# SAFETY CONSIDERATIONS AND APPROVAL PROCEDURES FOR THE INTEGRATION OF FUEL CELLS ON BOARD OF SHIPS

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## ABSTRACT

The shipping industry is becoming increasingly visible on the global environmental agenda. Shipping's share of emissions to air is regarded to be significant and public concern lead 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 additional 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 main propulsion. The presentation summarizes the legal background in international shipping related to the use for gas as ship fuel and fuel cells. The focus of the presentation will be on the safety principles for the use of gas as fuel and fuel cells on board of ships and boats. The examples given show the successful integration of such systems on board of ships. Furthermore a short outlook will be given to the ongoing and planed projects for the use of fuel cells on board of ships.

## 1.0 EMISSIONS IN SHIPPING

### 1.1 Emission in Shipping

Global warming, acidification and degradation of air quality are environmental impact categories high on the international agenda. Also the shipping industry is becoming increasingly visible. Public concerns and political pressure forces the shipping industry to reduce emissions. Recent studies indicate that the shipping industry corresponds to the global emissions with about 2-3 % for $CO_2$, 10-15% for NOx and 4-9 % for SOx [1, 2, 3, 4].
Most of the emissions from shipping are emitted in the costal area. About 70 % of the emissions occur in a distance up to 400 km from the coast (Fig. 1).

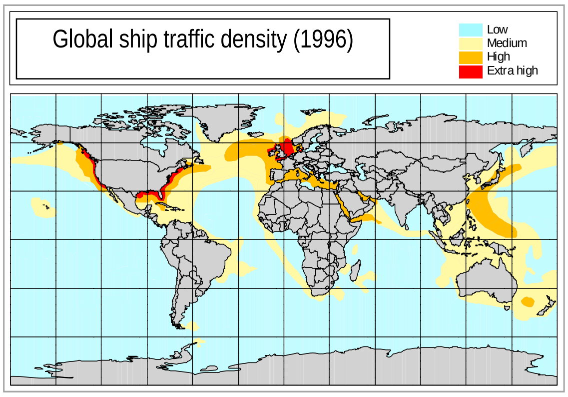


Figure 1. Estimated traffic density based on data from 1996 [5]

### 1.2 Legal Requirements

As a result of environmental concerns the international legislation set by the IMO (International Maritime Organisation) 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. 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 NOx emissions a reduction in three steps from 2000 to 2016 is planed. 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 [6]. According to the high political pressure a $CO_2$ trade for shipping is currently under discussion at the IMO [7].

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 [6].

### 1.3 Possibilities for Emission Reduction

According to the increasing 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 FC SYSTEMS FOR SHIPPING

Fuel cell systems are known for their advantages low noise, no or nearly no NOx 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. Nethertheless 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 an 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.

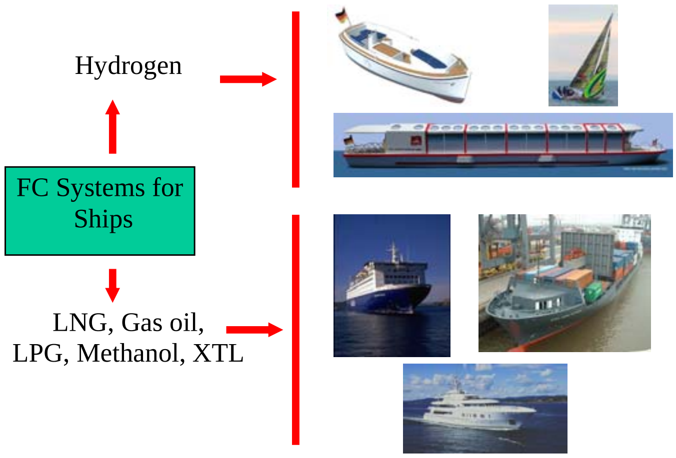


Figure 2. Which fuel for which application?

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.

### 2.1 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 [8,9,10,11].

### 2.2 First Applications

In principle fuel cell systems can be used for any maritime application. This starts from pleasure boats, yachts over fishing boats 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 the fuel logistics and the fact that fuel cells today can only provide a lower power range up to 350 kW. According to the EU funded feasibility study FC Ship fuel cell systems with a standardised module size from 500 kW to 1000 kW are needed for shipping applications [12].

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.

Fuel cell systems are and will only 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.

## 3.0 LEGAL BACKGROUND

### 3.1 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. One level below the IMO conventions and codes the unified requirements of the International Association of Classification Societies (IACS) are arranged which are minimum requirements for special topics with the purpose to harmonize the practice of classification societies. On level below the unified requirements the rules for classification and construction of the classification societies are established which incorporate the IMO codes and conventions and the unified requirements. Below these rules the technical standards are applied (Fig. 3).


Figure 3. 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 exception 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 will most likely come into force one the 1st June 2010 [13]. 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 is 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" [14]. These guidelines have been used successfully for a number of applications. Since mid of last year a second 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.

### 3.2 Safety Principles

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.

**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 [14].

**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. 4), a gas pipe within ventilation duct (Fig. 5) or by using gastight enclosures (e.g. gas tight H2 storage room, gas tight fuel cell enclosure, etc.).

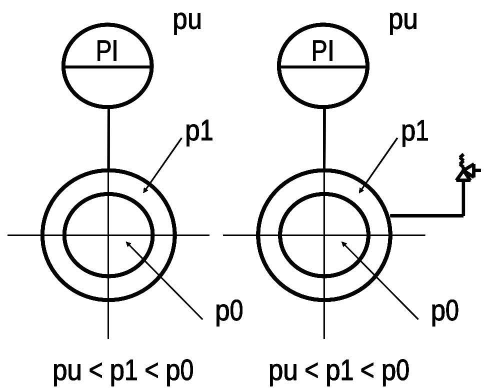


Figure 4. Sketches of Double-Walled-Pipes

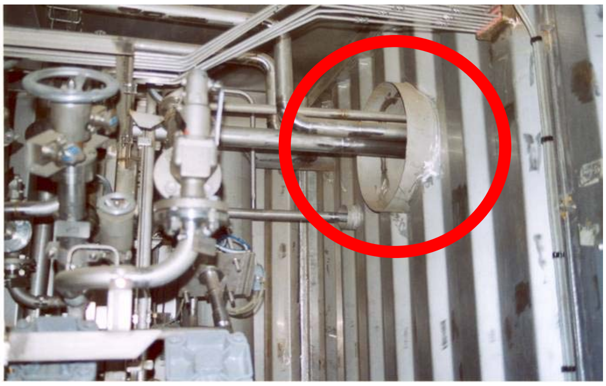

Figure 5. Gas Pipe in Ventilation Duct

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.

**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. 6), 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.

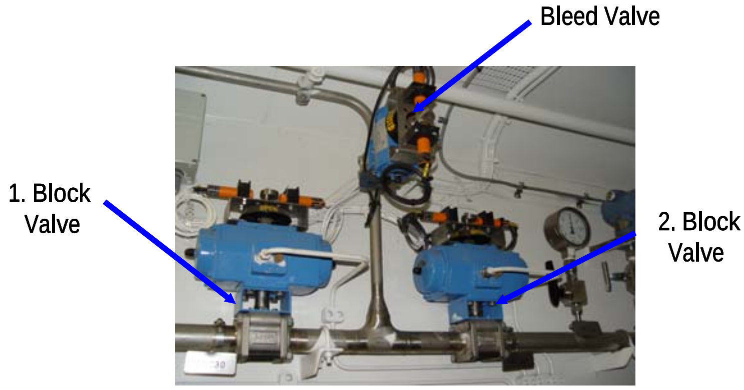


Figure 6. Double-Block-Bleed

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.

**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 340 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.

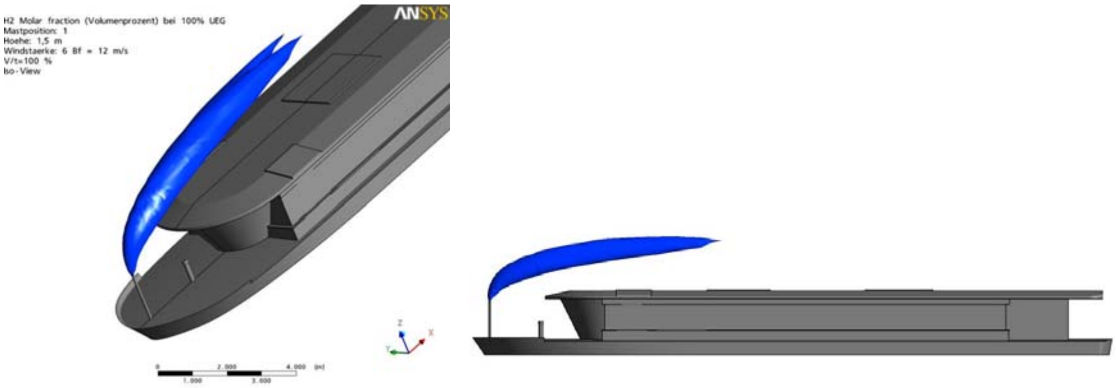


Figure 7. Example of a vent line of an inland navigational vessel

**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)

**Protection of high Pressure Storage Vessel**

One of the most critical failure 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.

**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).

**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. 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.).

**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 EXAMPLES OF SUCCESSFUL FC INTEGRATIONS

### 4.1 Pleasure boats

One early market for fuel cell systems in the maritime field are pleasure boats, according the fact that combustion engines are banned on many rivers and lakes, the relatively low power demand, small operation times and the fact that many pleasure boats are only used regional. Since 2003 fuel cell systems are used for auxiliary power and main propulsion. The power range for installed fuel cell systems reaches from 2 to 24 kW electrical power. In October 2003 the first pleasure boat with a GL certified fuel cell system, the sailing yacht No.1, started its operation on Lake Constance (Fig. 8).

Figure 8. Sailing Yacht No 1

Since the first application a few other pleasure boats with fuel cell powered propulsion have been developed during the years (Fig. 9, Fig. 10)

Figure 9. H2Yacht 675


Figure 10. zebotec – 50kW runabout

### 4.2 Commercial applications

In the following a few examples of commercial fuel cell system applications on board of ships are presented. The fuel cell systems on board of these ships have also been certified according the GL fuel cell guideline.

**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. 11). 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 11. SMART-H2 – ELDING I

**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. 12). 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 [15].

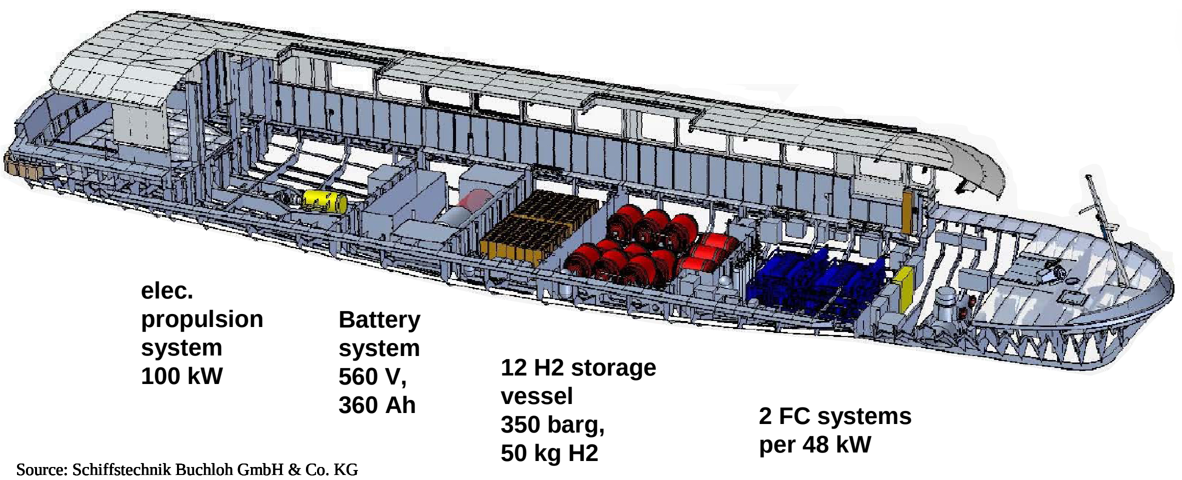


Figure 12. ZEMSHIPS project – FCS ALSTERWASSER

**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 [16]. The certification is done by Germanischer Lloyd.

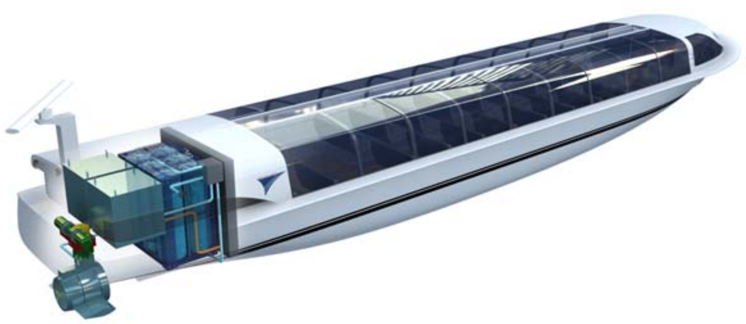

Figure 13. Fuel Cell Boat Amsterdam

**5.0 FURTHER ONGOING AND PLANNED 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) 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 [17].

**MC-Wap**

The MC-Wap project (Molten-carbonate fuel Cells for Waterborne Application) is also an EU founded project with a total budget of € 17.2 million. The duration of the project is 5 years (2005-2010). 16 Partners from 7 countries are involved in this project (CETENA SpA, Fincantieri SpA, Ansaldo Fuel Cells SpA, Politecnico di Torino, Technip KTI S.p.A., Marmara Research Center, RINA S.p.A., Johnson Matthey, Oel Warme Institut, ADROP F. GmbH, PROMEOS GmbH, Univ. of Erlangen, Nat. Tech. Univ. Of Athens, Inst. Of Chemical Tech. of Prague, Turbec AB, Tech. Univ. Bergakademie Freiberg). The main aim of the project is the design, construction, installation and testing of a marine 500 kWe MCFC Auxiliary Power Unit (APU) inclusive reformer [18].

**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 [19].

**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 project starts in 2009 and will end in 2014. 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.14).

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 project Hy-Ferry works on the integration of a hybrid system with a 250 kW PEMFC operated by hydrogen in inland waterway and costal vessels.

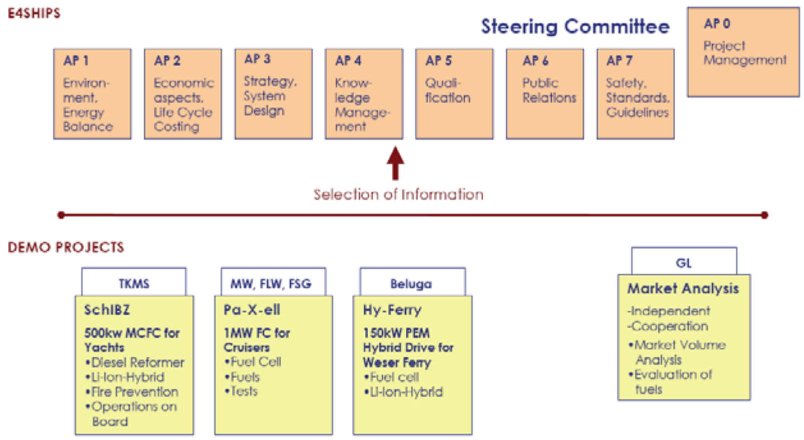


Figure 14. Structure of e4ships Project

## 6.0 OUTLOOK

Driven by environmental concerns and the need for sustainable and clean energy in shipping the fuel cell gets more and more 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 10 years. But according to the high power demand in shipping the fuel cell will not replace the existing engines completely for the foreseeable future. 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 and ferries the fuel cell could be a good alternative, where a lower power demand or only a regional fuel supply is necessary. In these special markets a growth of the fuel cell powered fleet can be expected during the next years.

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