e4ships
Fuel cells in marine applications

e4ships
FUEL CELLS IN MARINE APPLICATIONS
2009 - 2016

CONTENT

MESSAGE

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Hydrogen and fuel cells can make the crucial difference both in mobility and in buildings, making our energy system more efficient and reducing emissions. These key technologies enable us to integrate renewables in the energy sector and in transport, as electricity-based fuels. That is why in Germany, a strategic partnership embracing the government and industry has been investing in testing the technologies and their products in everyday life since 2006.

The National Innovation Programme Hydrogen and Fuel Cell Technology (NIP) has been instrumental in bringing key products closer to the commercial market. Today, for example, fuel cell heating appliances for private homes and the first hydrogen-powered vehicles are at the initial phase of commercialisation. The NIP, which has received € 500 million from the Federal Ministry of Transport and Digital Infrastructure (BMVI) and € 200 million from the Federal Ministry for Economic Affairs and Energy (BMWi), in addition to € 700 million euro from industry, offers the reliable framework required for the necessary research and development work.

In the field of fuel cells for maritime use, the e4ships lighthouse project has managed to bring together leading German shipyards, shipping companies, fuel cell manufacturers, suppliers and classification societies. The partners have set themselves the shared goals of using fuel cells to supply energy in shipping, reducing emissions including sulphur dioxide, nitrogen oxide, carbon dioxide, carbon monoxide and soot particulates, and thus contributing to climate change mitigation and to the future viability of the maritime industry.

Between 2009 and 2016, the BMVI invested over € 20 million in testing fuel cell technology in maritime applications. The experience and results of e4ships demonstrate that the technology is becoming a genuine alternative for the specific needs of shipping. It gives us an innovative technological response to climate issues, particularly when ships are in harbour and coastal waters. Smaller vessels could even be powered by fuel cell technology in future. Now is the time to prepare the second phase, which will culminate in the commercial breakthrough, and to set course for market activation as of 2017.

Enak Ferlemann
Parliamentary State Secretary at
the Federal Ministry of Transport
and Digital Infrastructure

FOREWORD

Fuel cell technology can make a valuable contribution to climate change mitigation and to ensuring the future viability of the maritime industry. By using fuel cells to supply energy in shipping, emissions such as sulphur dioxide, nitrogen oxide and soot particulates can be reduced. This is a major advantage in Emission Control Areas in particular, where the stricter environmental regulations that have cut the maximum permissible emission levels are a major challenge for shipping companies.

Together with fuel cell manufacturers, leading German shipyards and shipping companies were quick to decide to cooperate at a pre-competitive stage within the scope of the NIP lighthouse project e4ships, in order to test the technology according to the specific needs of the shipping industry. With a total budget of over € 35 million since 2009 (of which over € 20 million has been provided by the German Federal Ministry of Transport and Digital Infrastructure), the project has since addressed not only technical development, but also economic efficiency, climate change mitigation impacts and technical safety standards.

Thanks to the cooperation within the framework of e4ships, the consortium has already gained valuable experience with the use of an HT PEM fuel cell system (60 kW), as well as a battery hybrid fuel cell system (50 kW) on two seagoing vessels. The technology has thus proven that it offers an attractive and economical alternative to conventional ship aggregates.

The e4ships project will continue over the coming years. As well as further testing fuel cell technology in maritime applications under everyday conditions, the focus will be on preparing a suitable framework for market entry.

Dr. Klaus Bonhoff
Managing Director (Chair) of NOW – National Organisation Hydrogen and Fuel Cell Technology

INTRODUCTION

Energy conversion using fuel cells is a key technology for increasing the efficiency of ship propulsion systems, thus reducing CO_2 emissions. Fuel cells are also the most efficient way of reducing harmful emissions such as NOx and particulates to virtually zero. However fuel cells require "clean", sulphur-free fuel. Apart from hydrogen, which is the ideal fuel for fuel cells, methane, methanol, ethanol and sulphur-free diesel are possible options. We have come a long way, and still have a long but rewarding path ahead of us until these fuels are in widespread use in shipping.

With the support of the Federal Ministry of Transport and Digital Infrastructure (BMVI), the German shipbuilding industry began in the middle of the last decade to develop innovative technical concepts for the time when heavy fuel is no longer the dominant fuel for seagoing vessels. The launch of the e4ships lighthouse project in 2009 was one of the first important milestones on the road to sustainable drive systems for shipping in future.

The e4ships lighthouse project presented in this brochure is a research project funded by the German government. Partners include leading German shipyards, shipping companies and fuel cell manufacturers as well as ourselves, a classification society. Together we are finding the answers to vital questions relating to climate change mitigation impacts, economic efficiency and technical safety standards.

Aside from the technical questions, an essential component of the e4ships lighthouse project is to support the development of the international regulations required. Since 2004 the Federal Ministry of Transport and Digital Infrastructure has been supporting the development of the IGF Code of the International Maritime Organisation (IMO) - the IMO regulation for clean and environmentally-friendly shipping fuels. After a guideline for the use of gas as a shipping fuel was adopted by the IMO in 2009, further work on the "International Code of Safety for Ships Using Gases or other Low-Flashpoint Fuels" (IGF Code) was specifically supported by the partners involved in the e4ships project. Together with the BMVI, the German Shipbuilding and Ocean Industries Association (VSM) and the Community of European Shipyards' Associations (CESA) were instrumental in driving development in this area.

Without the structured support of the e4ships project this work would have been considerably more difficult to accomplish.

Following eight years of work on this set regulations, in January 2017 the IGF Code will come into effect initially for methane as a fuel. The IMO is currently working on regulations for methanol, ethanol and low-flashpoint, sulphur-free diesel fuel as well as integrating fuel cell technology into the IGF Code. New rules governing distributed power networks on board ships are an important precondition for the use of fuel cell technology. As the development of the IGF Code illustrates, the amendment of international regulations is an arduous task. Therefore the work on IMO regulations will continue to be an important part of the continuation of the e4ships lighthouse project.

I am grateful to have been able to accompany the development work in e4ships and the work in Pa-X-ell and SchIBZ thus far and hope that I can continue to make a contribution to bring these fuel cell systems up to market maturity.

Dr. Gerd Würsig
Chairman of the e4ships Steering Committee, Business Director Alternative Fuels, DNV GL

PROJECT STRUCTURE

The e4ships project is a cooperative venture funded by the German government that brings together leading German shipyards, shipping companies, fuel cell manufacturers and classification societies in the framework of the National Innovation Programme Hydrogen and Fuel Cell Technology (NIP).

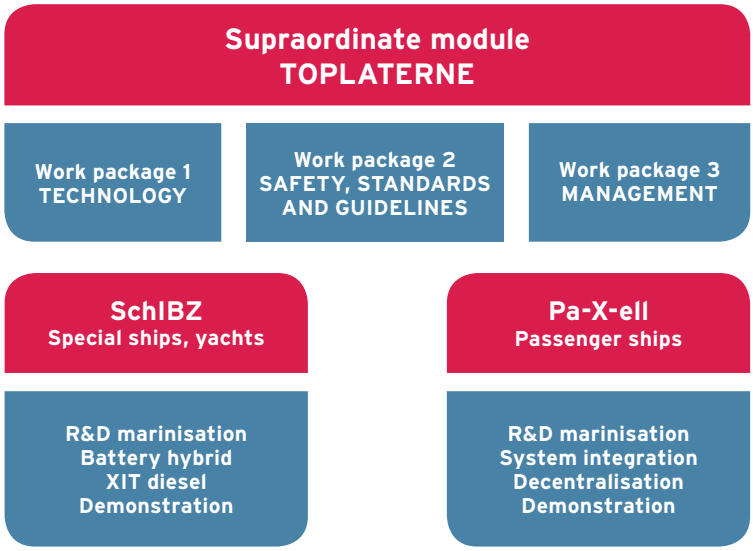
The project partners share an interest in the use of fuel cell technology to ensure a climate-friendly energy supply, primarily for use with auxiliary power units and on board ship supply systems.

The superordinate module, TOPLATERNE, addresses issues relating to climate change mitigation impacts, economic efficiency, technical safety standards, and the market introduction strategy, also for fuels not yet conventionally used such as sulphur-free diesel or methanol.

The two subordinate projects, SchIBZ and Pa-X-ell, are involved in testing the practical use of fuel cells in the maritime sector. The results of the two demonstration projects have also been used to help produce worldwide rules and standards for the licensing and installation of fuel cells on ships.

As well as the practical testing of the fuel cells themselves, proposals were elaborated for common regulations governing the use of low-emission fuels like sulphur-free diesel, natural gas or methanol on ships and their provision in ports, so that this innovative technology can be used in future around the world.

Structure of the e4ship project



TOPLATERNE MODULE

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e4ships has set itself the goal of substantially reducing harmful emissions through the use of fuel cells on seagoing ships. The first step is to achieve clean on board energy supply in the form of electricity, heat and cooling where appropriate. If ships obtain their energy from fuel cells when in port in future, a considerable improvement in air quality will be achieved. Gaseous fuels will be used for the fuel cells, and will eventually be available as a matter of course in many ports.

In the e4ships joint project, the two major shipyards MEYER WERFT and thyssenkrupp Marine Systems are developing technically different fuel cell systems with their partners, using different fuels - methanol in one case and diesel in the other. In both cases the result is an almost complete reduction of emissions of soot, sulphur and nitrogen oxides as well as a significant decrease in emissions of climate-damaging carbon dioxide.

Quite apart from the advantage of reducing emissions, the systems also offer a high level of efficiency. And they open the door for highly efficient combined heat and power generation on board ships. An evaluation conducted parallel to the technical implementation revealed significantly lower noise levels and exhaust emissions as compared to conventional systems using marine diesel or heavy oil. In addition, the modular approach offers a flexible and safe on board configuration. Through the modular arrangement a redundant energy supply is put in place that offers a higher level of safety for critical systems in particular.

For safety reasons, shipbuilding and shipping are heavily regulated internationally. Often it takes a long time before new technical systems or fuels are approved for use in ports around the world. The International Maritime Organization (IMO) is responsible

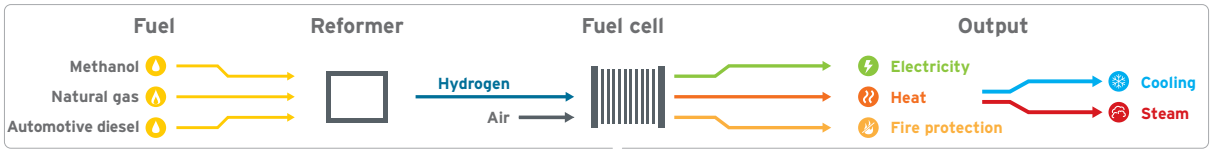
available on economically attractive terms. In this regard the focus is on the urgent issues of environmental and climate protection. Viable ships are, first and foremost, clean ships.

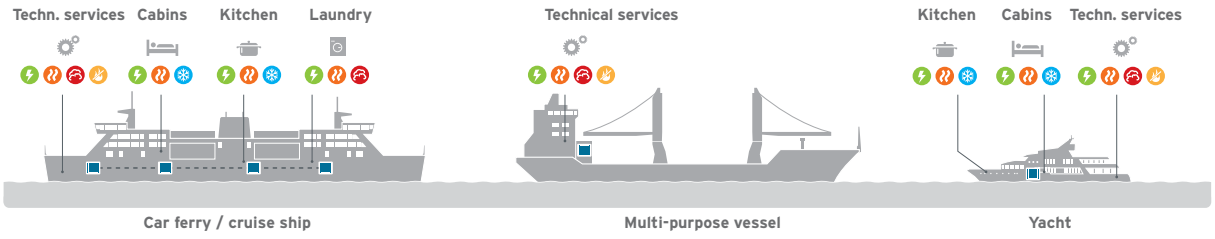
Currently the partners are implementing the next stage of fuel cells testing - practical deployment on a ferry and a cargo ship. Here too, as well as demonstrating the technical viability of fuel cells, common initiatives will be geared to improving international framework conditions with additional fuels approved for use, and evidence of economic feasibility delivered.

International Maritime Organization (IMO)

for the rules and standards in this field. Through the joint initiative of the partners and the Federal Ministry of Transport and Digital Infrastructure (BMVI) in the e4ships project, Germany, an IMO member state, has managed to incorporate the results of its tests in the IMO's decision-making procedures, thus paving the way for regulations that will provide for the commercial use of fuel cells on board ships in future. Now the focus will turn to having other environmentally-friendly fuels approved for international use in ports.

German shipbuilding faces strong international competition. Its future depends to a great extent on its ability to continue developing innovative technical systems and making these





Improved air quality
by reducing pollutants such as nitrous oxides (NO_x) and sulphur dioxides (SO_2)

+

Reduction of CO_2 emissions
by 25 to 30 %, as a contribution to climate protection and in response to stricter emission regulations

+

Economic viability
by being independent from finite fossil resources

LIFE CYCLE COSTING

Life cycle analysis is a methodology for determining the overall costs and environmental impacts of a product and for comparing it with other innovative solutions where necessary.

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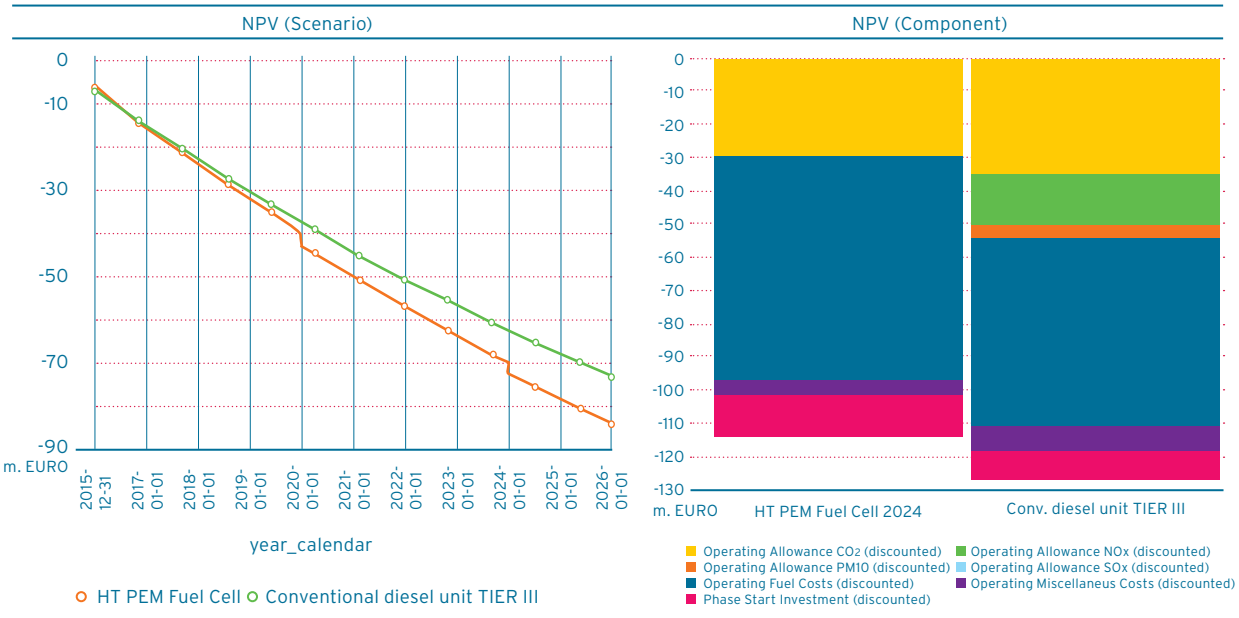
For the economic assessment, an innovative fuel cell system for the generation of electric energy was compared with a conventional on board diesel engine (including electric generator), under current operating conditions.

A typical demand profile for electricity generation, manufacture and maintenance costs of the electricity generation systems to be compared, fuel costs as well as the required replacement of fuel cell stacks after about 4 years in operation (see also net present value graph below) served as the input values. In addition to the environmental impacts during the operation of the two electricity-generating systems, the energy required to produce the fuels was calculated, along with the resulting CO_2 emissions. The influence of a possible internalisation of external costs was also examined, based on social costs per emitted tonne of harmful emissions, as laid out in the EU's "Update of the Handbook on External Costs of Transport".

Results indicate that fuel cells can be operated at a profit in future, if manufacturing costs can be reduced, further efficiency gains realised, and longer lifetimes of fuel cell stacks achieved. This will require intensive technical developments, but the partners believe that the targets can be achieved in the next decade. In addition, fuel cell technology must be placed on an equal political footing in terms of environmental impacts, as the internalisation of external costs shows (see graph below left). The legally permissible emissions levels for current diesel generators are still higher.



FUEL ANALYSIS

Evaluation of alternative fuels for on board electricity supply with fuel cells on ships.

The results of the studies available in e4ships demonstrate the huge potential offered by fuel cells in conjunction with environmentally-friendly fuels. They are significantly more efficient than conventional solutions, meaning that this technology will greatly contribute to reducing harmful emissions in shipping and to reducing ships' CO_2 emissions. The possibilities arising from the use of fuel cells to improve energy and emissions balances, indicate that this technology can substantially reduce ship emissions, when used with environmentally-friendly fuels.

The IGF Code (International Code of Safety for Ships using Gases or other Low-Flashpoint Fuels), adopted by the IMO in London in 2015, puts in place the preconditions for the use of LNG as a shipping fuel. Now it is a matter of extending the IGF Code to other alternative fuels including methanol and sulphur-free diesel, in order to ensure the urgently-needed wide range of potential fuels for fuel cells.

When comparing fuel cell systems with conventional systems for energy generation on board seagoing vessels (such as engines or gas turbines), it is always important to consider both fuel cell-specific emissions, like carbon dioxide (CO_2) and sulphur dioxide (SO_2), and system-specific emissions including soot particulates (particulate matter – pm), nitrogen oxide (NO_x), carbon monoxide (CO) and hydrocarbons (CxHy). Below is a short overview of the results of the study of a cruise ship and a mega yacht as well as the general trend in emissions regulations in shipping.

FUEL ANALYSIS

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Cruise ship

The example of a cruise ship with conventional energy supply compared to a ship with an integrated fuel cell system illustrates the potential to reduce emissions particularly clearly (see bar chart below).

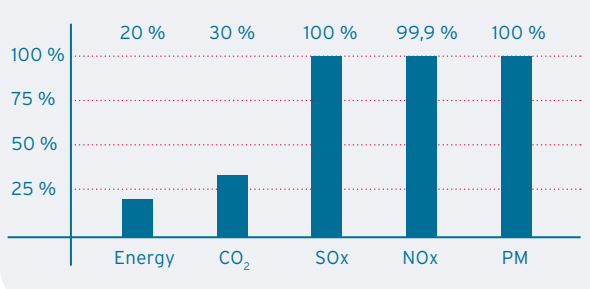
It is assumed in favour of conventional diesel engine systems that through an improved use of waste heat, very high thermal efficiency can be achieved. Even under these conditions remarkable emission reductions can be achieved by substituting HT PEM fuel cell systems. Using methanol as a fuel, CO_2 emissions can be reduced by up to 30 %. All other emissions can be almost completely eliminated locally.

Yacht

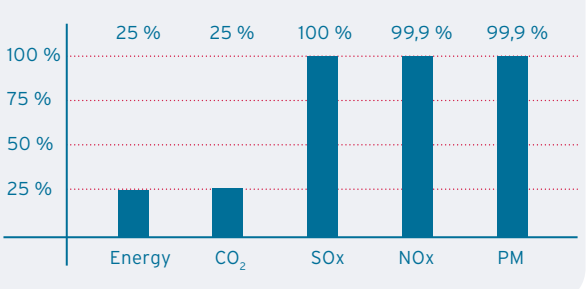
The situation is similar when fuel cell systems are used on yachts (see bar chart below). Assuming that the yacht is not in constant use, as is frequently the case, the yacht was deemed to spend 1,500 h/a at sea. Compared to a conventional diesel system run on marine oil diesel, CO_2 emissions can be reduced by some 25 % if an SOFC fuel cell is used, run on road diesel. All other emissions can be almost completely eliminated.

Quite apart from very low local emissions, another advantage of fuel cells is their high level of efficiency. This is particularly true when they are used in combined heat and power or combined heat, power and cooling systems. They make possible significant reductions in sulphur and nitrogen oxides as well as soot particulates, as compared to the current conventional use of heavy oil or ships' diesel in combustion engines to supply on board electricity.

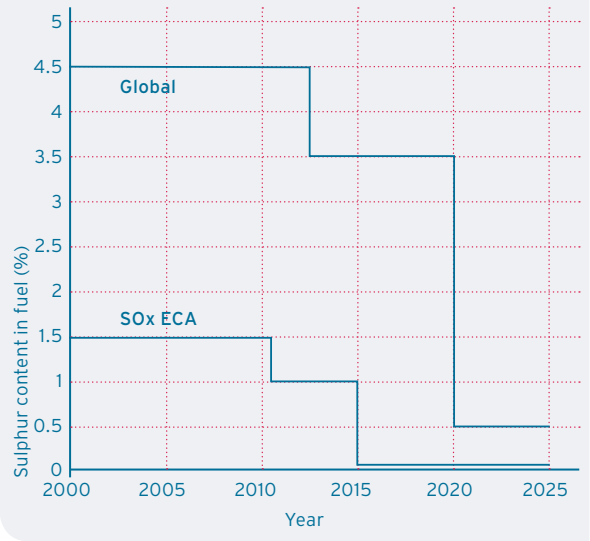
Energy and emission reduction potential of a typical cruise ship



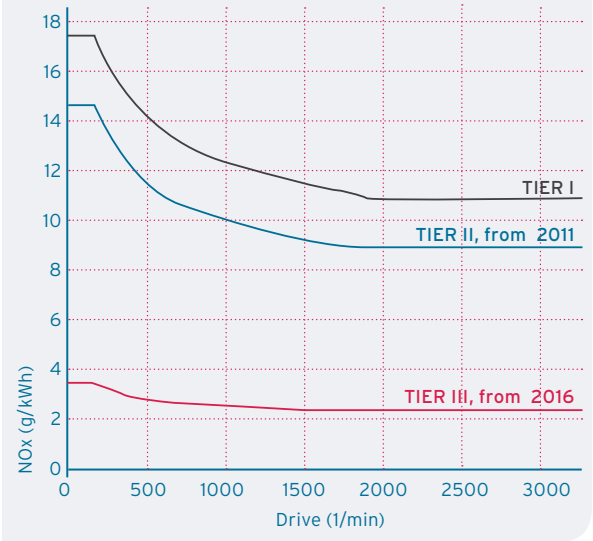
Energy and emission reduction potential of a mega yacht



Thresholds for sulphur in fuel [source: IMO]



Thresholds for nitrogen oxide emissions [source: IMO]



Fuel-related emissions

Fuel-related emissions, primarily CO_2 und SO_2, depend on the fuel composition. The electric work delivered by the system and the system efficiency can be used to calculate the quantities of energy and fuel required and the CO_2 und SO_2 generated.

The sulphur content of fuels has already been regulated by the IMO. In 2010 it was decided to limit the sulphur content of shipping fuels to 1.0 % in so-called "Sulphur Emission Control Areas" (SECAs).

Outside the SECAs, a maximum sulphur content of 3.5 % (35,000 ppm) has been in force since 2012. On 1 January 2015 the maximum permissible sulphur content of shipping fuels used in the North Sea and Baltic Sea as well as in the 200 nautical mile zone off the coasts of the USA and Canada was further reduced to 0.1 %. In 2020 a limit of 0.5 % will be introduced in the EU's 200 nautical mile zone. It is planned to introduce this limit at global level as of 2020 or 2025. The IMO is expected to make a final decision on this in 2018 (see graph above).

System-specific emissions

The system-specific emissions depend on a wide spectrum of factors. One important factor is the efficiency of the conversion and combustion process.

Through open combustion in piston engines and gas turbines, a mix of different pollutants are generated, which are either emitted or neutralised through a complex finishing treatment. In fuel cells, fuel is physically oxidised. The temperatures are well below those needed for open combustion and the simple structure consisting mainly of hydrogen and methanol means that no pollutants are generated. When carbon-based fuels are used, CO_2 emissions do result, but the higher level of efficiency means that emissions are lower than is the case with engines and turbines.

The use of fuel cells thus makes it much easier to comply with new emissions limits, without requiring the complex purification of exhaust gas.

PA-X-ELL PROJECT

The Pa-X-ell project under the leadership of MEYER WERFT, has been testing the use of high temperature PEM fuel cells in a number of different applications. The goal is to achieve long-term decentralised energy generation on passenger ships.

The fuel cell systems developed in the Pa-X-ell project are liquid-cooled HT PEM fuel cells on a modular basis, which use a mix of methanol and water as a fuel. Liquid cooling means that exhaust gases can be used in thermal processes, such as an absorption refrigeration system.

A fuel cell module currently has a maximum electric output of 5 kW and contains all components necessary for operation. Alongside the cell stack itself, the reformer, afterburner, in-process heat exchanger, the DC/DC converter and the controls are all located in the module housing. Six such modules can be integrated in a 19" control cabinet modified with an exhaust shaft as well as fuel and cooling water piping, providing an electrical output of 30 kW. The fuel cell module has been tested under different climatic conditions, to establish the limits of its usability. Results indicate that the systems can be used in the air temperatures and air humidity typical of the maritime environment.

The fuel cells used offer a high level of efficiency across a very large output range. Especially in the partial-load range, they achieve significantly higher efficiency levels than conventional diesel units. As well as developing the fuel cell systems, the project has run simulations of fuel cell integration in existing on board grids. Both stationary and transient processes were examined, in order to identify the influences of fuel cells on the overall system.

A further important aspect in the introduction of this new technology is the economic perspective. An overview of the results can be found in the section entitled "Life cycle costing".

To enable the project to gain experience with the operation of fuel cells, two demonstration units were built over the course of the Pa-X-ell project. The first was part of an onshore demonstration unit. Alongside the fuel cells, an absorption refrigeration system was installed in a 20 foot container, to generate initial practical experience with fuel cells while also testing the interaction with the refrigeration unit. This demonstration unit is located on the premises of MEYER WERFT and will continue to be used for long-term test purposes.

The second fuel cell system was installed on the MS Mariella ferry which operates between Stockholm and Helsinki. Here a 60 kW unit was designed and installed as a prefabricated unit on the sun deck of the ferry. In addition, a methanol tank was installed. It is filled by a tanker truck onshore. This system is also meant for long-term operation, in order to gain experience in the operation of

Composition of a fuel cell with the inside of a module, the module housing and the fuel cell cabinet.

fuel cells on ships. The challenge here is primarily to deal with the constant vibrations and ship movement caused by the ships' engines and sea swell. Both demonstration units will continue to be used beyond Pa-X-ell, so that the latest generations of fuel cell modules can be tested.

The long-term goal of the project partners is to deploy fuel cells in decentralised networks on board passenger ships. Decentralisation increases security, as the breakdown of a single unit has no serious effects on the overall system. Each individual fire zone on a ship can be supplied with power generated

Fuel cell demonstration unit on the premises of MEYER WERFT in Papenburg

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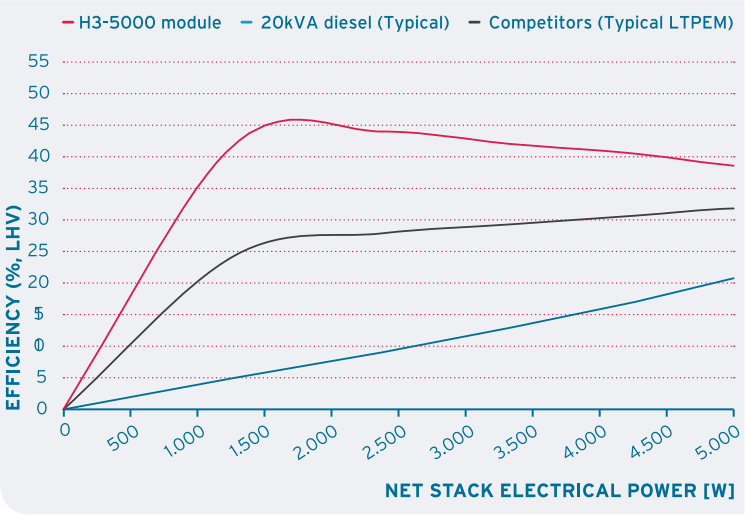
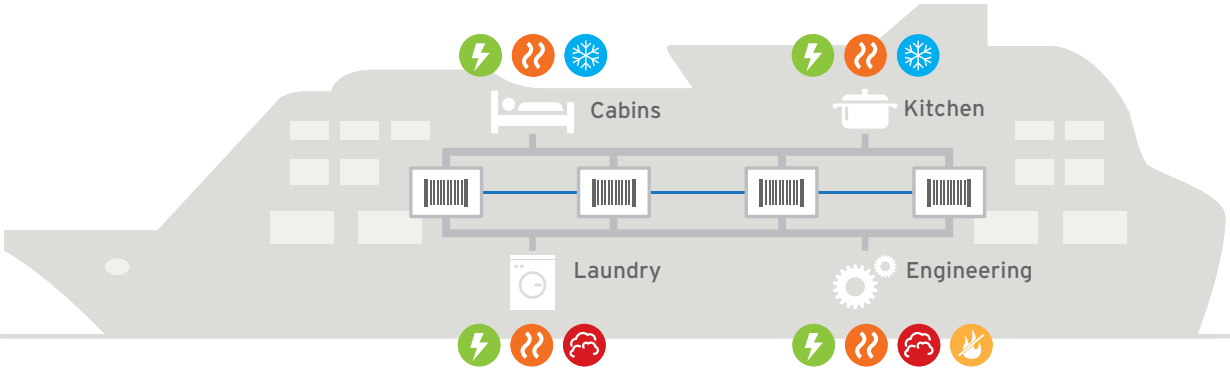
by fuel cells. Aside from the positive safety aspect of energy supply of the hotel area, reduced energy flows will also increase the efficiency of the overall system.

The fuel cell systems developed in Pa-X-ell are technically fairly mature, but the costs in relation to installed output, and the output per module are not yet competitive for large-scale applications. Here continued intensive development work is still needed, embracing module production and higher energy density.



Typical level of efficiency of the Serenergy fuel cell and competing products

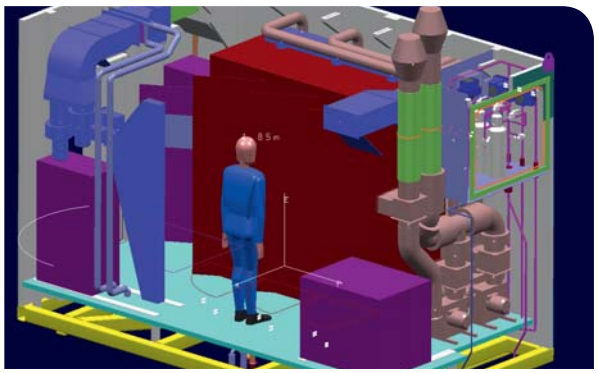
The principle of decentralised network with fuel cells supplying power for hotel operations and conventional combustion engines for ship propulsion



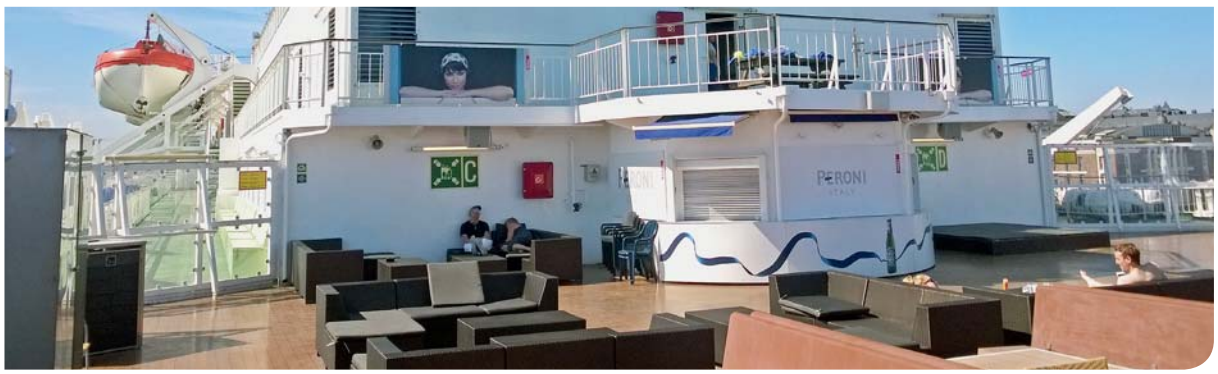
The demonstration project Pa-X-ell is a milestone in the building of passenger vessels. The developments achieved within the scope of Pa-X-ell and the practical implementation of these, as well as the concept of decentralised use of fuel cells, have already chalked up their first successes. We plan to use fuel cells systems of this sort to supply energy on some new MEYER WERFT ships. Now efforts must be redoubled to reduce costs and increase output, and thus make fuel cells a genuine alternative to conventional energy generation solutions.

Bernard Meyer,
Managing Director, MEYER WERFT

3D model of a testing facility (top) and prefabricated nstallation on board the MS Mariella ferry (bottom)

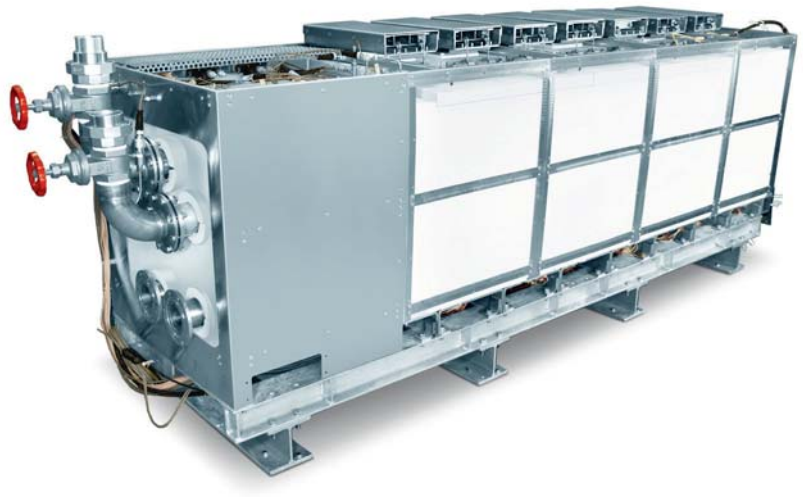


The fuel cell demonstration unit was installed on the sun deck behind the funnel



SCHIBZ PROJECT

The research project SchIBZ [SchiffsIntegration BrennstoffZelle] was initiated to improve the electricity supply on passenger ships and other special vessels.



Fuel cell module for up to 50 kW output

Increasingly strict legal requirements for ship emissions, as well as the wishes of the ship owners and operators that often go beyond these requirements, make it essential to supplement conventional electricity generation using simple diesel engines or to replace it entirely with another concept. A high level of efficiency in electricity generation is an important criterion.

As many of the available options for reducing harmful emissions and noise levels entail complex aggregates and additional commodities, thyssenkrupp Marine Systems GmbH, Hamburg began to explore alternative solutions and to develop the most promising of these within the scope of a project for use in shipbuilding.

Results of internal preliminary studies indicated that fuel cells as an aggregate currently offer the best alternative to an engine, because in principle no harmful emissions are generated and the system does not have rotating masses.

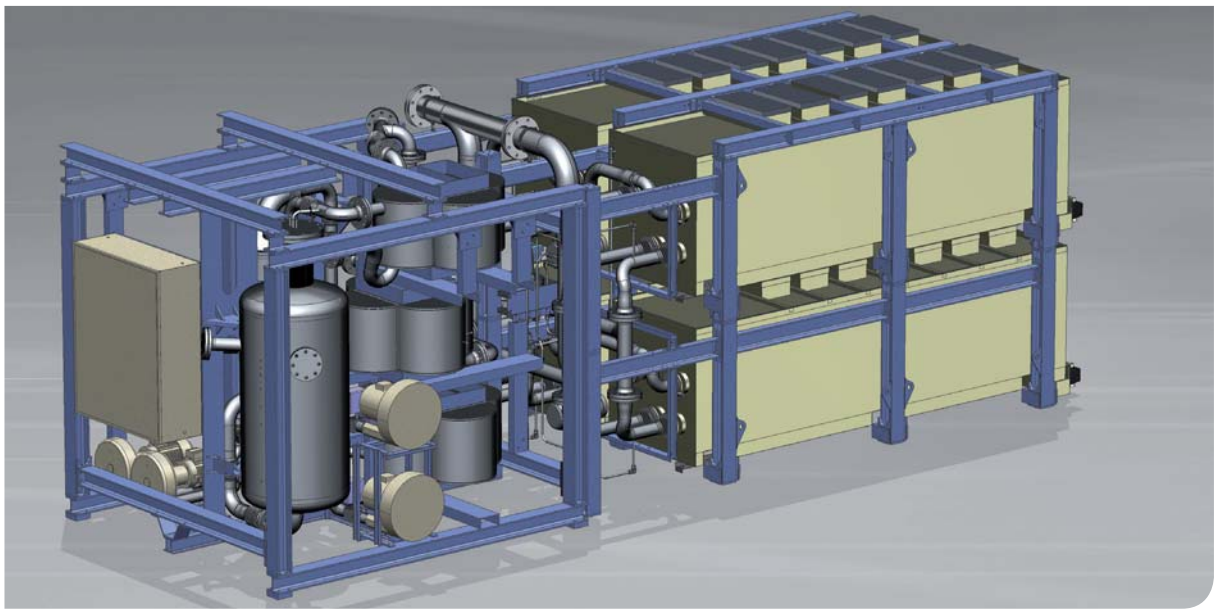
The fuel selected was sulphur-free diesel, which has much in common with the fuels used today in shipping. It has the advantage of being readily available worldwide and having the highest volumetric energy density. The requisite safety measures have been tried and tested. Methanol requires twice as much space and is twice as heavy, while liquid natural gas needs four times as much and hydrogen up to ten times as much.

Although the system selected is not CO_2-free, the higher electric efficiency level cuts CO_2 emissions by around 25 %. If biological or renewable diesel types are used, the overall CO_2 balance can be further improved in future. All other emissions will be completely eliminated.

In order to replace motor-driven generators with more environmentally-friendly fuel cell systems in the long term, thyssenkrupp Marine Systems established a consortium in which five companies and institutions are working on an interdisciplinary basis to develop, manufacture and test a seaworthy aggregate based on solid oxide fuel cells (SOFCs), supplied by sunfire GmbH, Dresden. The unit should be suitable for supplying power for hotel operations on board. In this respect it is scalable both as a unit and in terms of the number of modules per ship, so that the electrical output can be gradually increased up to the megawatt range. The fuel cell aggregate can be installed in different places on board, in order to guarantee a high level of security of electricity supply.

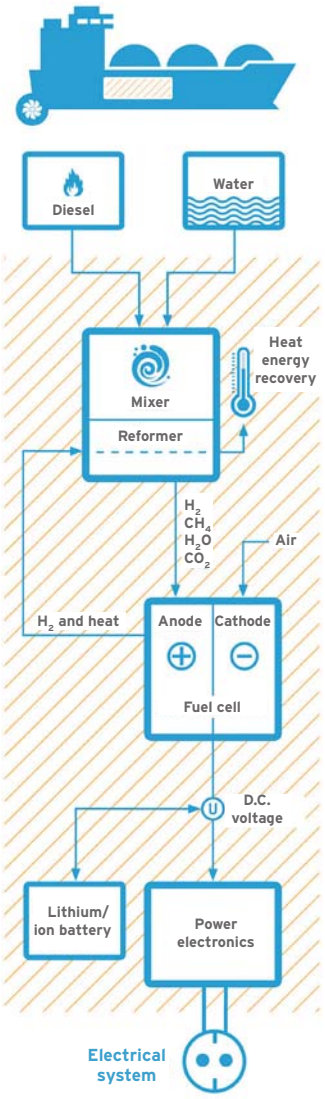
The work on the fuel cell system comprises all stages from the draft and the design of the system and the fuel gas generation to the fuel cell and its power electronics. It also includes the specification of installation requirements, room ventilation and safety concepts. An additional auxiliary unit is an energy buffer, which balances any discrepancies between the consumer grid and fuel cells. A hybrid solution with lithium-ion cells and a super condenser was developed with M&P GmbH, Dresden. It was designed specifically for the subsequent test environments in line with the conditions of the consumer grid. Further fields of work included the development of a system control unit and operational strategies as well as producing a demonstration unit. The steps involved were underpinned by numeric simulations and experimental studies performed by the Oel-Waerme-Institut, Aachen, and the Leibniz University Hannover. The primary document in this regard is the piping and instrument diagram produced by the Leibniz University.

Design of an aggregate with up to 200 kW output



SCHIBZ PROJECT

View of the test unit with the process module in the container



On the basis of this concept, and with the help of real parameters of the individual devices, this was modelled and interconnected in a Matlab/Simulin programme environment to produce an overall system. A thermodynamic exergy analysis, a parameter variation of the diesel model with this model was carried out and evaluated. Based on this, individual devices and the entire system concept were thermodynamically optimised under the given framework conditions. The model is to be validated using experimental data from the system parallel to the pilot operation. With the validated model, different possible load cases as well as control strategies are to be developed.

What is special about the system is that it uses diesel fuel with a sulphur content of 15 ppm as a fuel for the SOFC. With a relatively simple, cost-effective fuel gas process developed by the Oel-Waerme-Institut, an electrical efficiency level of over 50 % can be achieved. If exhaust heat is used a total degree of use of 90 % can be achieved.

The fuel cells and the residual gas burner system work at temperatures of 750 °C, where no thermal nitrogen oxide (NO_x) is produced, so that the aggregate exhibits minimal NO_x emissions despite the use of diesel without exhaust gas treatment.

The emission of sulphur oxide (SO_x) and methane (CH_4) is completely inhibited. In order to check all sub-processes which were individually tested beforehand in terms of the overall system, a demonstration unit with an initial net output of 50 kilowatt was built and tested on shore. This is a containerised system tested by the classification society DNVGL, Hamburg. Parallel to this, a concept is being developed to scale the aggregate output up to 500 kWel.

To prepare for operation at sea, tests were performed in compliance with DNVGL regulations. These involved firstly testing at an angle of 22.5° degrees, as occurs on the open sea, and secondly testing with a predefined vibration spectrum, which simulates stresses through machine vibrations and sea swell. In both tests no failures were noted in the SOFC under operating conditions. From 2017, the demonstration unit will generate between 25 and 50 % of the on board energy supply of the MS Forester, which is owned by the shipping company Braren, Kollmar.

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thyssenkrupp Marine Systems feels an obligation to protect the environment in the design of its products. That is why we launched the SchIBZ project in order to provide shipping with an environmentally sustainable energy supply. The results we have achieved in the project confirm the high efficiency and low pollution level of using diesel in a fuel cell. For long range use, the high energy density of diesel is particularly advantageous. Now that we have proven that our development is sea-worthy we are ready for pilot projects.

Andreas Burmester,
COO thyssenkrupp Marine Systems

Layout of the pilot facility on the MS Forester test platform

RESULTS

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Climate protection standards for shipping, in the form of European law for instance, are becoming increasingly strict. The e4ships lighthouse project is developing two different types of climate-protecting fuel cells (HT PEM and SOFC) and testing these on board ships in order to substantially reduce harmful emissions. Their use will bring about a clear improvement in air quality, primarily in ports and coastal sea areas. Fuel cell technology is thus a major component in addressing the urgent issue of reducing ship emissions. In addition a conversion to low-emission drives and fuels is vital if shipping is to retain the high level of interest, especially in the tourism sector. The changeover to clean and efficient systems is therefore in the best interests of shipyards and shipping companies, which are actively pursing this.

The e4ships project has for the first time successfully demonstrated new technical solutions to reduce emissions through the use of fuel cells on ships. The systems tested offer the possibility of combined heat, power and cooling which makes them particularly efficient. Compared to conventional systems operated with marine diesel or heavy oil, they demonstrated significantly lower noise levels and exhaust emissions. The decentralised and modular approach offers not only a flexible and secure arrangement on board but also considerable advantages through the redundancy of the system (ensuring safe return to port). Parallel to this, common requirements in the establishment of national, European and international regulations, norms and standards were brought to the relevant expert bodies, to pave the way for the use of alternative fuels and fuel cells in international shipping in future. At regular project meetings a platform was put in pace for technical discussions between project partners. Meanwhile joint communication work created a high level of awareness for the lighthouse project in both the political sphere and among the general public.

OUTLOOK

The use of fuel cells brings about a considerable improvement in air quality, which is especially important in ports and coastal sea areas.

The e4ships project is a milestone in the use of climate-friendly fuel cells in maritime applications.

The systems tested in the Pa-X-ell and SchIBZ demonstration projects are still prototypes, which must be further tested and optimised in real operation. Possible research activities include the use of high temperature fuel cells (SOFC and HT PEM) on seagoing ships as well as low temperature fuel cells PEM on inland waterway vessels. Possible fuels are methanol, natural gas, (CNG, LNG), diesel or hydrogen. Apart from implementation on different ship types, it will be a major challenge to derive uniform technical standards for all system variants and performance classes. Planning and preparation are also needed for higher output systems for the future.

The results to date provide a basis for further development. They offer various adaptation options to further develop components, integrate them into an overall system and to prepare for the market launch. Priorities for further research activities also include auxiliary units for large ships with redundant systems as well as further improvement in efficiency. This goes not only for large seagoing ships but also for inland waterway vessels, where the overall drive system is the focus.

Parallel to technical development, regular consultation and coordination with the authorities responsible for the licencing of the use of fuel cells and gaseous fuels, primarily the International Maritime Organization (IMO), is essential if the systems are to be approved for use on board ships. This presupposes intensive dialogue with the coordinators in IMO member states. In Germany this is the Federal Minister of Transport and Digital Infrastructure. For inland waterways, consultation is needed with the Zentralstelle Schiffsuntersuchungskommission/ Schiffseichamt (ZSUK) (Commission of ship inquiry/ standards bureau), with a view to using fuel cells on board inland waterway vessels.

COMMUNICATION

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The e4ships project was presented very successfully at its own conferences at the beginning and at end of the project, and at numerous other events, conferences and trade fairs. The response was enormous.

The project regularly participated in the world's largest shipbuilding fair, the SSM (Shipbuilding, Machinery and Marine Technology) in Hamburg and in the German government's open days. It featured at a status presentation at the Federal Ministry of Transport and Digital Infrastructure, and was presented at the regular National Maritime Conference of the Federal Ministry for Economic Affairs and Energy.

Additionally articles were published in trade publications (including Schiff und Hafen, Hansa, Schiffbau Industrie, Neue Energie) and the project featured in radio reports (NDR, Deutschlandfunk). The production and regular updating of the website, the regular publication and updating of brochures and flyers as well as the production of two films on the project were all elements of the highly-effective PR work.

Final film

Results conference in September 2016

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