Review Of Alternative Energy Resource For The Future Ship Power

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Abstract. In the near future, reduce emissions from the combustion of the ship's main engine by increasing the propulsion efficiency of ships that are already operating and/or optimizing ship designs during the design process. The International Maritime Organization (IMO) has introduced stringent regulations to reduce GHG emissions for the global shipping industry. Another solution to reduce emissions is to use alternative renewable energy and clean. This paper will describe what energy is used for ship propulsion nowadays and other alternative energy sources that can be used for main engines, additional or hybrid power. Wind energy, solar PV, and fuel cells are renewable energy options for small ships' main propulsion, navigation, lighting, and electronic devices. Furthermore, the method used for writing this paper is collecting the best paper and selecting technology alternatives energy that is possible to install on the ship.

Keyword: Energy Alternative, Fuel Cells, Renewable Energy, Solar PV, Wind Energy.

1. Introduction

With the increase in the trade industry and the need for world shipping, fuel consumption for sea transportation is increasing from year to year [1]. As a result, in 2050, the world's anthropogenic CO2 emissions in the shipping industry will contribute to carbon dioxide (CO2) reaching 12-18%. Thus, residual fuel consumption causes pollution and the greenhouse effect [2]. In addition, NOx emissions from the shipping industry contribute to 15% of global NOx emissions. Therefore, it is necessary to implement an effective regulatory strategy to reduce it [3].

Most of the main propulsion engines of ships use diesel engines, almost 95% of the ships in the world [4]. The solution to reducing SOx, NOx and CO2 emissions is to use selective catalytic reduction (SCR)[5] and exhaust gas recirculation (EGR) [6] [7]. However, reducing emissions GHG is still focused on fossil fuels, and it will be challenging to comply with increasingly stringent regulations. The development of regulations in the International Maritime Organization (IMO) to comply with international regulations has carried out the International Convention for the Prevention of Pollution from Ships (MARPOL) by introducing ways to significantly limit ship emissions to pollutant emissions due to fossil fuel consumption in the future by using the Ship Energy Efficiency Management Plan (SEEMP), and the Energy Efficiency Design Index (EEDI) [8].

To reduce emissions to the extreme or faster is to use alternative energy for the ship's main engine [9][10][11]. Lately, alternative energy has become a popular research material to overcome the global
energy crisis, and several researchers have led to the use of renewable energy and energy storage systems for ships [12].

New energy technologies for ship power systems have been widely developed by researchers and have also been implemented on a prototype scale. Some of these new energies are solar energy, wind energy and fuel cells. To supply the energy needs of ships, alternative energy as solar energy is readily available at sea and has low maintenance costs. Furthermore, solar energy can be used as the main energy source, especially for the main engine of small ships, while for large ships, it can be used to meet electrical energy for lighting, navigation systems and communication devices. Before the invention of the steam engine in the 19th century, shipping around the world used wind energy sources and sails to propel ships. Recently, wind energy has become a consideration for alternative fuels to reduce emissions, such as Flettner, modern sails and sail kites to increase ship power and reduce fuel consumption. Fuel cells are also an alternative energy candidate for ships. Some researchers and industry are trying to realize fuel cells to become the main propulsion of ships or hybrid systems. However, solar and wind energy has a low density, and availability is not continuous. How to overcome this requires energy storage for a long time. Fuel cell systems and hydrogen storage are future alternative energy challenges that can be relied on by keeping operating safety a top priority.

2. Alternative Energy Resource

Fossil energy sources are decreasing and the demand for human energy is increasing, so alternative energy sources are needed. An alternative energy source that is environmentally friendly and reduces the greenhouse effect is renewable energy. Renewable energy that has been proven and has been used as an energy source is solar energy, wind energy, marine energy, hydropower, biomass and biofuel.

The International Energy Agency (IEA)'s annual report estimates a 13% reduction in renewable energy capacity to add renewable electricity capacity in 2020 compared to 2019 Error! Reference source not found. course is due to delays in construction activities related to supply chain disruptions, social distancing guidelines and lockdown measures and emerging financing challenges. And other factors are due to ongoing policy uncertainty and uncertain market developments, such as financing new energy projects during the covid-19 outbreak.

![Figure 1. Renewable electricity capacity additions, 2007-2021, updated IEA forecast[13]](image-url)
Figure 2. Marine Fuel Mix 2010 [14]

Error! Reference source not found. In 2020 and 2021, the countries of China, Europe, the United States and India will experience increased capacity additions for electrical energy sources from renewable energy. The type of renewable energy that will prioritize wind and solar PV energy sources. Overall there is a downward revision of almost 10% of combined capacity growth in 2020 and 2021. Using technology and country policies base the movement of this revision. During Covid-19, Solar PV projects in Europe, China and the United States experienced a 36% decline in growth. As for wind energy, the forecast for project decline in 2020 and 2021 is revised, with the most significant contribution from Europe, China and the United States. Meanwhile, new renewable alternative energy sources can be used to increase power or as the main power of ships are wind and solar energy.

2.1. Energy used for ships
The current condition of marine transportation mostly uses HFO fuel, and MDO/MGO reports from the global marine fuel trend 2030 [14]. Error! Reference source not found. shows the scenario of fuel consumption used based on the type of ship, namely tankers (crude /chemical /products), bulk carriers/ cargos and containerships independently. HFO fuel usage is greater than MDO/MGO.

An overview of the alternative marine fuel and conventional is often a matter of point of view and interpretation. Thus, in the near future, alternative marine fuels will become the target of using environmentally friendly fuels. Alternative fuels include methanol, hydrogen, LNG, equivalent biomass derivatives, or substitutes for other options.

In 2015 the Bulk Carrier/General Cargo ship had been using clean energy using LNG (Error! Reference source not found.). The use of HFO is still widely used from ship types, while the percentage of container ships from 2010 to 2020 has decreased. By 2025 the target is to have ships made from hydrogen. In 2030 the percentage of HFO and MDO use fossil fuels is still significant. With the tightening of regulations for GHG by IMO, it is hoped that all types of ships will use clean energy such as hydrogen and methanol to increase the percentage of clean energy.
2.2. Solar Energy

The solar energy conversion system into electrical energy is divided into passive and active technologies, as shown in Error! Reference source not found.. Active solar energy technology is to absorb solar radiation, and passive technology collects solar power without converting light and thermal [15]. The well-known active solar power technologies are concentrated solar power (CSP) and photovoltaic (PV) technology. The use of solar PV is more suitable for parts of the earth in the medium to high latitudes and CSP systems are preferred for thermal energy storage, especially in dry areas with relatively low latitudes [16].

For solar energy that is suitable and easy to install on ships is the solar PV type, because the space or area around the ship's deck is limited. Error! Reference source not found. shows that LCOE Solar PV from 2010 to 2018 experienced a very significant decline, down 77% from the price of around USD 0.37/kWh to USD 0.084/kWh. By 2030 the auction price for solar PV will be between USD 0.08/kWh and 0.02/kWh. By 2050, solar PV is expected to be one of the cheapest power sources available, especially in areas with very good solar radiation, with 2050 costs in the range of USD 0.014–0.05/kWh [17].

![Figure 3](image-url)

**Figure 3.** The fuel mix for containership, bulk carrier/general cargo, tanker (crude) and tanker (product/chemical) fleet (%) [14]

![Figure 4](image-url)

**Figure 4.** The Levelized cost of electricity (LCOE) for solar PV is already competitive now compared to all fossil fuel generation sources and would be fully competitive in a few years [17].
The prospect of using solar PV for ship energy needs will increase along with competitive prices under the LCOE of fossil fuels. Due to the fluctuating energy requirements when the ship is operating, it is very necessary for sustainable energy management and reliable energy storage systems.

![Solar Energy Conversion Technologies](image)

**Figure 5.** Classification of solar energy conversion technologies [15].

2.3. **Wind Energy**

Wind energy is one of the fastest-growing renewable energy sectors, with wind energy costs now flattened in proportion to the cost of electricity generated by thermal power plants such as coal and gas. Wind energy sources in Indonesia are quite large but have different characteristics from countries in the subtropical hemisphere whose winds are greater than countries in the tropics. The working principle of marine energy on land and at sea is almost the same as utilizing a work method that uses the basic force of lift or drag. The difference is the location of the installation. Wind Offshore the installation location is in the middle of the sea either in a floating or fixed structure and some people classify wind energy installed on the beach as well as wind offshore.

Wind can be defined as the flow of air over the earth's surface. Since air is a fluid, air and water flow (in the ocean) follow the same principle. The pressure gradient in the air (or sea) leads to flow from high-pressure areas to areas of low pressure. These pressure variations cause pressure gradients due to the uneven heating of land and oceans on the earth's surface — especially the heat difference between the tropics and the high latitudes. Therefore, the wind is an indirect form of solar energy. Because of the earth's rotation, this large-scale wind pattern will be affected by the Coriolis Force. Near the earth's surface, land or ocean, friction slows down the wind, and surface roughness (e.g., topography, forests, waves) is the main cause of these frictional forces. Hence the spatial and temporal variations of the wind are controlled by solar radiation, Coriolis (i.e., earth's rotation), and earth's surface (mountains, buildings, sea, etc.). These variations can be studied at multiple scales: global wind patterns, regional climates, variations within wind farms, and around turbine blades.

A promising solution to reduce emissions and fuel savings by double digits is Wind Assisted Ship Propulsion (WASP) as a renewable energy source for the future in the shipping industry [18].
There are two main types of wind turbines: the vertical axis wind turbine (VAWT) and the horizontal axis wind turbine (HAWT) (see Error! Reference source not found.). The most common types of horizontal axis wind turbines are: 3-bladed aerofoil and several multi-bladed turbines. The most common types of vertical axis wind turbines are: Savonius, Darieus, or Panemone.

Offshore winds global weighted average LCOE decreased by 48% between 2010 and 2020, from USD 0.162 to USD 0.084/kWh, with 9% year-on-year reductions in 2020. Furthermore, auctions and tender results show that starting in 2023, the cost of electricity will drop to between USD 0.05/kWh and USD 0.10/kWh, with this level achievable even in a relatively new market.

Improvements in technology, including bigger ones turbine, longer blades with higher hub better altitude and access to wind resources, like from a farm the shore winds move further from the coast increasing global weighted average capacity factor. This increased from 38% in 2010 to 45% in 2017, before dropping to 40% in 2020 as China increase its share in global distribution.
2.4. Fuel cells
In 1838 Christian Friedrich Schönbein, a Swiss scientist discovered the basic principles of the fuel cell. Sir William Grove in 1939 carried out further research based on the electrolytic principle of inadvertently reversing water [20].

Fuel cells (FC) are equipment that functions to convert chemical energy from fuels such as hydrogen, which reacts directly with oxygen into electrical energy and theoretically and practically produces much higher efficiency than conventional power generation sources [21][22]. On the other hand, FC has a lower Environmental Impact Scheme (EIS) than conventional technology and is small in size, quiet, and more efficient [23].

The fuel cells are classified according to the choice of electrolyte and fuel. Presently six different major types of fuel cells are available.

- Proton Exchange Membrane Fuel Cell (PEMFC):
  - (a) Direct formic acid fuel cell (DFAFC);
  - (b) Direct Ethanol Fuel Cell (DEFC).
- Alkaline fuel cell (AFC):
  - (a) Proton ceramic fuel cell (PCFC);
  - (b) Direct borohydride fuel cell (DBFC).
- Phosphoric acid fuel cell (PAFC)
- Molten carbonate fuel cell (MCFC)
- Solid oxide fuel cell (SOFC)
- Direct methanol fuel cell (DMFC)

They are further classified on the basis of operating temperature.

The low operating temperature ranges from (50–250) °C for PEMFC, AFC and PAFC, and high operating temperature in the range of (650–1000) °C like MCFC and SOFC. Based on the review conducted [24]-[25], the main advantages, disadvantages and suitability of the application of all fuel cells are briefly described in the reference.

3. Trend Future Ship Power
In this section, we will discuss some of the applications of alternative energy, such as the use of solar, wind and fuel cells.

3.1. Wind Power for Ship
The two main ways to apply wind energy in the shipping industry today are Wind Assisted Ship Propulsion (WASP) and Wind Power Generation. Offshore wind energy is more suitable for power generation than onshore wind energy because the energy loss and wind speed reduction caused by friction at sea is more diminutive than inland [26].

There are two types of WASP of equipment used to capture wind energy for ship propulsion, namely wind power ships: traditional and modern. Examples of traditional WASPs are rectangular sail ships, and triangular sail ships. Furthermore, modern WASP is Walker Wingsail ships, Flettner rotor sail ships and skysail ships.

Rectangular sail ships. The breakthrough of traditional WASP technology vessels in Japan, such as the "Shin Aitoku Maru" [Error! Reference source not found.a] was the first oil tanker with modern sails mounted on its deck. In recent years, University of Tokyo researchers have carried out the "Wind Challenger" project [Error! Reference source not found.b], which aims to install four large sails on ships to harness maximum wind energy over the sea [27].
Triangular sail ships. In 1986 a passenger ship with the largest "Wind Star" triangular sail was built with components consisting of masts, brackets and sails. A total of 4 masts installed on its deck with a length of 50 meters each cover an area of 2000 m$^2$ using six lateen polymer screens. The ship can sail at a speed of 12-13 knots and can supply power to propel the ship for 90% of operating or sailing time, increasing energy efficiency by about 25%[29].

Walker Wingsail ships. The main component of the walker wing sailing ship is to use a multi-element three-plane sail in the form of symmetrical foil, and there is a flap to adjust the angle of attack of the sail. The foil and the flap gap makes the high-energy airflow from the lower surface to the wing's upper surface and adds a greater lifting force [30].
Flettner rotor sail ships. The Flettner rotor works to rotate the cylinder exposed to the wind and generate a Magnus force that converts wind energy into thrust [32]. However, Flettner's past rotor sail technology did not perform as well as steamers and diesel. The main reason is that the very large screen size of the Flettner rotor causes two serious drawbacks. One is that more deck space is required, and the other is an adverse effect on ship stability [32].

Error! Reference source not found. is a 10,000 DWT cargo ship "E-Ship I" with Flettner rotor sails. It can increase the ship's energy efficiency by 30% under favourable working conditions, with four Flettner rotor sails 27 m high and 4 m in diameter on deck [33]. Another Flettner rotor sailing vessel, "M/V Estraden" Error! Reference source not found. built in 2015, is equipped with two Flettner rotor sails 18 m high and 3 m in diameter, producing a main engine equivalent of 2 MW for propulsion [34].

![Flettner rotor sail ships](image)

**Figure 11.** Flettner rotor sail ships [31].

Skysail ship. Principle work skysail ship converts wind power to drag a ship with a rope connected to a kite flying in front of the ship attached to a high altitude. The propulsion system with skysail requires several components to control the skysail, the launch or release method, roll the skysail and optimization setting wind route. This propulsion system does not reduce deck space or change the ship's main dimensions [35]. Another advantage of this system is that it can reduce the wave factor that causes slamming forces and torque on the ship so that it will increase performance and increase ship safety [36]. The challenge for this system is implementing automatic control to manage kite flight, manage launch and recovery operations and keep the kite flying in an efficient position that is most important. Skysail ship was first implemented and successfully reduced engine load by 20% and saving $1000 in fuel was the "Beluga skysail" Error! Reference source not found. ship in 2007 with its maiden voyage from Hamburg to Houston using a skysail area of 160 m² [36].

![Skysail ship](image)

**Figure 12.** "Beluga Skysail" ship [36].
3.2. Solar Power for Ship
A PV plant's energy density and relatively low energy conversion efficiency will produce power of only a few hundred watts to a few kilowatts. Therefore, this feature decided that solar energy is usually used as the main power source in small-scale ships and an auxiliary power source in large-scale ships. However, for large power requirements and long operating times, a storage system or battery is needed.

Medium and small scale ships using solar PV as ship propulsion need a power system configuration using batteries for energy storage. The first solar powered ship capable of crossing the Atlantic in 2006 was the ship "Sun 21" using a PV panel area of 65 m² above the hull [39].

Figure 13. Sun 21 [39]

In 2010 Taiwan had designed and built the first cruise ship in Asia using solar power and can save energy from 1/3 to 1/4 of a diesel-fueled ship. See [40].

Figure 14. Solar Ship of Love II [40].
The largest solar-powered ship and has completed 60,023 km circumnavigation without using fossil fuels in 2012 is the ship "Turanor Planet Solar" [41].

Figure 15. Turanor Planet Solar [41].
The car carrier "Auriga Leader" uses solar power with 328 PV panels with a power of 40 kW installed on the ship's deck and contributes to an annual fuel reduction of 13 tons and CO2 emissions by 40 tons. The output power of the installed PV generating system can meet 6.9% of the demand load for onboard lighting and 0.2%–0.3% of the demand load for ship propulsion.

![Figure 16. Auriga Leader](image)

The "Emerald Ace" is another ocean-going solar powered vessel with 768 PV panels with a power of 160 kW.

![Figure 17. Emerald Ace](image)

3.3. Fuel Cell Power for Ship

Electric power on ships usually supplies power for auxiliary equipment, although there is a tendency for propulsion, like a ship with a hybrid system where electric power is used for propulsion and supplying energy storage [37]. To supply the electricity needs of ships, mostly use diesel generators, where chemical energy is converted into electricity through heat and mechanical energy. In contrast to how a fuel cell works, it converts chemical energy directly into electrical energy [38]. Section 2.4 has described several types of fuel cells and table 1 below are some of the vessels and types of fuel cells used.
Table 1. Type of Fuel Cells Powered Ships

| Vessel                        | Fuel Cells | Logistics fuels | Capacity (kW) |
|-------------------------------|------------|-----------------|---------------|
| USCGC Vindicator              | MCFC       | F-76            | 2500          |
| Viking Lady                   | MCFC       | H2,LNG, Biofuel | 330           |
| (FellowSHIP)                  |            | Methanol        |               |
| e4ship SchIBZ                 | SOFC       | Diesel          | 100           |
| e4ship PA-X-ell               | HT-PEMFC   | Methanol        | 120           |
| A 20 m tourist boat           | PEMFC      | H2              | 50            |
| (South Korea)                 |            |                 |               |
| FCS Alsterwasser              | PEMFC      | H2              | 48            |
| A yacht of MTU                | PEMFC      | H2              | 4.8           |
| A canal boat in England       | PEMFC      | H2              | 5             |
| Hy-Ferry project              | PEMFC      | H2              | 240           |
| Nemo H2                       | PEMFC      | H2              | 60            |
| NedStack                      | PEMFC      | H2              | 60            |

Table 1 shows that the type of fuel cell often used is PEMFC (Proton Exchange Membrane Fuel Cell). Fuel cells are a priority for researchers and industry to become a promising alternative energy source. Abundant materials, environmentally friendly and sustainable without being affected by changes in weather. Several countries have started programs to use fuel cells such as Germany, Japan, Austria, UK, Netherlands, France, US, Australia and Canada [44].

The United States warship USCGC "Vindicator" has replaced four diesel generators with fuel cells for fuel cell development and demonstration needs on board ships. The goal is to meet the electrical power needs of the ship [45].

![USCGC "Vindicator"](image)

Figure 18. USCGC "Vindicator" [45].

In Germany, the PA-X-ell e4ships project aims to increase the energy supply of large ships using a 120 kW fuel cell for propulsion. The world's first commercial fuel cell-powered passenger ship -
"Alsterwasser", part of the Zemships (Zero Emission Ships) project (Error! Reference source not found.), runs successfully on inner-city waterways in Hamburg [46].

![Image of Alsterwasser](image)

Figure 19. “Alsterwasser”

The industry currently developing fuel cell module systems is ABB. The system is based on a proton hydrogen exchange membrane (PEM) fuel cell. The fuel cell technology is applicable to both high and low voltage, as well as AC and DC power systems, and can be used in combination with batteries or engines. These systems can be fully hydrogen-electric or integrated as part of a hybrid power system [47]. In Japan, Yanmar has been working on developing a future powertrain that uses hydrogen as a fuel. The company has signed a memorandum of understanding with Toyota Motor Corporation to develop a hydrogen fuel cell system for maritime applications based on components of the hydrogen fuel cell system including the high pressure hydrogen tanks on the MIRAI, a hydrogen fuel cell car manufactured by Toyota. Aiming to create an easy-to-install module with a superior cruising range, Yanmar aims to install a maritime fuel cell system on its own vessels and begin field demonstration tests by the end of FY2020. Furthermore, the company plans to expand the technology for various applications and applications[48].

4. Review and Synthesis
Alternative energy for ships using wind, solar PV and fuel cells can increase the efficiency of the ship’s energy needs. For example, wind energy technology using Wingsail can increase energy efficiency by 25%, Flettner motor 30% and Skysail up to 20%. Large ships that use Solar PV energy mainly to reduce the main energy needs that use fossil fuels and increase energy efficiency by 6.9%. Compared to wind, solar PV requires a large panel area and only depends on the time of day and sunny weather. Meanwhile, wind energy in the sea can be captured as an alternative energy source at any time as long as there is a wind speed that can capture its energy. Meanwhile, fuel cell energy for ships is more directed at replacing 100% fossil energy or building new ships and not for additional ship energy. Furthermore, Figure 20 shows about increasing the ship’s efficiency energy.
The alternative energy technologies mentioned above can be implemented in several commercial vessels such as container ships, bulk carriers, cargo, chemical products and tankers. Figure 21 shows the feasibility of installation on a ship based on the ship's deck area. Types of ships such as containers, bulk carriers and cargo during operations such as loading and unloading require a free area so that alternative energy technologies can only be installed around the bow, stern, and poop decks which are smaller in area than the ship's main deck.

The tanker has a large main deck so that installing wingsail, flettner, skysail and solar PV is more optimistic because it does not interfere with loading and unloading. But it must be reviewed with the existing regulatory system because tankers require a high level of ship safety.

Figure 21. The feasibility of installation on a ship based on the ship's deck area
5. Conclusions
The use of alternative energy sources is the most promising for power needs in the modern shipping industry. Alternative renewable energy such as wind energy, solar energy, and fuel cells can be used for ships' main propulsion, especially for medium or small scale ships or to add power for lighting, navigation, and communication needs of large ships, reducing fuel consumption. This is because reducing the greenhouse effect (GHG) and fuel costs.

The basic conclusion in this paper about alternative energy sources for the future of ship power are:

- Some wind energy technologies that have future prospects are the Wingsail Walker and Skysail. As for the Flettner rotor, it affects the ship's stability and reduces the loading space of the ship. Wind energy increasing the ship energy.
- The type of solar power suitable for marine applications is the type of Solar PV, not CSP. Because solar energy density is low, it is best to increase the power needed for ships such as lighting, navigation, and other electrical components.
- Fuel cells are more promising to be used as an energy alternative for ships, either for ships' main propulsion or for the ship's electrical power needs.
- Wind energy technology can increase ship efficiency energy between 20%-30% than solar PV that only 6.9%. Nevertheless, the implementation of fuel cells must replace fossil engines or new ship buildings.
- Type of ships such as container, bulk carrier and cargo are minim of the area to install renewable energy device, while tankers have a large main deck area for the installation of renewable energy technology.
- Hybrid technology (solar PV, wind energy, fuel cells and fossil fuels) is very good for optimizing renewable energy sources that can be converted into ship propulsion or other electrical needs.

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