

## Smart and Futuristic Vessels- Future of Fuel Cells in Marine Vessels

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**Abstract:** Shipping is vital to world economy and with new MARPOL regulations for low sulphur content has led to the increase in fuel prices which has put the pressure on shipping companies. Therefore the industry must prepare for alternative fuels and propulsion system.

Fuel Cell is one such promising system that resolves the environmental and increasing price issues. They provide efficient and eco friendly power supply solutions than conventional internal combustion engines and gas turbines. The paper illustrates the types and working of fuel cells focusing on *SOFC fuel cell* in combination with advanced thrusters. Further, the research focus light on the present and future applications of fuel cells and the prospective hybrid *SOFC-GT power system* working. The pros and cons of the fuel cells are put in comparison with the present conventional power and propulsion systems used on ships.

The paper is concluded showing the promising future of fuel cells in respect to new norms for emissions, increasing fuel prices and the maintenance cost of the present power systems.

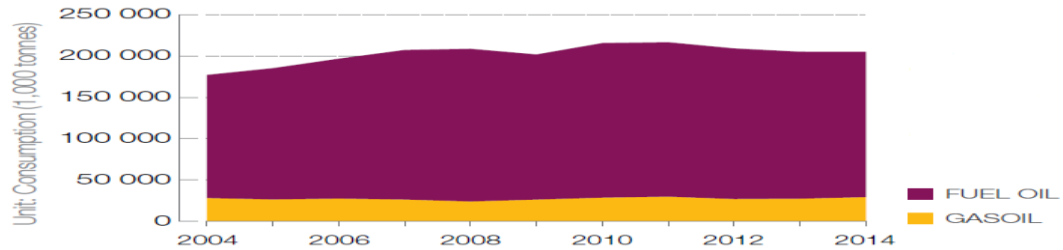
**Keywords:** Fuel Cell, Marpol, SOFC-GT

### 1. INTRODUCTION

At present some 95% of the world's goods are moved by sea. Since 1980 the total international seaborne trade has increased by 67% in terms of weight. Accordingly, preliminary UNCTAD estimates indicate that global seaborne shipments have increased by 3.4 per cent in 2014 that is at the same rate as in 2013.

The International Maritime Organization Informal Cross Government/Industry Scientific Group of Experts estimated that in 2007 global merchant marine fuel oil consumption was in the range of 369 million tonnes which due to the use of thermally efficient diesel engines has reduced to around 250 million tonnes per annum but with increase in

shipping would increase to some 486 million tonnes till 2020 [International Maritime Organization, 2007].



**FIGURE 1: Consumption of Fuel oil and Gas oil**

Recent developments have led many in the industry to question whether the present modes of ship propulsion are sustainable due to three main factors:

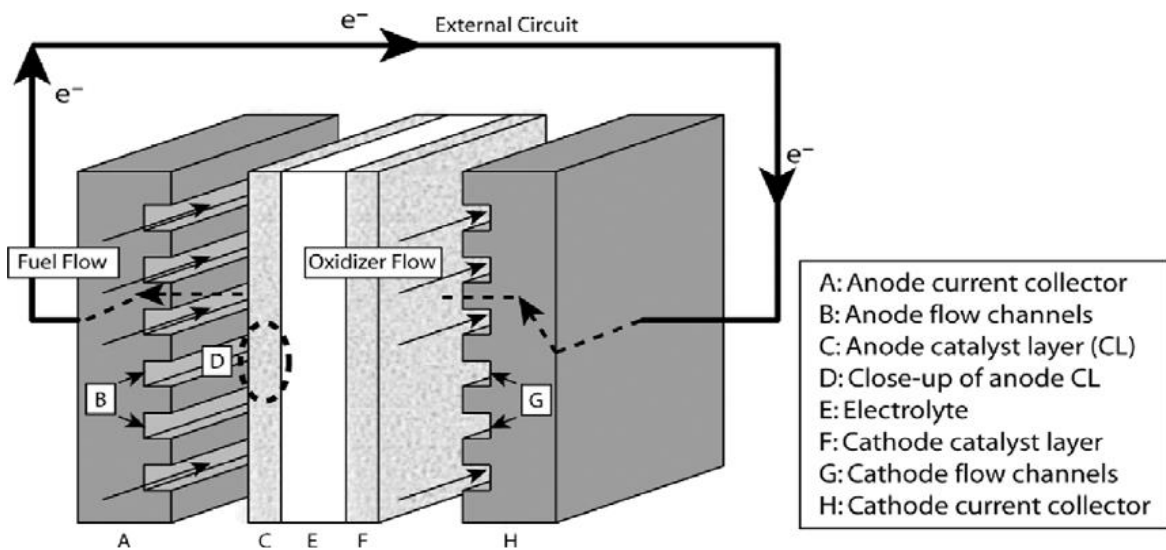
- Rising fuel costs as a result of the escalating price of oil.
- Environmental regulations introduced to mitigate the effects of climate change.
- The potential introduction of carbon taxes.

From 2015, ship sailing in the Sulphur Emission Control Areas (SECAs) cannot use fuel with more than 0.1% of sulphur. Globally, ships will have to cut their fuel's sulphur content to a maximum of 3.5% in 2012 and to 0.5% in 2020. The IMO MARPOL Annex VI has also strengthened the standards relating to NOx emissions, with NOx emissions to be cut by 16-22% as from 2011 compared to 2000 levels, and by 80% in 2016.

## **2. Main Work**

### *2.1 Fuel cell*

Fuel cells are electrochemical devices that directly convert chemical energy in fuels into electrical energy. Since the intermediate steps of producing heat and mechanical work typical of most conventional power generation methods are avoided, fuel cells are not limited by thermodynamic limitations of heat engines such as the Carnot efficiency. In addition, because no combustion process is involved, fuel cells produce power with minimal pollutants.



**FIGURE 2: Basic principle of Fuel Cell**

Basic physical structure of generic fuel cells is shown in Figure that fuel cells consist of an anode (negative electrode) and a cathode (positive electrode) which are sandwiched around an electrolyte. Fuel is fed to the anode and oxygen is fed to the cathode. Activated by a catalyst, hydrogen atoms separate into protons and electrons. Electrons go through the external circuit creating electricity flow. Protons migrate through electrolytes to the cathode. Protons then reunite with oxygen and the electrons to produce water and heat.

### 2.1.1 Types of fuel cells:

#### 2.1.1.1 PEMFC:

They are characterized by a solid phase polymer membrane. The hydrogen fuel is fed continuously to anode electrode, and protons and ions are produced with an oxidation reaction. The operating temperatures of these types of fuel cells are usually as low as around 100.

PEMFCs are capable of high power densities of over 2kW/L and 2W/cm<sup>2</sup>. Recently, a FC has run with a power density of 5.5W/cm<sup>2</sup> at 10A/cm<sup>2</sup> with pure hydrogen and oxygen in laboratory conditions. [3]

#### 2.1.1.2 AFC:

The electrolyte in this kind of fuel cell is KOH operating at a temperature range from 50~250°C. Some noble metals, such as Ni, Ag, metal oxides, are used as electro-catalyst this kind of cell can reach high level of electrical efficiency up to 60%. The global combined heat and power (CHP) efficiency can be more than 80%. The volumetric power densities of AFC are around 180W/kg and 500 W/L and the cell power density is about 130mW/cm<sup>2</sup>. [3]

### 2.1.1.3 PAFC:

In this kind of fuel cell, phosphoric acid is used as the electrolyte. The system operates in a temperature range between 50 to 250°C. The chemical reaction is the same than in a PEMFC but pure hydrogen must be used as fuel. This solution also needs platinum as electro-catalyst in both anode and cathode.[3]

PAFCs have demonstrated system efficiencies around 40%, which is a higher value than values obtained in many PEMFC systems

### 2.1.1.4 MCFC:

Molten Carbonate Fuel Cells operate at a very high temperature range of 600 to 700°C. In this temperature range the molten alkaline carbonates can conduct positive and negative ions. Due to the high operating temperature, hydrocarbons reacting on CO can be converted to hydrogen

In the stack. MCFC does not need expensive platinum as catalyst but it needs nickel and nickel oxide for anode and cathode.[3]

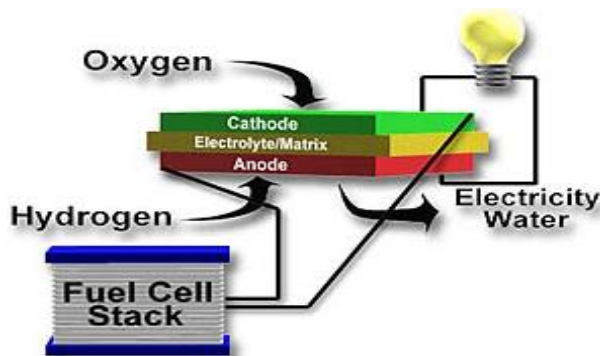
### 2.1.1.5 SOFC:

SOFC uses a ceramic material electrolyte. The ceramic electrolyte can conduct oxygen ions. These ions produced at the cathode, travel from the cathode to the anode, and then combine with hydrogen to produce water. These types of fuel cells usually operate at very high temperatures range of 600- 1000°C.

The main advantage is that SOFCs operate at a high efficiency range usually from 40% to 60%, can achieve an efficiency of 70-80% if they are integrated with a gas turbine (SOFC-GTs).[3]

## 2.2 Fuel cells power system main components:

- Anode
- Cathode
- Anode catalyst –usually made of platinum powder
- Cathode catalyst- usually made of nickel
- Electrolyte & basic circuit connectors



**FIGURE 3: Layout of Fuel Cell**

### 2.3 Working:

- Hydrogen flows into the fuel cell and through the porous anode.
- The anode's catalyst separates the hydrogen atoms into protons and electrons.
- The electrons flow to the electrical circuit, generating electrical power.
- The protons flow through the electrolyte to the cathode.
- Oxygen flows into the fuel cell to the cathode and the cathode catalyst combines protons, electrons, and oxygen's to form water (as its only emission).
- Along the process the flow of electrons is achieved/generation of electricity.

### 2.4. Ship Propulsion

#### 3.1 Azimuth thruster:

An azimuth thruster is a configuration of marine propellers placed in pods that can be rotated to any horizontal angle (azimuth), making a rudder unnecessary. These give ships better maneuverability than a fixed propeller and rudder system.

#### 2.4.1 Types of azimuth thrusters:

- **Electrically operated azimuth thrusters**, more commonly called pods, where an electric motor is fitted in the pod itself, connected directly to the propeller without gears. The electricity is produced by an onboard engine by fuel cells.
- **Mechanically operated azimuth thrusters**, which connects a motor inside the ship to the outboard unit by gearing. The motor may be diesel or diesel-electric.
- Depending on the shaft arrangement, mechanical azimuth thrusters are divided into L-drive and Z-drive. An L-drive thruster has a vertical input shaft and a horizontal output shaft with one right-angle gear. A Z-drive thruster has a horizontal input shaft, a vertical shaft in the rotating column and a horizontal output shaft, with two right-angle gears.

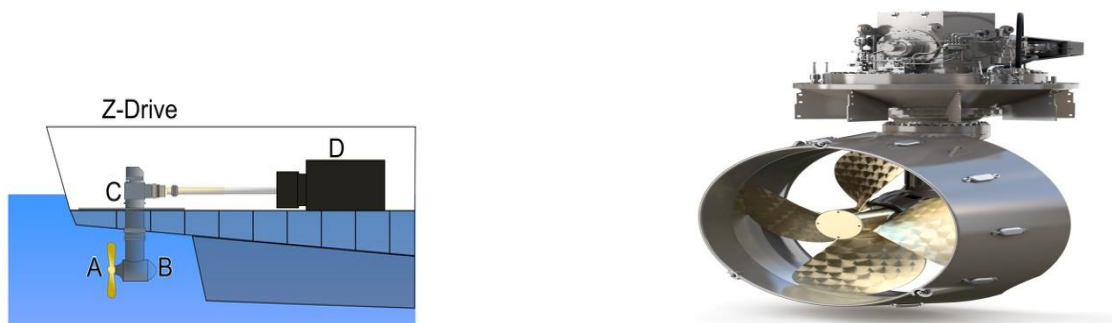


FIGURE 4: Z-Drive

FIGURE 5: L-Drive

### 2.5. Hybrid SOFC-GT engine

Gas turbine (SOFC-GT) system as the power module for the fuel cell powered cargo ship. The notional SOFC system module, which will be the building block for the proposed power plant, has an electrical output of 5 MW with efficiency of 50% and volumetric density of 40 W/liter. We use four SOFC modules and one gas turbine-generator set to make one hybrid SOFC-GT engine, which will produce a total electrical net output power of 24MW for the combined power plant [2]. The schematic diagram of the hybrid SOFC-GT engine is shown in Figure below:

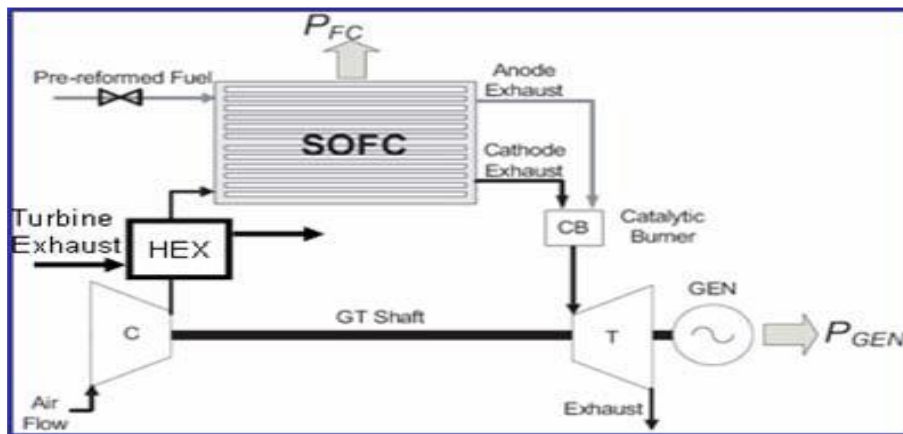


FIGURE 6: Working of SOFC-GT engine

A catalytic burner is connected to the exhaust of the SOFC system to convert any fuel left in the SOFC anode exhaust into heat energy. This burner can also be used for the start-up operation to speed up the system warm-up process. The high temperature SOFC exhaust, with the temperature further elevated by the burner, will then power the turbine to recuperate the high quality heat energy in the exhaust. The turbine will drive the compressor, through a mechanical shaft, to deliver the air to the SOFC modules, thereby saving the auxiliary power that is needed to drive the air compressor and increasing the total system efficiency. The turbine also drives a generator that is connected to the same mechanical shaft to generate additional electrical power. This hybrid SOFC engine with a gas turbine as the bottoming cycle boosts the efficiency of the total system from 50% to 60% and total power from 20 MW to 24 MW.

2.5.1 Some Of The Ships That Are Already Running Such Technology With Slight Variation In The Propulsion Plant Are:



***HORNBLOWER HYBRID***



***SCANDLINES***

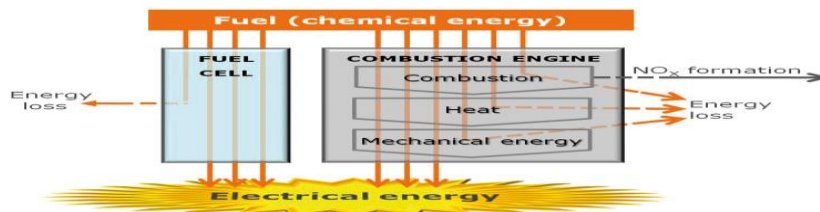
## 2.6. Advantages of fuel cells in ship propulsion

### 2.6.1 Improved efficiency:

The direct electrochemical conversion of fuel energy to electricity in fuel cells provides fewer sources of loss than in combustion engines. At optimal load, the best fuel cell stacks have an electric efficiency of 50-55 %, giving a fuel to electric efficiency of 45-50 % when internal consumption is included.

These values are slightly higher than the typical values of fuel to electric efficiency for state-of-the-art marine diesel generators, which are just above 40 %. New gas engines claim to achieve efficiencies greater than 45 %.

For part load operation, where combustion engines have lower efficiencies and emissions of local pollutants are higher, fuel cell power packs generally maintain or even increase their efficiency.



**FIGURE 7: Comparison between the losses of conventional engine and fuel cells**

Losses in the electrochemical conversion process generate heat that is recoverable. Depending on the type of fuel cell technology, the amount and quality of exhaust from fuel cell stacks are high compared with combustion engines

### 2.6.2 Reduced emissions to the air:

CO<sub>2</sub> emissions lead to global warming. By using fuels such as liquid natural gas (LNG) or methanol that have less carbon content than conventional ship fuels, these emissions can be reduced.

PM, NO<sub>x</sub>, and SO<sub>x</sub> emissions from ships can result in severe consequences to human health and the environment (e.g. Corbett et al. 2007; Edie et al. 2012) [1]. In the long-term, the potential uptake of fuel cells on board could contribute to reducing these consequences.

NO<sub>x</sub> is formed by combustion at high temperatures, a process that does not occur in fuel cells, and thus NO<sub>x</sub> emissions from fuel cells are negligible.

As sulphur must be removed from the fuel before it is supplied to the fuel cell, SO<sub>x</sub> emissions are eliminated. PM is not emitted from fuel cells, as the fuel cannot contain heavy hydrocarbons.

### *2.6.3 Other advantages:*

Use of a fuel cell power plant instead of a combustion engine will reduce noise and vibrations due to less moving parts improving comfort for crew and passengers.

Fewer moving parts also lead to a reduction in maintenance requirements during operation compared with combustion engines as this have less moving parts and less alignment and dynamic balance of the machineries to be maintained.

Reduced plant size and flexibility in laying it out: when limited space is required for fuel and gas processing, can easily be installed in independent modules. This makes the total installation less vulnerable to single failures and, in principle, the modules could be placed in several different locations around the ship.

## *2.7. Challenges in adopting this technology*

Despite potential benefits, the marine market is not in itself large enough to drive fuel cell technology developments. Hence, it cannot be expected that fuel cells will penetrate marine markets before they become firmly established in the commercial utility sector, and shipbuilders will need to use and adapt products developed first either for the power industry or for DOD. In addition, cost advantages to onsite shore users due to large-scale production may not accrue to the marine industry.

- High cost of platinum and other catalysts that are used in the manufacture of the F.C systems which results in very high first costs of plant installation making it very difficult to compete with conventional systems.
- startup time, especially in some of the systems like PAFCs;
- High reformer cost, especially in small systems where fuel compound supplied at the time of processing reforms itself into the hydrogen;
- carbon monoxide intolerance of electrodes;
- high cost of membranes ( especially for in the case of solid polymer electrolyte fuel cells);

- low efficiency of the oxygen electrode;
- deterioration of the cost/performance ratio in small systems; and
- Need to replace cells periodically.
- Most importantly due to the major concerns of economical production and distribution and safe storage of hydrogen.

### 3. Conclusion

- Promising technology to be in par with **stringent emission control norms** and **decrease dependency on the Heavy oils and other fossil fuels.**
- Most viable for niche market use in the near future for larger ocean going vessels too.
- Has potential for widespread marketplace acceptance if we can build an effective and efficient renewable bunkering infrastructures and hydrogen stations. And required bunkering infrastructure has to be built for the shipping Industry like the automobile industry having a “Hydrogen Stations & Hydrogen Highways” concept being developed in few places of Germany, Hawaii, and Iceland est.
- It will help us in reducing the maintenance factors in the conventional systems and improve the safety features of the crew and passengers.
- The technology to keep the future secured, with regards to conservation of the environment and decrease dependency on the extinguishing fossil fuels.
- Fuel cell are commercially available today in some markets, as number of small ferries and boats, where their unique benefits bring special value, but for wide spread acceptance and penetration into market of this early products require government incentives to make them affordable to be competitive to the cost to power capacities of the marine propulsion engines.

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