

New Developments for Maritime Fuel Cell Systems

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New Developments for Maritime Fuel Cell Systems

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1 Introduction

As a result of environmental concerns in shipping the international legislation set by the IMO (International Maritime Organisation) requires the reduction of SO_x and NO_x emissions from shipping (MARPOL Annex VI). To reduce the SO_x emissions in environmental sensitive areas so called SECAs (Sulphur Emission Control Areas) are established for example in the Baltic and North Sea. In these areas a maximum sulphur content of 1.5 % in fuel oil is permitted. This value will be decreased in 2010 to 1.0 %. In 2015 this limit shall be again reduced to 0.1 %. For the NO_x emissions a reduction in three steps from 2000 to 2016 is planned. For all three types of diesel engines (low, medium and high speed engines) specific limits per g/kWh are defined. Beneath the inner motor measures also emission scrubbers are permitted [1]. According to the high political pressure a CO₂ trade for shipping is currently under discussion at the IMO [2].

The European Union introduces additional laws to reduce ship emissions in European waters. The EU limits the sulphur content in fuel oil to 1.5 % since 2006 for all passenger ships sailing between EU ports. According EU-Directive 2005/33/EG it is planned to reduce the sulphur content in the fuel down to 0.1 % for all ships in European ports, alternatively the use of land based power is permitted [1].

Mainly caused by the strong emission regulations in shipping, the demand of more environmental friendly energy converters, better energy efficiency and emission reduction methods is rising continuously. Several methods like exhaust gas treatment, use of gas as ship fuel either as dual fuel engine or gas motor, electrical onshore connections in the ports, energy efficient energy management and improvements of the whole system (e.g. hull design with low resistance) are currently under discussion. Additionally the fuel cell gets more and more in the focus of the maritime industry to be also a good possibility according to the benefits of high efficiency and low emissions.

2 Regulatory Background in Shipping

In shipping the legal requirements are based on the conventions and codes of the International Maritime Organisation (IMO) which are mandatory for all ships in the international trade. The most important conventions are the SOLAS (Safety of Life at Sea) and the MARPOL (Maritime Pollution) conventions. In addition to the IMO legislation the unified requirements of the International Association of Classification Societies (IACS) give guidance on interpretation of special topics with the purpose to harmonize the practice of classification societies. In practice the class societies rules classification and construction incorporate the IMO codes and conventions and the unified requirements. Below these rules the technical standards are applied (Fig. 1).



Figure 1: Rule Framework in Shipping.

According to the SOLAS convention it is not allowed to use fuel oils with a flashpoint below 60 °C. The only exceptions are Liquid Natural Gas Tankers under the legislation of the International Gas Carrier Code (IGC-Code). All flag states have to follow this requirement. Therefore in practice, any gas applications are principally forbidden on board. Today all ships which are operated with gas as fuel with a flashpoint below 60 °C are operated by special permission of the local authority, but only for national use. According to the good experiences of the Norwegian government and the rethinking in the use of more clean energy, the IMO started on the request of Norway to develop a guideline for the use of natural gas as ship fuel. These so called provisions for gas as ship fuel will come into force on 1st June 2010 [3], but only for natural gas as fuel for internal combustion engines. It is intended to develop a code for gas as ship fuel in parallel, which includes all kind of gases and may be fuels with a flashpoint below 60 °C for all kinds of energy converters, including the fuel cell. This Code may come into force in 2014 with the regularly update of the SOLAS convention.

Germanischer Lloyd was the first classification society worldwide which published already in 2003 a “Guideline for the use of Fuel Cell Systems on Board of Ships and Boats” [4]. These guidelines have been used successfully for a number of applications. In 2008 and 2009 other classification society published rules for fuel cell systems. Further rules from other classification societies are under development to follow the ongoing development in this field.

3 Fuel Cell Systems in Shipping

Fuel cell systems are known for their advantages low noise, no or nearly no NO_x emissions and a high efficiency already in the low power range. Furthermore they are of modular design, which leads to benefits for their integration. The big disadvantages of fuel cells are their high costs regardless the fuel cell type and the low specific power which feature more or less strongly to all fuel cell types. The lifetime of a fuel cell stack is today also a big issue for most types of fuel cells. In addition the fuel logistic and the fuel price are obstacles to introduce the technology. Pure hydrogen which is the preferred fuel from a technical point of view is not widespread. Only a few filling stations exist, even less for maritime applications. Nevertheless in regional applications with relatively low power demand, like ferry boats or pleasure boats, it may be possible to establish a sufficient fuel supply with one filling station.

In all other cases, especially in applications with a high power demand another logistic fuel than hydrogen is necessary, according to the fact of the low volumetric energy content of hydrogen (Fig. 2). The required volume for the fuel becomes the most limiting factors for gases as alternative fuels in shipping application.

Fuels other than hydrogen require reformer systems to be applied with fuel cells. Several types of reformer systems are present, but most challenging for them is to get rid of the sulphur, especially in typical maritime fuels. Nevertheless ongoing changes in international regulation which will allow the use of natural gas from mid 2010 and the environmental requirements regarding lower sulphur content in bunker fuel will support the use of reformer systems in the future.

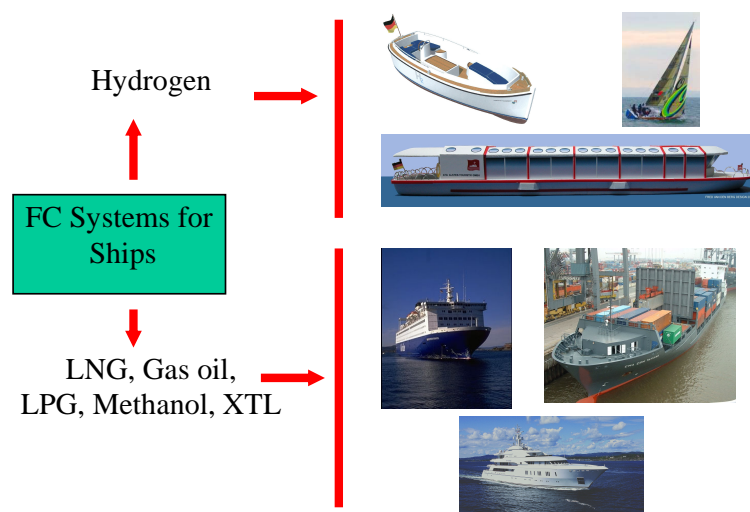


Figure 2: Which fuel for which application?

IMO has initiated the development of an international code which will allow the use of different fuel gases and may be also liquid fuels with a flashpoint below 60°C. These developments will also support the use of fuel cell systems in the international shipping.

3.1 Suitable FC systems

For the use in shipping low as well as high temperature fuel cells are suitable. In case of use of low temperature fuel cells, the PEMFC (Proton Exchange Membrane Fuel Cell) seems to be the best candidate for the use in naval applications when operated with hydrogen. If the PEMFC is operated with a reformer system it can not compete with conventional internal combustion engines with regard to the efficiency. For the high temperature fuel cells the PAFC (Phosphoric Acid Fuel Cell), MCFC (Molten Carbonate Fuel Cell) and SOFC (Solid Oxide Fuel Cell) is suitable. All three systems normally operate with an upstream reformer system to create a hydrogen rich gas mixture out of hydrocarbons. The PAFC is the mostly deployed fuel cell on commercial bases. Therefore, the PAFC is today an alternative for the use on board of ships. But according to the low efficiency compared to traditional energy converter on board ships, the PAFC is no real opportunity. The MCFC and the SOFC are the most promising fuel cell systems for the use in shipping. The high efficiency and the use of combined heat and power make them suitable for the use in shipping. Today only a few

developments of SOFC systems in a reasonable high power range exist. With regard to the status of development the MCFC seem to be the most promising fuel cell system for maritime applications today [5,6,7,8,9].

3.2 First applications

In principle fuel cell systems can be used for any maritime application. This starts from pleasure boats, yachts over fishing boats, inland navigational, harbour and supply vessel up to cargo ships and passenger vessel. Even on board of military ships and submarines fuel cells can be used. According to the high power demand of ships (up to 100 MW for main propulsion and 12 MW for auxiliary power for a big container vessel), it has to be mentioned that fuel cell systems at their current status of development are only suitable in niche applications. The main problems are related to the fuel logistics and the fact that fuel cells today can only provide a low power range up to 350 kW. According to the EU funded feasibility study FCShip fuel cell systems with a standardised module size from 500 kW to 1000 kW are needed for shipping applications [10].

In the power range up to 500 kW the fuel cell systems can be used for main propulsion and auxiliary energy. This relates to inland navigational vessel, pleasure boats and yachts, etc. According to the high power demand for propulsion of seagoing ships, the today existing fuel cell system can only be used for auxiliary power. In this area passenger vessel, mega yachts and research vessel will be the first application for fuel cell systems on board. By using 3 to 4 fuel cell systems with a power range up to 500 kW, it is possible to provide the basic load of auxiliary energy for larger seagoing vessel for up to 90 % of the auxiliary energy demand [9].

Fuel cell systems are and will only be used in the areas, where the benefits dominate the costs. The most common example in this respect are the submarines of the German manufacturer HDW used e.g. by the German and Italian navy. Other application areas will be the use of FC-Systems in areas, where the use of internal combustion engines is not permitted (environmental restrictions) and therefore alternative propulsion systems are required.

4 Possible Market Potential for Fuel Cell System in Shipping

Germanischer Lloyd has worked on a market analysis for fuel cell systems on seagoing vessels, which was published in the beginning of 2010 [9]. The aim of the study was to identify the possible market and market fields for fuel cell systems on sea going vessels. The study includes beneath the market reflection also the supply logistic and the environmental and economical effects by the use of fuel cell systems in shipping especially for the city of Hamburg.

For the market analysis the world fleet of large commercial vessels (approx. 50.000 vessels) was analysed regarding different reference vessel which represent the most typical ship types. In addition the market for large yachts was included in the evaluation. The analysis based on the use of standardised 500 kW fuel cell modules. For the analysis a partial replacement of auxiliary power on the bases of the standardised modules was assumed. The analysis gives an outlook till 2030.

It can be expected that Mega Yachts, RoRo-Vessel and Cruise Ferries are the first applications for fuel cell systems. These ship types have been analysed more in detail. A market share of fuel cell systems for auxiliary power of 5 % was assumed. The analysis shows that these ship types have a yearly demand for such a technology of about 22 units. This seemed to be a small number, but means a quadrublication of the production capacity of a major MCFC manufacturer in 2008. Additionally it has to be considered that these ship types have only a market share of about 3.5 % of the world fleet!

The outlook over approximately half of the world fleet shows that till 2030 a market volume up to 4250 fuel cell units of 500 kW is possible. The demand for FC systems with a power below 500 kW was not considered in detail but it is obvious that this market is bigger with regard to the number of units. E.g. for small container vessel up to 850 TEU and general cargo vessel there will be an additional market volume for 250 kW fuel cell units up to 600 units till 2030.

These few figures show, that the shipping industry has a very high market potential for fuel cell systems in the future, if the specific maritime requirements can be fulfilled.

Today fuel cell applications in shipping are small scale applications in most cases. Some examples are given below.

5 Examples for Successful Fuel Cell Integrations in Shipping

5.1 SMART-H2 – Whale watching boat ELDING I

Within the SMART-H2 project (Sustainable Marine & Road Transport on Hydrogen in Iceland) also the marine application of hydrogen will be demonstrated. The main goal of SMART-H2 (2007-2010) will be a demonstration fleet of 20-40 hydrogen vehicles, of different types and using different propulsion technologies and to demonstrate the hydrogen technology onboard a publicly accessible boat. Therefore a 125 ton whale watching boat for 150 passengers was chosen (Fig. 3). The ship's Auxiliary Power Unit (APU) consists of a 10 kW fuel cell operated by compressed hydrogen providing electricity for the ship operation. This enables the boat to switch of the internal combustion engines during whale watching. The ship started its operation in April 2008.



Figure 3: SMART-H2 – ELDING

5.2 ZEMSHIPS project – FCS ALSTERWASSER

The ZEMSHIPS project (2007-2010), founded by the EU-Life program, has the aim to test practically an emission-free ship operation within an environmental sensitive area and to promote this technology for maritime applications. ZEMSHIPS is the first project in the world to integrate a hydrogen fuelled fuel cells system of this size on a commercial passenger vessel. It combines two fuel cell systems with a peak output of 48 kW each with a 560-V lead gel battery pack (Fig. 4). The prototype FCS ALSTERWASSER has a length of approx. 25.50 metres, a breadth of 5.25 metres and can transport up to 100 passengers. Project partners are ATG Alster Touristik, Germanischer Lloyd, Hamburg University of Applied Science, Hochbahn, hySOLUTIONS, Linde Group, Proton Motor, UJV Nuclear Research Institute. The ship started its operation in 2008-08 [11].

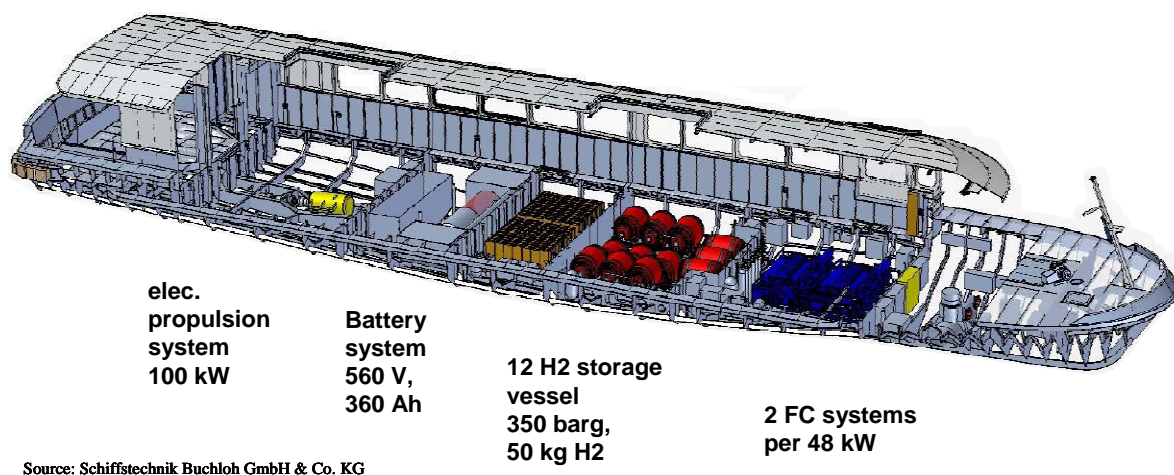


Figure 4: ZEMSHIPS project – FCS ALSTERWASSER.

5.3 Fuel Cell Boat Amsterdam

The aim of Fuel Cell Boat BV is to realise an inland passenger vessel with a fuel cell system fuelled with hydrogen, including the infrastructure for the refuelling of the vessel. The ship has a length of 22 metres, a breath of 4.25 metres and will be equipped with a fuel cell system of 60-70 kW. The capacity is about 100 passengers. The ship is planned to come in operation summer 2009 [12]. The certification is done by Germanischer Lloyd.

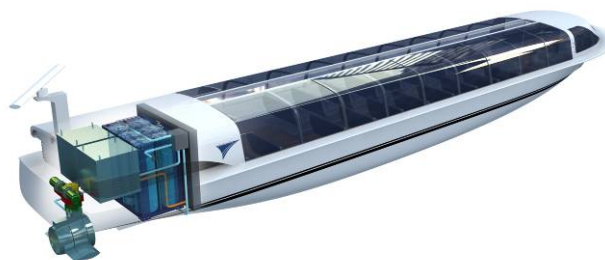


Figure 5: Fuel Cell Boat Amsterdam.

5.4 Further RUNNING projects

In the following a short overview of some ongoing fuel cell projects is given.

5.4.1 MethAPU

The EU founded MethAPU project (Validation of a Renewable Methanol Based Auxiliary Power System for Commercial Vessels) is running from 2006-2009. The objective of this project is to develop and validate marine SOFC of 250 kW running on methanol. The validation will be carried out with a 20 kW SOFC test unit, which will be operated for one year onboard a car carrier. Partners are Wärtsilä, Lloyd's Register, Wallenius Marine, The university of Genua and Det Norske Veritas. The costs of the program are some € 1.9 million [13].

5.4.2 FellowSHIP

FellowSHIP (Fuel Cells For Low Emission Ships) is a three phase project. The overall aim of the project is the development, demonstration and qualification of fuel cell hybrid power pack for ships. The first phase (2003-2005) includes a feasibility study and the basic design development. The second step (2005-2009) comprises the building, testing and demonstration of a 320 kWe fuel cell system on an offshore supply vessel, fuelled with LNG. In the third step (2010-...) the testing, qualification and demonstration of power packs from 1 to 4 MWe is planned. Partners of the project are Wärtsilä Ship Power Automation, MTU Onsite Energy, Vik-Sandvik, Eidesvik, Det Norske Veritas. The Budget is about € 18.75 million [14].

6 Outlook on Ongoing Projects

6.1 e4ships – Lighthouse project for FC systems in shipping

e4ships is a Lighthouse project founded by the National Innovation Programme – NIP of the German government. The purpose of the project, is to demonstrate that fuel cells can function in ship's power supply systems under everyday conditions. The project starts in 2009 and will end in 2016. The project is divided in a superior project which includes the steering committee and general topics and three demonstration projects for the realisation of suitable fuel cell systems for ships (Fig.6).

The first project SchIBZ includes the development of a 500 kW MCFC system operated on XTL as fuel. The system shall be tested on a commercial paper carrier in northern Europe.

Pa-X-ell, the second demonstration project, is working on the integration of MCFC systems on board of ships, fuelled by LNG. The first system shall be integrated on a cruise ship. The long term aim is to substitute the auxiliary power systems of RoPax Ferries and Cruise ships. The auxiliary power required for these vessels is in the range of 3000 to 10000 kW per vessel.

The project Hy-Ferry works on the integration of a hybrid system with a 240 kW PEMFC operated by hydrogen in inland waterway and costal vessels.

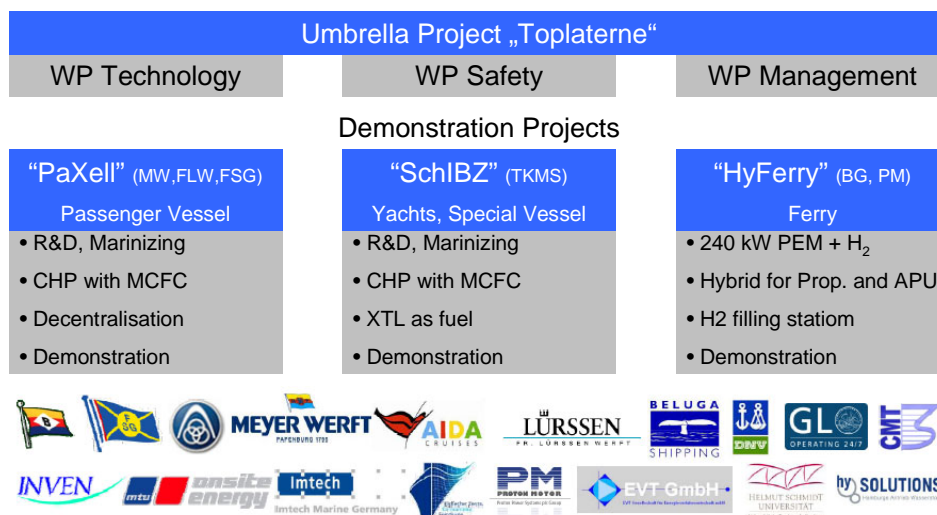


Figure 6: Structure of e4ships Project.

7 Conclusion

Driven by environmental concerns and the need for sustainable and clean energy in shipping the fuel cell gets in the focus of the maritime industry as a possibility for clean energy conversion on board. Till now fuel cell systems on board of ships are still in the demonstration phase. The only exception is the PEMFC in the submarines from German yard HDW. The PEMFC now starts to come into the market. The high temperature fuel cell, especially the MCFC will probably come into the market during the next 5 to 10 years. According to the high power demand in shipping the fuel cell will not replace the existing multi Megawatt main engines of large ships in the foreseeable future. Nevertheless the potential for auxiliary power generation by FC-Systems is much larger than the markets under discussion for large FC-Systems today. In addition this market is less price sensitive than the current target markets of most FC manufacturers. The adoption of fuel cell technology on board will first take place in the replacement of auxiliary power generators. Nevertheless in special markets and applications the fuel cell already today is a good alternative for traditional engines. Especially for pleasure crafts, inland navigational vessel, ferries and also large passenger vessels the fuel cell can be a good alternative. Where a lower power demand or only a regional fuel supply is necessary hydrogen fuelled systems can be applied.

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