FUEL CELLS IN MARITIME APPLICATIONS CHALLENGES, CHANCES AND EXPERIENCES

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ABSTRACT

The shipping industry is becoming increasingly visible on the global environmental agenda. Shipping's share of air pollution is becoming significant, and public concern has led to ongoing political pressure to reduce shipping emissions. International legislation at the IMO governing the reduction of SOx and NOx emissions from shipping is being enforced, and both the European Union and the USA are planning to introduce further regional laws to reduce emissions. Therefore, new approaches for more environmental friendly and energy efficient energy converter are under discussion. One possible solution will be the use of fuel cell systems for auxiliary power or even main propulsion. The paper summarizes the legal background in international shipping related to the use of fuel cells and gas as fuelin ships. The focus of the paper will be on the first experiences on the use of fuel cell systems on board of ships. In this respect an incident on a fuel cell ship in Hamburg will be discussed. Moreover, the paper will point out the potential for the use of fuel cell systems on board. Finally, an outlook is given on ongoing and planed projects for the use of fuel cells on board of ships.

1.0 INTRODUCTION

As a result of environmental concerns in shipping the international legislation set by the IMO (International Maritime Organization) requires the reduction of SOx and NOx emissions from shipping (MARPOL Annex VI). To reduce the SOx emissions in environmental sensitive areas so called SECAs (Sulphur Emission Control Areas) are established for example in the Baltic and North Sea. Beneath these regions also the North American continent will be surrounded by an emission control area of about 200 nautical miles from August 2012. Further regions are under discussion world wide. In these areas a maximum sulphur content of 1.5 % m/m in fuel oil is permitted. This value has been decreased in 2010 to 1.0 % m/m. In 2015 this limit shall be again reduced to 0.1 % m/m. In these then so called ECAs (Emission Control Areas) the NOx emissions will be reduced additionally in three steps from 2000 to 2016. 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 CO_2 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 % m/m 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 % m/m for all ships in European ports, alternatively the use of land based power is permitted [1].

Mainly causes 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.

2.0 REGULATORY BACKGROUND IN SHIPPING

In shipping the legal requirements are based on the conventions and codes of the International Maritime Organization (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 society's 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 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 came into force one the 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 kind of energy converters, including the fuel cell. This Code may come into force in 2014 with the regularly update of the SOLAS convention. Currently the chapter 6.12 – Fuel Cells is under development in the IGF-Code. It is intended to manage all general topics e.g. fuel supply in the general parts of the code and all fuel cell specific topics will be integrated in the chapter 6.12 for fuel cells. Furthermore the integration of additional gases and low flame point fuels (LFF) are under discussion. These topics will be discussed during the next BLG meeting (Committee for Bulk, Liquids and Gases of the IMO) in January 2012.

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.

3.0 SAFETY PRINCIPLES FOR THE USE OF FUEL CELL SYSTEMS ON SHIPS

For the use of fuel cell systems on board of the ships a few safety principles have to be followed to ensure a system, which provides the same safety level than conventional technology. Some main safety principles and their practical application are shown in the following.

3.1 Single failure criterion

The single failure criterion is applied in general. This means that the fuel cell system shall be designed in such a way, that no single failure can lead to any dangerous situation. Furthermore all safety related components have to be certified for their purpose [4].

3.2 Two-Barrier-Principle for gas supply

The two-barrier-principle for gas supply means, that each gas is surrounded by two independent barriers. If one barrier fails the second barrier will ensure the safe containment of the gas. Several measures are possible to fulfil the two-barrier-principle. The principle can be achieved by either a double-wall-piping (Fig. 2), a gas pipe within ventilation duct (Fig. 3) or by using gastight enclosures (e.g. gas tight H2 storage room, gas tight fuel cell enclosure, etc.).

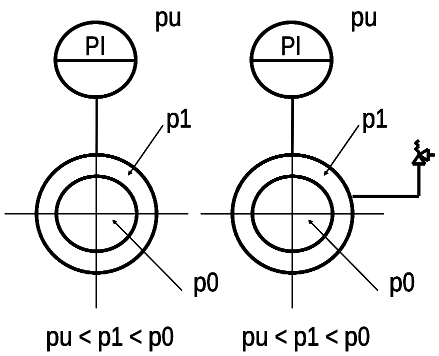

Figure 2. Sketches of Double-Walled-Pipes

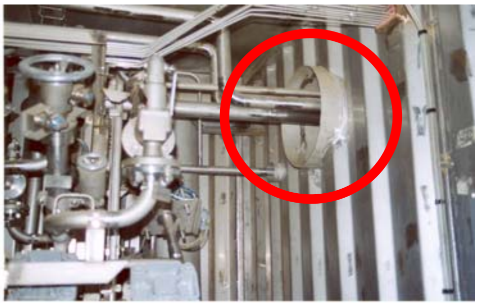

Figure 3. Gas Pipe in Ventilation Duct

A failure of a barrier of the double-walled-pipe can be monitored by a pressure sensor between the pipes. Therefore, the pressure level between the pipes has to be lower than the pressure of the inner pipe and higher than the ambient pressure. In that case a failure of the inner and outer barrier can be detected. A failure of the gas pipe in the ventilation duct will be typically detected bay a gas sensor at the end of the ventilation channel.

3.3 Separation of Systems

In general, safe areas have to be gas tight separated from areas where possible hazardous atmosphere can occur. Following the two barrier principle the separation of gas systems can be carried out by a double-block-bleed valve configuration (Fig. 4), the separation of rooms from fire loads by a fire safe insulation (e.g. A-60 insulation) and for the ventilation air flow by separate independent ventilation system for the respective room (gas storage room, fuel cell enclosure, etc.). The gas storage room and fuel cell installation space have to be separated from safe areas, engine rooms, etc. Additionally it is required to separate the gas storage room from fuel cell installation space.

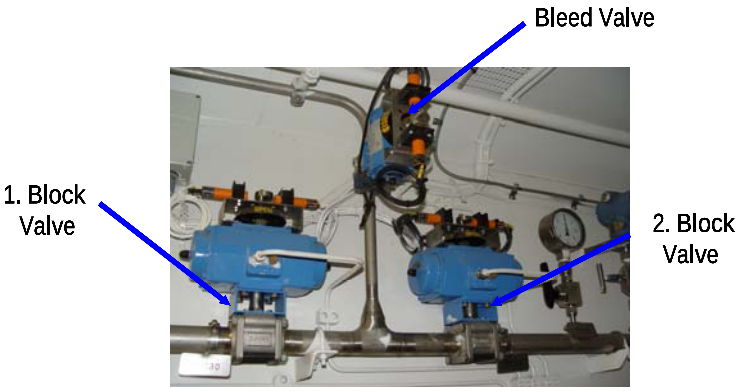

Figure 4. Double-Block-Bleed

It has been demonstrated by the practical experience with the Germanischer Lloyd fuel cell guidelines that the named principles can either be applied for large systems as shown in the figures above but also to small systems of only a few kW.

3.4 Safe Venting of Gases

To ensure a safe operation of a fuel cell system several vent systems are installed. These include the venting of flammable gases from the safety valves. If compressed gas is used as fuel like it is the case for the FCS ALSTERWASSER (ZEMSHIP Project) were 350 bar hydrogen is used, melting plugs can be used to depressurize the bottles in case of fire. Normal operation venting includes the venting of rooms with gas containing components and exhaust gases from the fuel cell which may also content flammable gases. The vent lines have to be installed in such a way, that no hazards can occur from these venting systems. Therefore, the vent line openings have to be installed in such a way, that no ignition sources are in the vicinity, a sufficient distance to safe areas is ensured and it is ensured, that dangerous gases and vapours can’t be drawn into safe areas. For high pressure vent lines from melting plugs and safety valves it has to be additionally ensured that the vent openings are installed vertically upwards to avoid a kind of “flame thrower” effect if they are needed in case of fire.

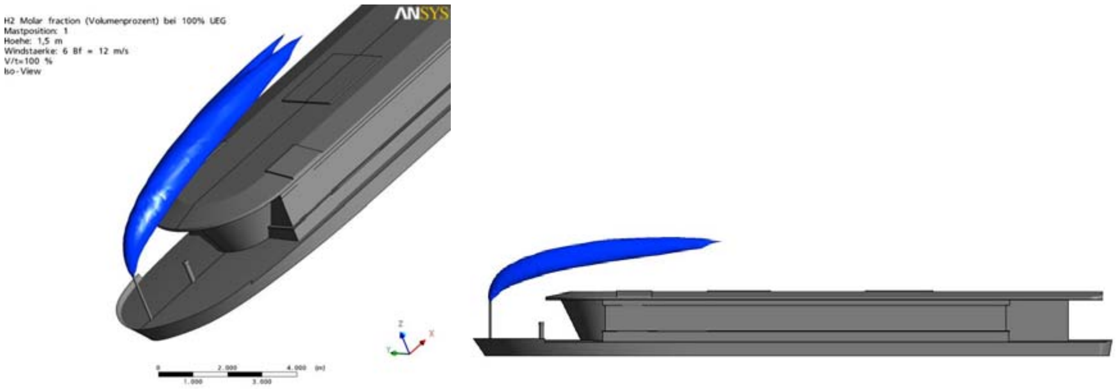

Figure 5. Example of a vent line of an inland navigational vessel

3.5 Explosion Protection

To avoid the risk of explosion all areas where flammable gas can occur have to be suitable for this purpose. Therefore an area classification has to be carried out – generally according DIN EN 60079-10 - to define the hazardous areas and the necessary explosion protection measures. The classical explosion protection concept persists of three steps:

1. Prevention of explosive atmosphere
   (e.g. Ventilation, two barrier principle, prevent accumulation of gas, permanently tight systems [e.g. welded pipes])
2. Prevention of ignition sources
   (e.g. only use of certified equipment, temperature below 80 % self ignition temperature, avoid electrostatic electricity)
3. Reduction of explosion effects
   (e.g. separation of locations, double-block-bleed, two-barrier-principle, active and passive fire protection measures, use of non flammable materials)

3.6 Protection of high Pressure Storage Vessel

One of the most critical failures which can occur is the rupture of a pressure storage vessel due to overpressure, fire, etc. Therefore, a rupture of a pressure vessel has to be avoided under all circumstances. So the pressure vessel has to be protected by active systems like combined fire detection and extinguishing system and passive systems like melting plugs and safety valves. It has to be mentioned that "real" safety valves have to be installed, not only overpressure valves, which have no certified outflow rates. In general it has to be ensured that piping systems, designed for lower pressure, shall be protected against overpressure.

3.7 Protection of external Influences

To avoid a disturbance of the fuel cell system on board, the fuel cell system has to be designed according the typical environmental conditions on board of the ships. Furthermore the fuel cell system has to be protected against external influences like collisions, mechanical damage and fire. Especially in shipping fire is the most critical failure.

To avoid problems caused by external influences the following measures are typically used. To avoid any damage from collisions the location of the fuel cell installation shall be chosen accordingly (e.g. sufficient distance to shell plating). Mechanical damages can be avoided by suitable head guards (e.g. protection plates above gas pipes). And fire risks can be minimised by using suitable passive and active fire protection measures which are commonly used in shipping (e.g. fire protection insulation, automatic fire extinguishing system).

3.8 Safety Monitoring

In general, all components in the safety chain have to be certified for their purpose. For critical systems a SIL certification (Safety Integrity Level) or equivalent redundancy is necessary. The most important monitoring systems related to safety are the fire and gas detection system in the gas storage room and fuel cell installation space. In general the alarm- and shut-down limit for the gas detection system shall be 20 % and 40 % of LFL (Lower Flammability Limit). But this has to be considered in detail by including the position of the sensors and their reaction time. If the ventilation is included in the safety system or in the explosion protection concept, an air flow monitoring is necessary. In Case of failure of ventilation a shut-down of the system is required to avoid undefined hazardous situations. Additionally further monitoring systems may be necessary according to concrete layout of the system (e.g. level switches in water separators in the purge line, etc.).

3.9 Further Things to consider

Beneath the technical design of the system it has to be considered that it is also of great importance to look on the operational procedures. Therefore, a detailed description of operational instructions shall be documented in the manual for refuelling, start and stop of the system and emergency shut down. During the commissioning phase it is important to test the system according its proper function. For example pressure- and tightness tests, functional testing of the fuel cell and its integration on board and the test of the safety system and safety chain. After once in operation periodical inspections of several system components are necessary to adhere the safety of the system (e.g. calibration of gas sensors, periodical inspection of storage tanks, periodical tightness test, functional testing of the safety chain, etc.).

4.0 FIRST EXPERIENCES FOR THE USE OF FUEL CELLS ON BOARD OF SHIPS

In the following you will find a selection of fuel cell projects and their experiences.

4.1 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 t whale watching boat for 150 passengers was chosen (Fig. 6). 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. During its operation time the system on board performed very well. The project ended successfully as planned in 2010.

Figure 6. SMART-H2 – ELDING I

4.2 ZEMSHIPS Project – FCS ALSTERWASSER

The ZEMSHIPS project (2007-2010), founded by the EU-Life program, had 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. 7). The prototype FCS ALSTERWASSER has a length of approx. 25.50 m, a breadth of 5.25 m 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 [6].

Figure 7. ZEMSHIPS project – FCS ALSTERWASSER

The FCS ALSTERWASSER was operated two seasons very successfully on Lake Alster without any relevant problems. During a test trial on the yard in April 2010 a fire break out on the vessel. The vessel was heavily damaged but luckily no people were injured. According to the good safety concept neither the fuel cell nor the hydrogen storage were damaged. Furthermore neither one of this systems was the reason for the fire. Meanwhile the vessel is successfully repaired and will continue its operation from spring 2011.

4.3 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 m, a breath of 4.25 m 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 2011 [7]. The certification is done by Germanischer Lloyd.

Figure 8. Fuel Cell Boat Amsterdam

4.4 Further running Projects

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

MethAPU

The EU founded MethAPU project (Validation of a Renewable Methanol Based Auxiliary Power System for Commercial Vessels) was running from 2006-2010. 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 [8].

The project could successfully demonstrate the ability of the SOFC technology to withstand the particular demands of the marine environment. Furthermore it could be successfully demonstrated, that methanol as marine fuel could be utilised safely on board of a vessel. It could be also shown that the use of a fuel cell system on board of a vessel would present no greater risk to the ships than conventional marine engines and fuels [10].

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 (2005-2011) comprises the building, testing and demonstration of a 320 kW molten carbonate fuel cell system on an offshore supply vessel, fuelled with LNG (Liquefied Natural Gas). In the third step (started 2011) further testing, qualification and demonstration 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 [9].

The operation experiences of the fuel cell on board of the "Viking Lady" are very successfully. Only minor disturbances appeared in the beginning. The shipping company is very pleased with the installed fuel cell system and is thinking about possible further applications [11].

5.0 THE INCIDENT ON THE FUEL CELL SHIP "ALSTERWASSER" - LESSONS LEARNED

During a test run after maintenance of the "FCS Alsterwasser", at the shipyard in Oorkaten, Germany on 28 April 2010 the onboard installed lead-acid batteries overheated. Due to this overheating, a fire in the battery compartment ensued. The vessel was heavily damaged by the fire (Fig. 9).

Figure 9. Damages on FCS ALSTERWASSER

It seemed to be that the incident was no good reputation for the fuel cell society, but it pointed out, that the incident is very positive for the fuel cell technology, because:

- No people were endangered or injured
- Neither the fuel cell nor the hydrogen caused the incident
- The safety system puts the fuel cell and the hydrogen storage vessel in a safe state before the fire developed, the safety system worked unobjectionable
- Despite of the massive damages was neither the fuel cell system nor the hydrogen storage was damaged or endangered
- The safety concept of the vessel was fully proven

This incident shows that it is possible to integrate a fuel cell system on board a vessel safely and the system is even been able to withstand a major incident, if the integration done in a correct way.

In following one example of the safety concept is given, which ensures a safe integration of a fuel cell system on a vessel:

- separation of the danger areas
  (Fig. 10)

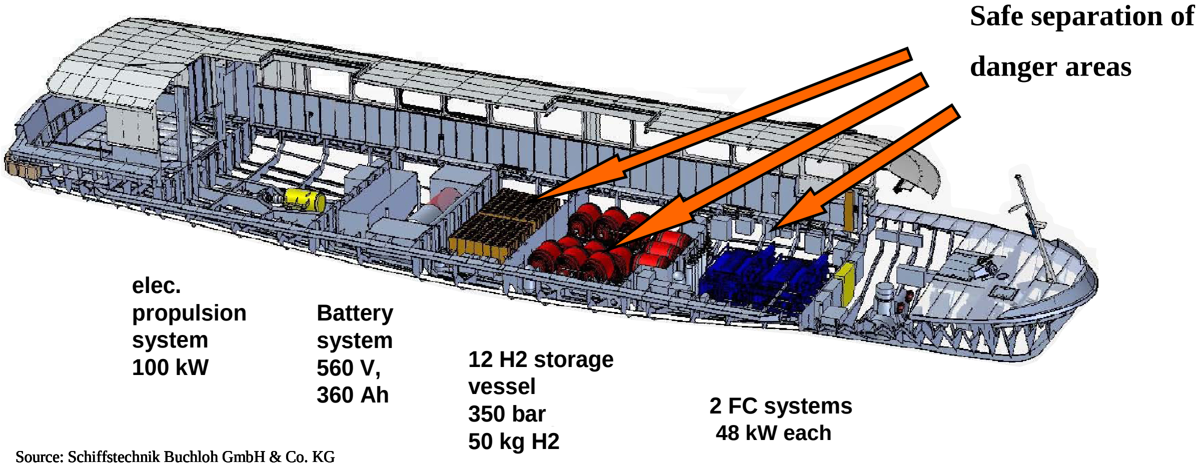

Figure 10. Design of FCS ALSTERWASSER

In the case of the fire of the FCS ALSTERWASSER this safety measure makes sure that the fire was not able to influence the hydrogen storage and fuel cell system. Even though the temperature of the fire was able to melt the aluminium furniture in the passenger area, the temperature in the hydrogen storage room was not higher than on a warm summer day, although the source of fire was in the adjacent battery compartment.

This incident clearly proofs the suitability of the safety concept which was based on the fuel cell guidelines of Germanischer Lloyd [4].

6.0 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 [5]. 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 four times 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 2035 a market volume up to 3900 fuel cell units of 500 kW is possible (Fig. 11). 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 (Twenty-foot Equivalent Unit) and general cargo vessel there will be an additional market volume for 250 kW fuel cell units up to 700 units till 2035.

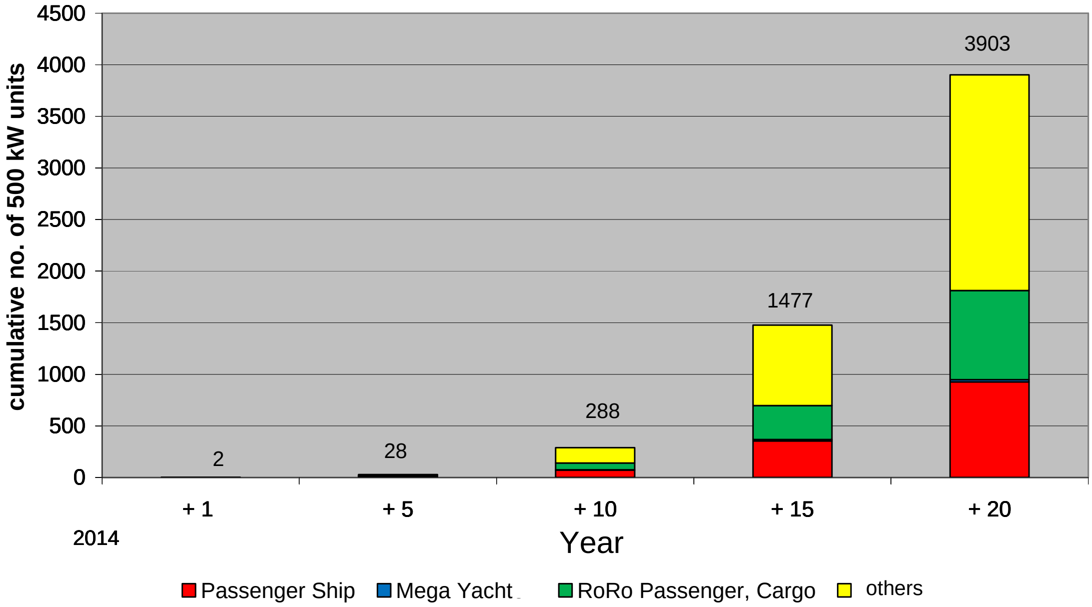

Figure 11. Market potential of total maritime market for 500 kW fuel cell systems

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 above.

7.0 OUTLOOK ON ONGOING PROJECTS

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 two demonstration projects for the realisation of suitable fuel cell systems for ships (Fig. 12).

The first project *SchIBZ* includes the development of a 500 kW SOFC system operated on XTL (Anything-To-Liquids [synthetic fuels]) as fuel. For demonstration a 120 kW demonstrator will be build and then installed and tested on a commercial paper carrier in northern Europe. Beneath the fuel cell system itself the reformer system will be one of the main issues.

Pa-X-ell, the second demonstration project, is working on the integration of high temperature PEM fuel cell 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 3 to 10 MW per vessel. The main issue beneath the fuel cell integration is the decentralisation of the energy supply for the vessel on board. Within the project further important point is the efficient use of the waste heat of the fuel cell systems. Therefore the use of an absorption chiller, which will also be developed within the project, is planned.

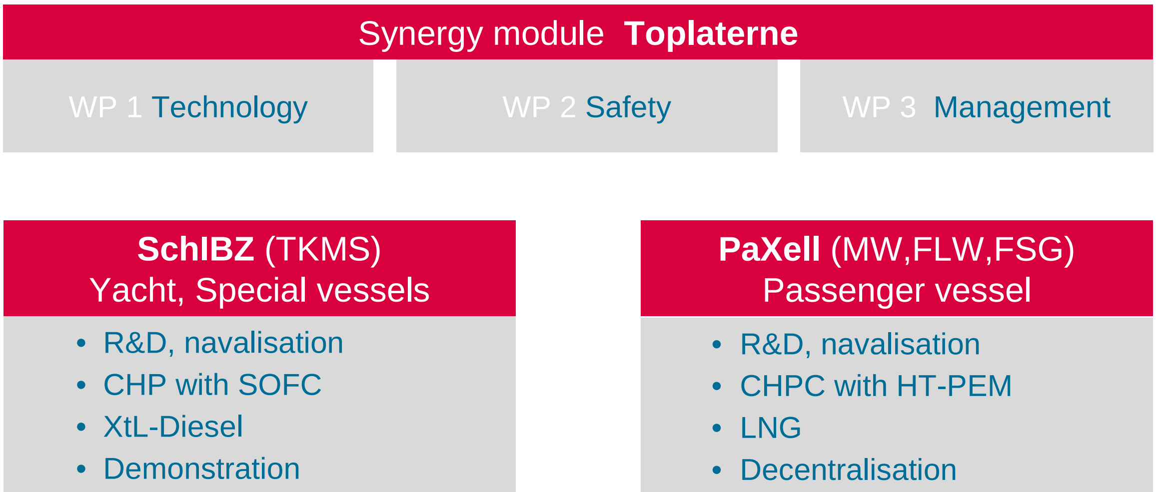

Figure 12. Structure of the *e4ships* Project

8.0 CONCLUSIONS

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 (Proton Exchange Membrane Fuel Cell) in the submarines from German yard HDW. The first experiences with fuel cells on board of ships demonstrate their suitability for shipping under normal and abnormal conditions. If integrated in the right manner the fuel cell systems will be at least as safe as conventional energy systems on board. The PEMFC now starts to come into the market for smaller vessel. The high temperature fuel cell, especially the SOFC will probably come into the market during the next 5 to 10 years. The HT-PEMFC technology has also a high potential for maritime applications. 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 fuel cell system is much larger than for example markets for land based applications which are under discussion for large fuel cell system today. In addition this market is less price sensitive than the current target markets for land based applications of most fuel cell 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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