criteria were then assessed to ensure quality. The quality of the study was determined based on the clarity of the research objectives. In addition, the alignment between objectives and results was taken into consideration in assessing the quality of the study. The selected articles will be extracted data according to the specificities of RQ.

-Phase of Reporting Research Results

In this phase, research was conducted from 05-10 December 2023. This phase starts from re-selecting articles that have been selected by looking at suitability with the Research Question (RQ). The number of articles obtained was 30 articles that were used as material to answer the RQ. RQ1 was reported using the 30 selected articles. RQ2 is reported using the 30 selected articles. Meanwhile, RQ3 is reported using 30 selected articles.

3 RESULTS AND DISCUSSION

By using Systematic Literature Review (SLR), the following table of research results was obtained:

Table 2. Research Results with the SLR Method

No.	Vessel Type	Types of Fuel Cells	Percentage of Energy Efficiency	Reference
1.	Container Vessel	SOFC	58.06%	[13]
2.	Shipping Vessels	SOFC-GT- ORC	89.73%	[14]
3.	Cargo Ship	SOFC- PEMFC- GT-ORC- SRC-KC- WHB	60.96%	[15]
4.	Ferry Boat	PEMFC	23.8%	[16]
5.	Shipping Vessels	SOFC	64.01%	[17]
6.	Tanker	SOFC	47.946% - 48.47%	[18]
7.	Tankers and Cruise Ships	SOFC- PEMFC	34%	[19]
8.	Tanker	SOFC	86%	[20]
9.	Cruise Ship	SOFC	11%	[21]
10	Cargo Ship	SOFC	52%	[22]
11.	Cruise Ship	PEMFC	13.83%	[23]
12.	Shipping Vessels	SOFC	41.53%	[24]
13.	Cargo Ship	PEMFC- ORC-DEC	40.45%	[25]
14.	SRV Hybrid Hydrogen Vessel	PEMFC	6.9%	[26]
15.	Crude Oil Tanker	SOFC	16%	[27]
16.	Tanker	PAFC- MCFC	49.75%	[28]
17.	Cargo Ship	SOFC	60.96%-64.46%	[29]
18.	Shipping Vessels	SOFC	60-65%	[30]
19.	Cruise Ship	PEMFC- SOFC	55%	[31]
20	Ferry Boat	LT- PEMFC	55%	[32]
21.	Shipping Vessels	SOFC-ICE	55%	[33]
22.	Cargo Ship	SOFC-GT	48.8%	[34]
23.	Cargo Ship	SOFC	2.88%	[35]
24.	Ro-Ro Passenger Vessel	SOFC- PEMFC	84%	[36]
25.	Ferry Boat	PEMFC	54.2%-74.3%	[37]
26.	Oil Tanker	SOFC-ICE	46.6%	[38]
27.	General Cargo Vessel	SOFC	58-60%	[39]
28.	Ferry Boat	SOFC- PEMFC	55%	[40]
29.	Shipping Vessels	PEMFC	53%	[41]
30	Ferry Boat	PEMFC	65%	[42]

From the Table 2, it can be seen that there are various types of ships that can be used fuel cells which are RQ1. Of the 30 articles, 8 types of ships that can be applied fuel cells were found. Container vessel, hydrogen hybrid SRV vessel, and Ro-Ro passenger vessel, are each discussed in one article. Furthermore, there are 4 and 7 articles that discuss it on cruise ships and cargo ships. Ferries and tankers are discussed in 5 and 6 articles. Then, shipping vessels were discussed in 6 articles. In one article, the ships used as research materials are tankers and cruise ships.

Furthermore, table 2. is also able to answer RQ2 and RQ3, namely "What are the types of fuel cells used as energy conversion technology?" and "What is the percentage of energy efficiency of fuel cells for greenhouse gas mitigation?". In the table, it can be seen that there are 2 types of fuel cells in 30 research articles. The types of fuel cells are Solid Oxide Fuel

Cell (SOFC), and Proton Exchange Membrane Fuel Cell (PEMFC). The best fuel cells system without any combination is PEMFC as fuel cells that have a fairly good percentage without combining with other systems with a percentage of 6.9% - 74.3%. This is followed by SOFC where there are 12 articles that give percentages in the range of 2.88%-86% on container ships, cruise ships, tankers, cruise ships, and cargo ships.

Both fuel cells can be integrated into other technologies such as GT, ORC, SRC, and ICE. Gas Turbines (GT) are often used in combination with fuel cells for peak power or propulsion. Similar to ORC, Steam Rankine Cycles (SRC) uses steam instead of organic fluid. Furthermore, Organic Rankine Cycle (ORC) can recover waste heat from fuel cells to generate additional electricity. Internal Combustion Engine (ICE) offer proven reliability, power, and flexibility, but also come with significant environmental drawbacks, including greenhouse gas emissions and air pollution.

The companies that support the development of this fuel cell are KC, WHB, MCFC, PAFC, DEC, and LT. KC (Korea Electric Power Corporation) is involved in the SOFC and PEMFC projects. Furthermore, Wintershall Dea (WHB) is developing various fuel cell applications and Molten Carbonate Fuel Cell (MCFC) is developing MCFC technology, and PAFC is developing PAFC systems. For PEMFC technology, Daimler Engine Corporation (DEC), and Lifetime Technology (LT) companies are also developing in the same technology.

From the answered RQ, it can be seen that fuel cells have a high potential to mitigate greenhouse gas emissions due to marine transport, namely ships. The potential for success is further increased when a combination of more than one fuel cells is carried out. This is done to maximise the system that is considered good and needs to be improved through a combination of other fuel cells systems.

4 Conclusions

Greenhouse gas emissions have had a devastating impact on the environment. One of the contributors to emissions is the marine transport sector. To solve this problem, it can be seen from the results of this study that fuel cells can be used as a potential solution to reduce greenhouse gas emissions. Various types of fuel cells that can be used are SOFC and PEMFC. Both fuel cells can be integrated into other technologies such as GT, ORC, SRC, and ICE. The companies that support the development of this fuel cell are KC, WHB, MCFC, PAFC, DEC, and LT. Among these types, the best fuel cell without combination is PEMFC followed by SOFC, which offers high efficiency without combination. These fuel cells can also be combined to maximise an already well-proven fuel cell system. Thus, the potential of fuel cells is very high to mitigate greenhouse gas emissions.

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