MARITIME

Maritime Fuel Cell Applications

Technologies and ongoing developments

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21 February 2018

Content

Introduction

Enhancement of Ship's emissions, efficiency and comfort

- *Fuel option*
  - MGO
  - LNG
  - Other low-flashpoint fuels
- *Energy efficiency*
  - Hull form
  - Machinery improvement
  - Alternative energy converters
- *Logistics and speed*
  - Speed reduction
  - Vessel utilization
  - Alternative Sea routes

Maritime Fuel Cells are promising to enhance

❖ Ship Energy Efficiency

❖ Emissions

❖ Noise & Vibration

Abstract from DNV GL Energy Transition Outlook 2017: Maritime Forecast to 2050

Introduction

Motivation

- Improvement of Ship Energy Efficiency
- Use of alternative fuels
- Reduction of emissions to air
- Reaching insignificant noise and vibration level

Driver

- Environmental regulations and initiatives to
  - Increase efficiency of ship operation
  - Reduce NO_X, SO_X, CO_2 and particle (PM) emissions

Introduction

Fuel Cells for Transportation

- Fuel Cells Systems have been tested for all modes of transport
- Different Fuel Cell types were developed

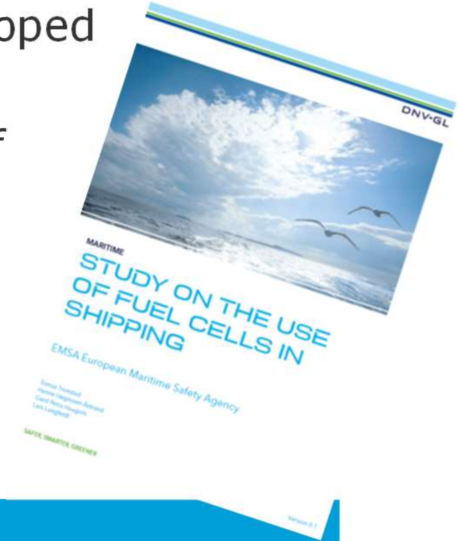
Studies are showing that in terms of*

– Development status

– Efficiency

– Load change behaviour

– Fuel flexibility

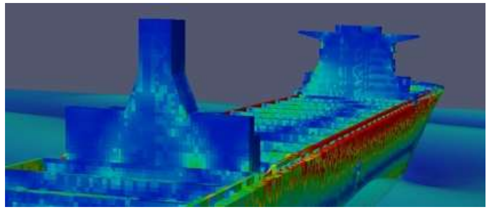


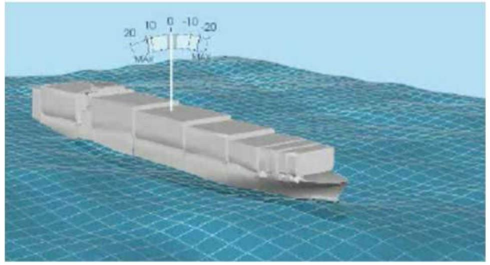
PEMFC and HTFC are most suitable for maritime applications

*recently: EMSA Study on the use of Fuel Cells in Shipping

Introduction

Challenges for FC in shipping





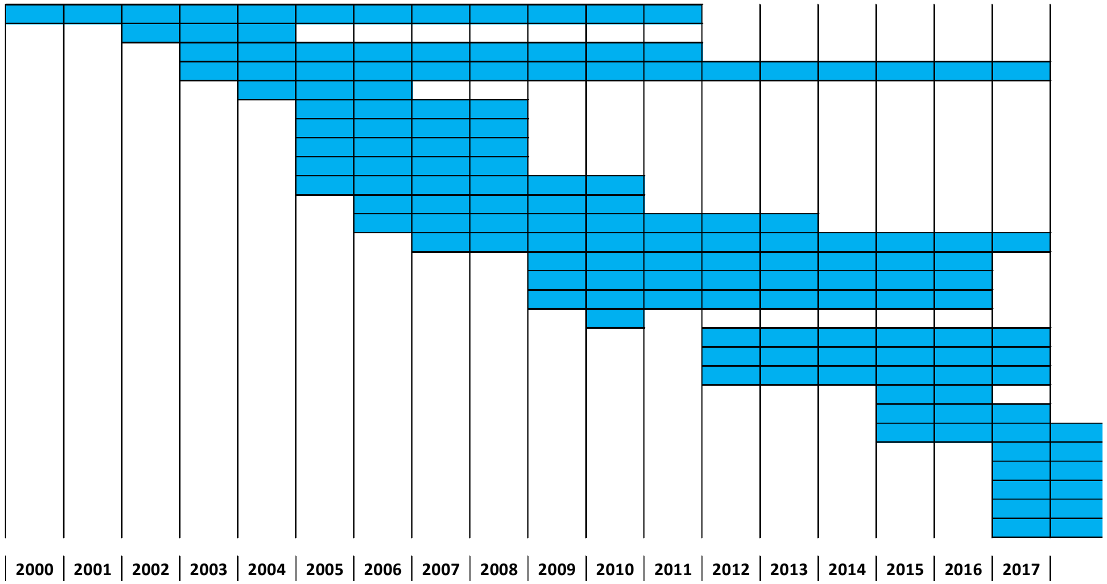
- Maritime Environment
  - ship motions
  - vibrations
  - humidity till 60 %
  - salty air
  - temperatures:
    - Full load capacity and efficiency till 45 °C
    - Full response for electrical equipment till 55°C
- Design requirements
  - testing criteria (add-ons to land-based application)
  - reliability and availability
  - fuel storage, distribution, processing onboard

Introduction

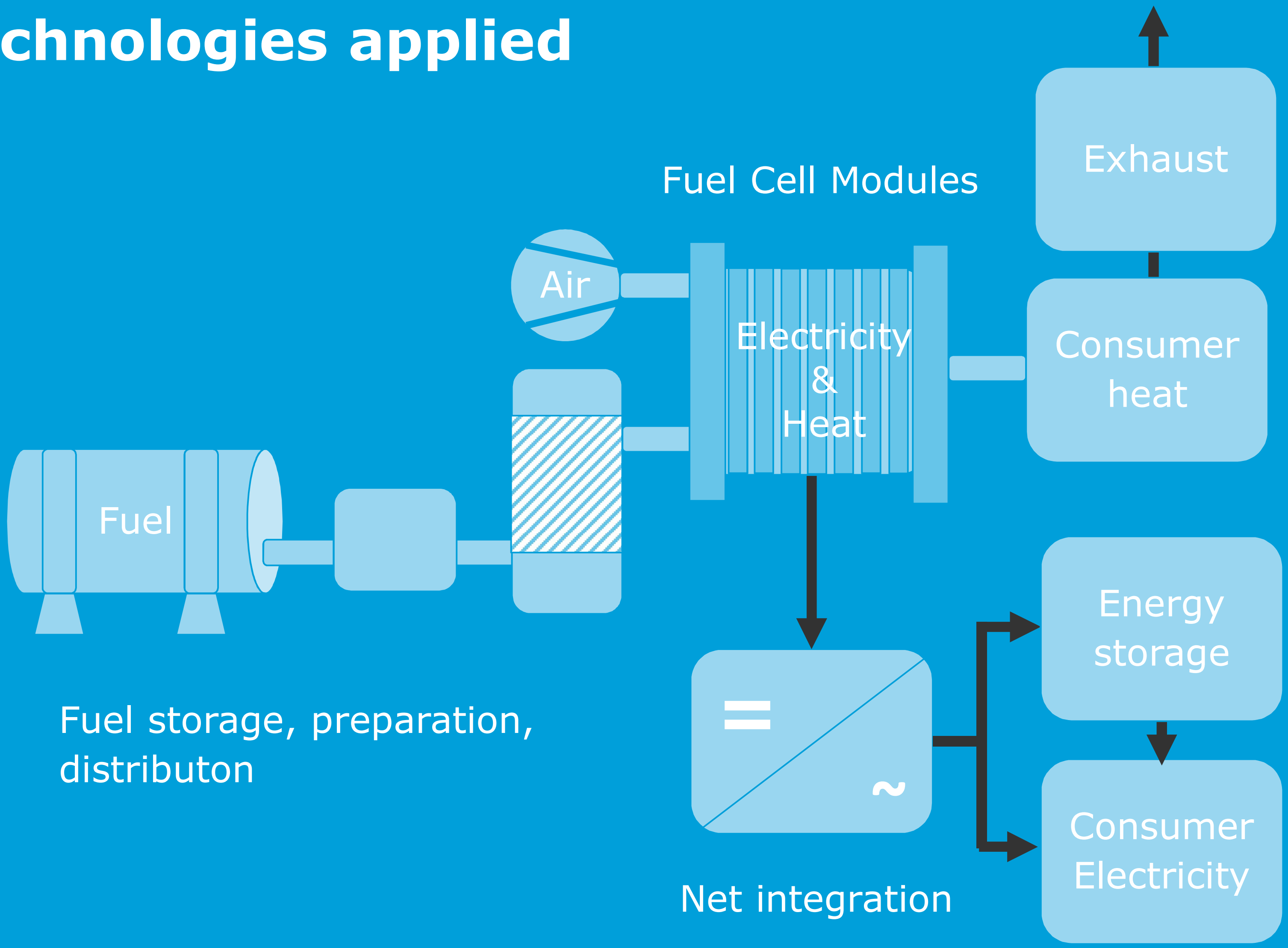
Developments

- Start with first maritime FC applications in the early 2000
- Mostly based on European and US development programmes
- Technology readiness of FC for maritime application has been proven
- Recent development projects focusing on a common rule frame work for maritime Fuel Cells

Maritime Fuel Cell Project Time table



Technologies applied



Technologies applied

Suitable Fuel Cell Types

PEMFC

- High development status
- Dynamic load profiles possible

MCFC, SOFC (HT-FC)

- High efficiency
- Low requirements on fuel and air quality (in comparison to PEMFC)
- High temperature exhaust air at 650°C to 1,000°C enables combination with CHP processes

Fuel cell type	Temperature (°C)	Electric efficiency (%)
Proton Exchange Membrane (PEM)	30-100	> 50
High Temperature PEM (HT-PEM)	160-200	~45
Molten Carbonate (MCFC)	~650	> 50
Solid Oxide (SOFC)	500-1100	> 50

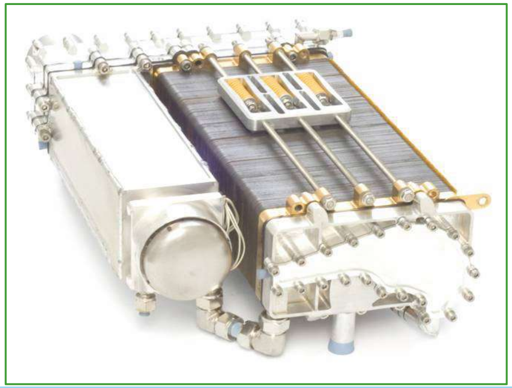
Figures derived from project results including losses depending on fuel to be used; increase of efficiency expected due to further development

Technologies applied

PEMFC demonstrations projects

- Submarines, yachts, ferries and boats have been fitted with PEM fuel cells running on hydrogen
- Practical examples are
  - 100 kW installation on the inland passenger vessel *ALSTERWASSER* in Hamburg, 2006-2013
  - 60 kW installation on the inland passenger vessel *NEMO H2* in Amsterdam, 2012
  - 60 kW HT-PEM installation on the passenger ferry MS MARIELLA (***Pa-X-ell project***), 2016
  - 35 kW installation on the inland passenger vessel MS INNOGY in Essen, 2017

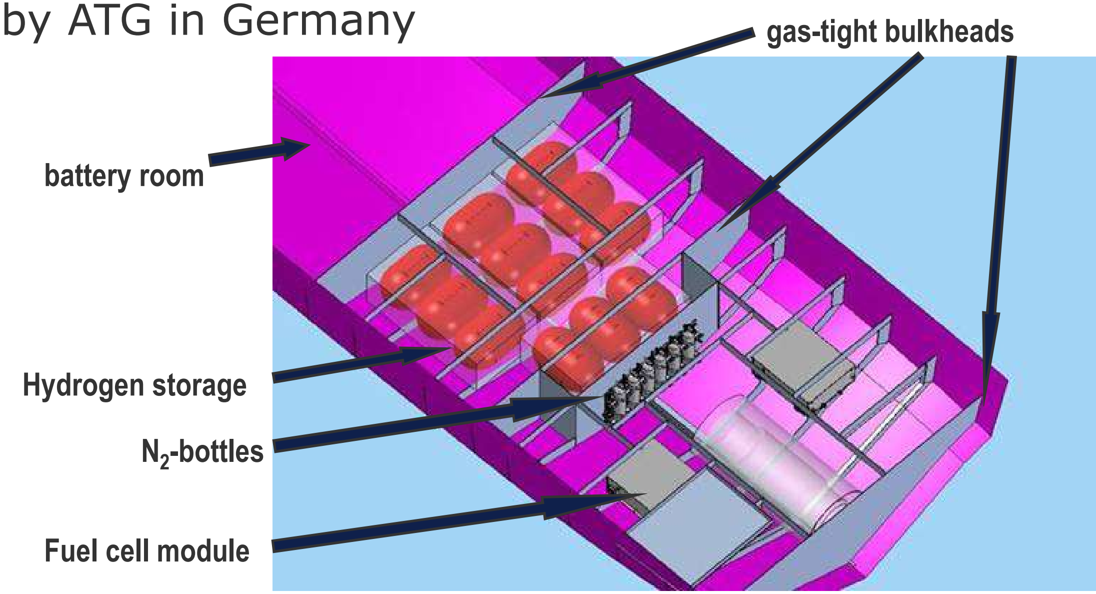
Fuels used in this projects: Hydrogen, Methanol

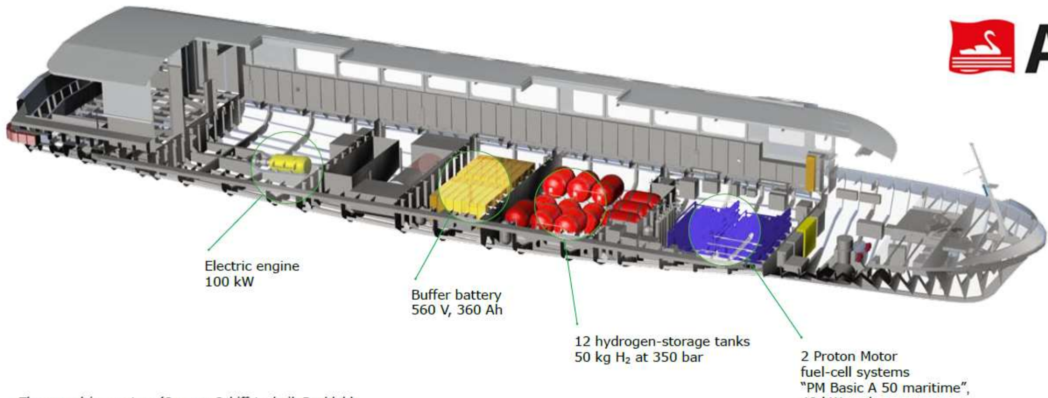


Technologies applied

MS ALSTERWASSER – operated by ATG in Germany

- 100 Passengers
- 25,46m x 5,36 m (L,W)
- 100 kW propulsion motor
- 2 Fuel Cell systems from Proton Motor, each 50 kW
- 360 Ah lead-gel batteries
- Hydrogen storage tanks, 350 bar, 50 kg
- Separation of gas storage room, Fuel Cell space and battery space
- Duration: 2006 - 2013

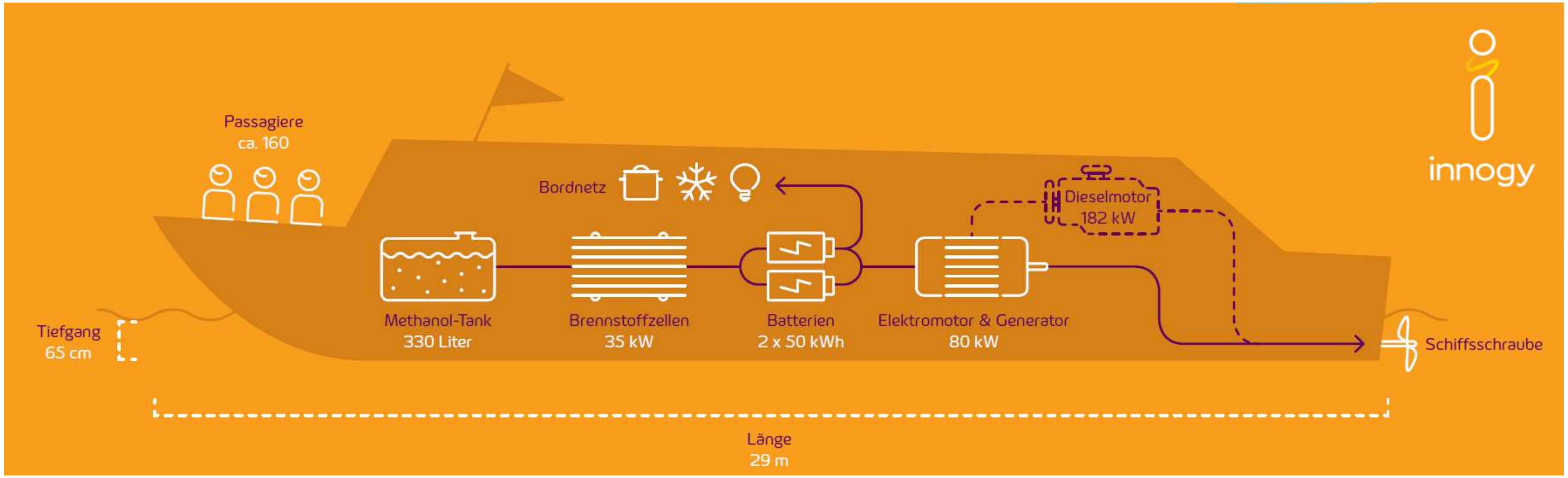




The propulsion system (Source: Schiffstechnik Buchloh)

Technologies applied

MS INNOGY – operated by innogy in Germany started 2017



Technologies applied

MS MARIELLA – operated by Viking Line between Helsinki and Stockholm

- Passenger ferry for 2,500 Pax
- Fuel Cell Demonstrator of the ***Pa-X-ell project*** led by the Meyer Yard
- HT-PEM Fuel Cell plus bunkering and storage of pure methanol
- 3 racks from serenergy with overall electric power output of 60kW fed into ship grid
- Methanol tank Capacity: 6m³ (Double walled type)

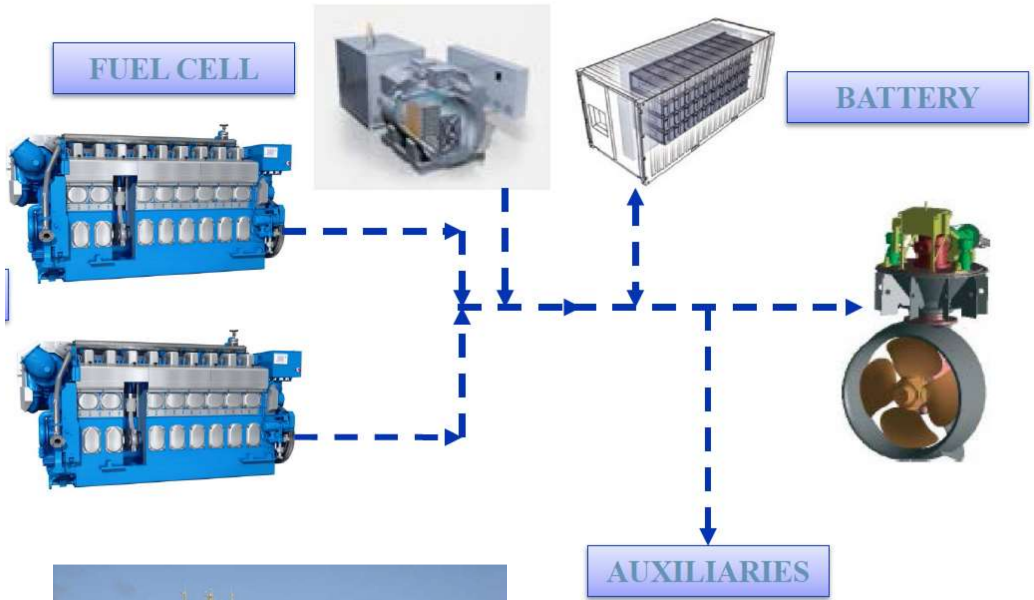
MCFC and SOFC demonstration projects

- Several commercial vessels have been fitted with Molten Carbonate and Solid Oxide fuel cells running on Methanol / Natural Gas
- Practical examples are:
  - A methanol-fuelled SOFC plant of 20 kW tested on board of the car carrier Undine, 2006
  - The LNG fuelled MCFC plant of 330 kW MCFC installed on board of the *Viking Lady* (***FellowShip project***), 2003-2011
  - A SOFC installation to be tested onboard of a commercial vessel during the ***SchIBZ project***

Technologies applied

VIKING LADY – operated by Eidesvik Shipping

- Gas-electric OSV with FC and Battery
- Operations of a 330KW MCFC on board of Viking Lady
- Li-Ion battery system with 0.5 MWh capacity
- Test of stand-alone fuel cell power pack integrated in a ship
- Operating successfully for 18,500 hours

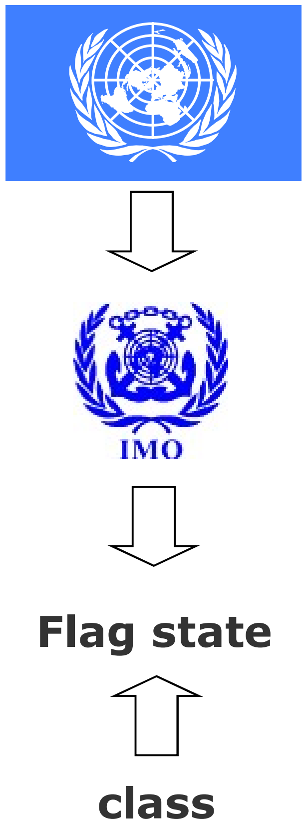


Rules & Regulations

International maritime legislation

- **IMO**: International Maritime Organization
- Established in 1948 as a UN agency
- Main purposes:
  - Prevent pollution from ships
  - Enhance safety of shipping and ships
- Main conventions:
  - **MARPOL** (marine pollution) from 1973 / 1978 → Environmental protection
  - **SOLAS** (Safety of Life at Sea) from 1974 → ships safety

➢ **Classification societies are approving in accordance to own rules and regulations on behalf of the flag state**



Role of classifiaction societies

Survey of ships during the whole lifetime based on own class rules and guidelines

Newbuildings

- Drawing approval
- Construction supervision
- Approval

Fleet in service

- Periodical survey

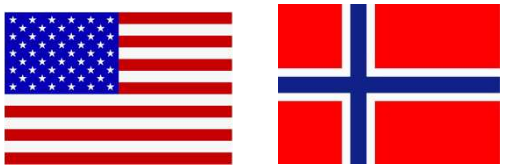
Class societies does have their own rules & guidelines

Overview Rules and Regulations

International Maritime Regulations

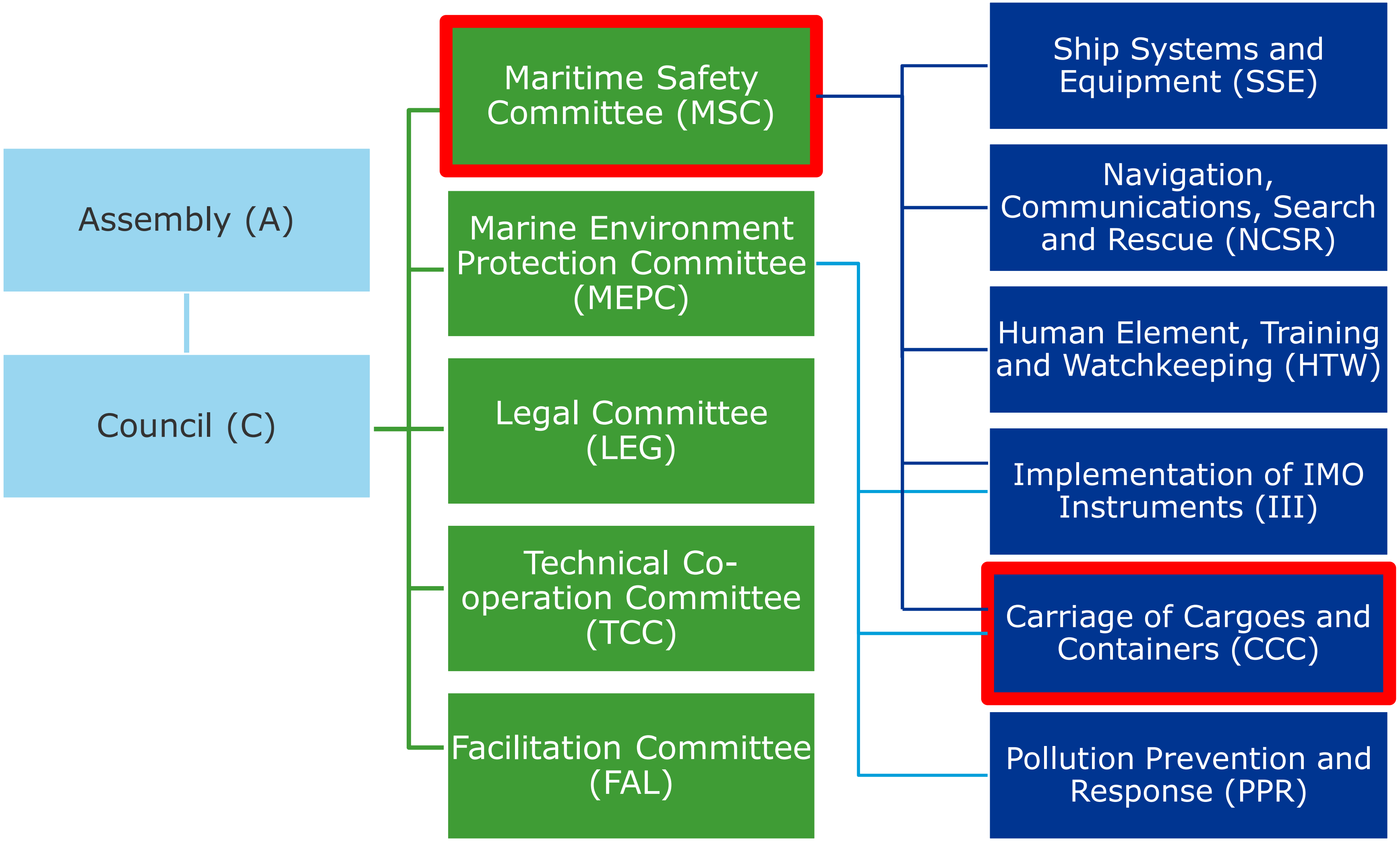
Class Rules

International Standards

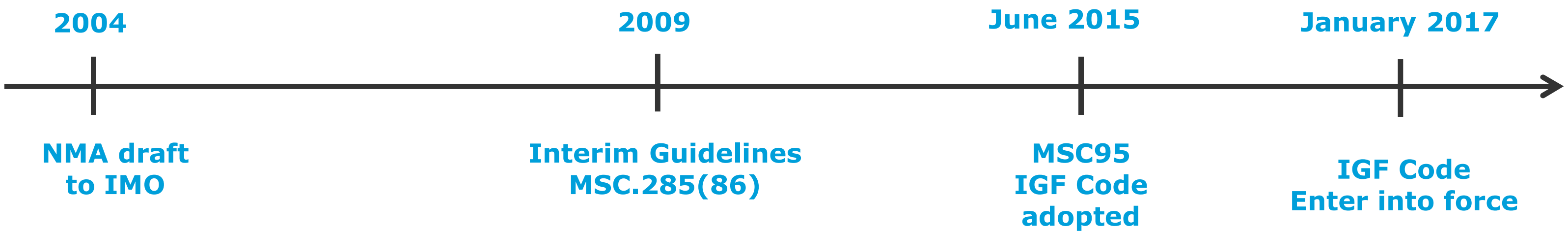


National Regulations

Committees and Sub-committees of IMO



Current Status – Statutory requirements



- Main driver: New rules for gas as ship fuel (initiated by the Norwegian Maritime Authority (NMA) in 2004)
- Interim guidelines for natural gas-fuelled ships, Voluntary guidelines MSC.285(86) from 2009.
- **IGF Code -** Code of Safety for Ships using Gases or other Low flashpoint Fuels, adopted by IMO June 2015, replaced the interim guidelines by January 2017
- The IGF Code will provide mandatory provisions for low-flashpoint fuels and fuel cells
- Currently natural gas regulated. General provisions for low flashpoint fuels defined. The use of other low flashpoint fuels including **hydrogen can be approved based on alternative design**.

Current Status - Alternative Design

Currently, for Fuel Cells and Hydrogen

- IGF codes provides the possibility for alternative design process
- The *equivalence* of the alternative design shall be demonstrated by a ***risk-based approach*** as specified in SOLAS regulation II-1/55 and approved by the Administration
- The "Guidelines on Alternative Design and Arrangements for SOLAS Chapters II-1 and III (MSC.1 / Circ. 1212)" providing guidance to perform the ***Alternative Design Process***

Preliminary Analysis

- Identification of rule deviations
- Hazard Identification
- Scenarios, methods and assumptions for quantification

Quantitative Analysis

- Quantification of selected scenarios
- Comparison to conventional design

Report of Assessment

- Documentation
- Presentation to flag

Current Status – Class Rules

Most of the maritime fuel cell process chain covered by Class rules and recommended practices

- **Approval of Fuel Cell installation acc. DNV GL class rules**
  - Pt.6 Ch.2 Sec.3 FUEL CELL INSTALLATION – FC installations
  - Environmental tests acc. DNV GL CG 0339 Sec.3
    - Vibration tests
    - Inclination test
    - Salt mist test
    - Temperature condition test

Additional requirements to be considered acc. to e.g.

- IEC 62282-3-100 Stationary fuel cell power systems- Safety
- IEC 62282-2 Fuel cell modules
- Risk Assessment

Ongoing Developments

Ongoing developments

- **e4Ships** – German funded Lighthouse project for maritime Fuel Cell application
  - Phase 1: 2009 – 2017
  - Phase 2: 2017 - 2021
- **Aim** – Development of maritime Fuel Cell systems capable for serial production. Provide input for Rule development (e.g. IGF Code)
- Developments are in line with the objectives of the German *"mobility and fuel strategy"*:
  - Introduction of *alternative and regenerative fuels*
  - Development of *innovative power technologies*
  - Aiming a big share of Hydrogen and Fuel Cell application for all modes of transport in a long-term view

e4ships
Brennstoffzellen im maritimen Einsatz

A project of

nip
Nationales Innovationsprogramm Wasserstoff- und Brennstoffzellentechnologie

Funded by

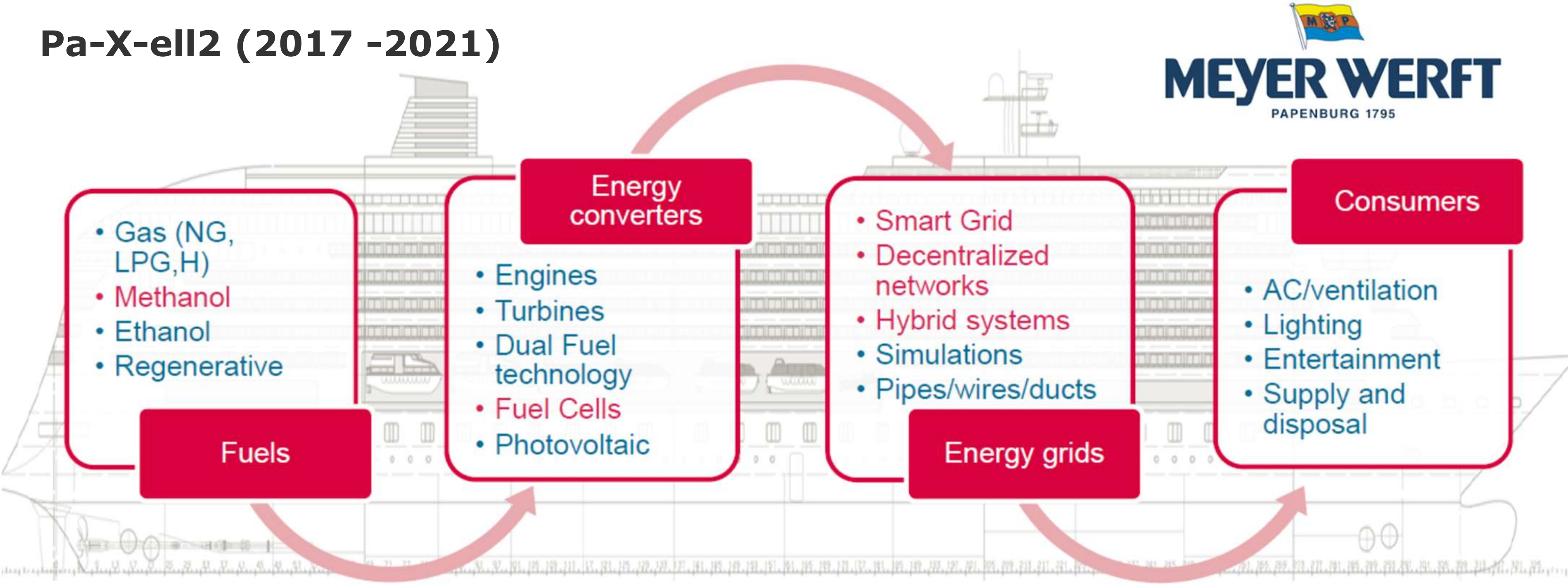
Bundesministerium für Verkehr und digitale Infrastruktur

Coordinated by

NOW
Nationale Organisation Wasserstoff- und Brennstoffzellentechnologie

Ongoing developments

Pa-X-ell2 (2017 -2021)

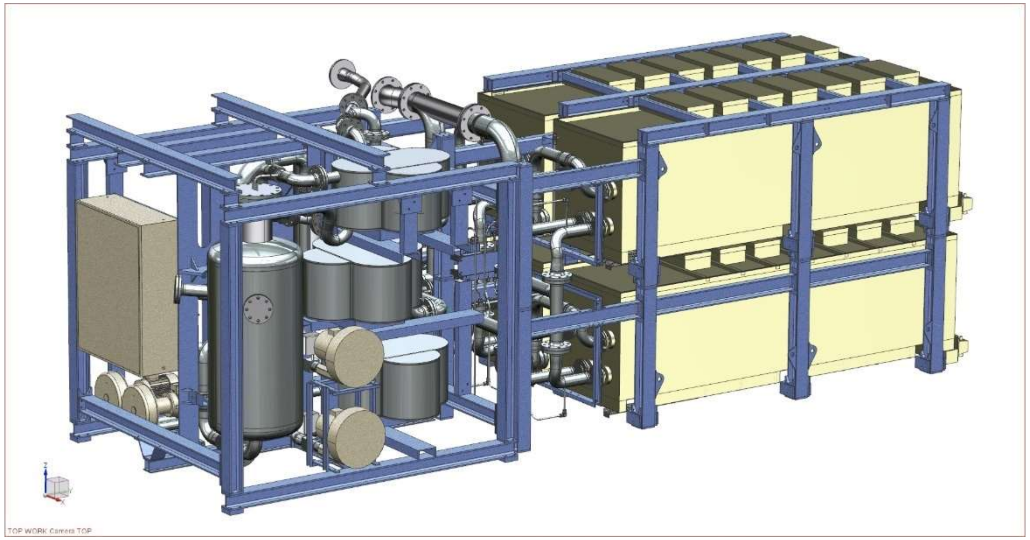


- Further development / optimization of FC-power system (market readiness)
  - Increase performance and lifetime (>20,000hs)
  - Development of NG reformer
- Long term testing on board MS MARIELLA
- Development decentralized energy network and hybrid system

Ongoing Developments

SchIBZ2 (2017 -2021)

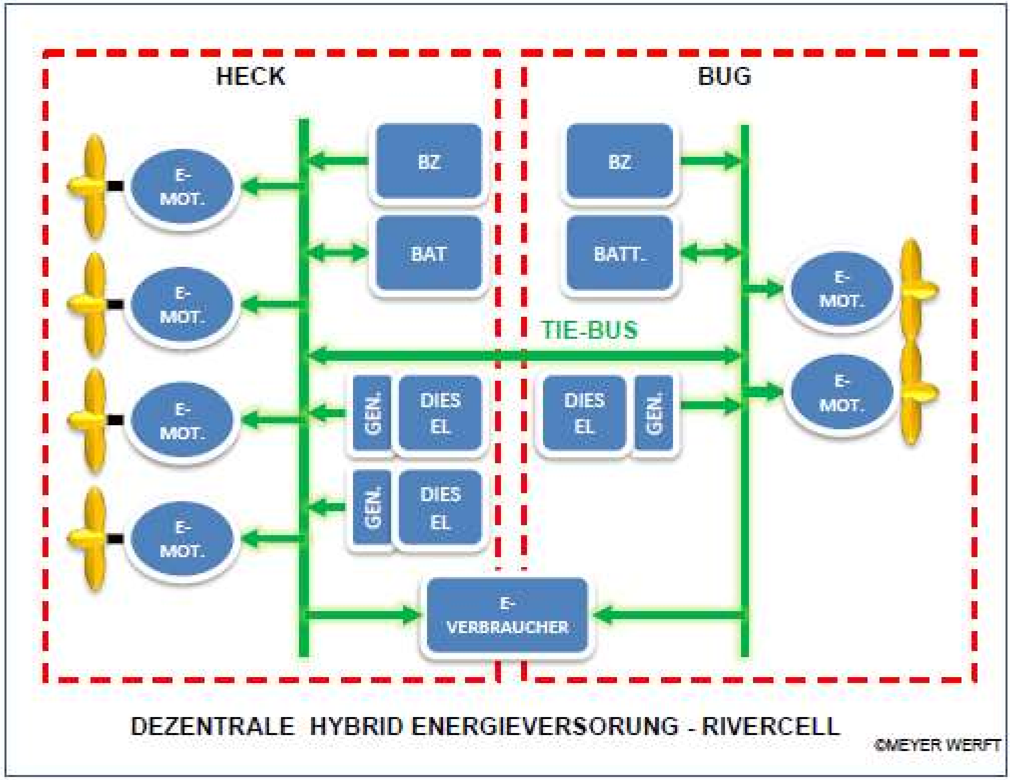
- Final testing of diesel reforming in combination wit a SOFC system
- Operation onboard MS FORESTER until end-of-life
- Supply of 25 to 50% of the power demand
- Buffering of load fluctuations
- Addition of heat recovery
- Enhancement for distributed networks
- Integration with DC-grid
- Development of NG reformer

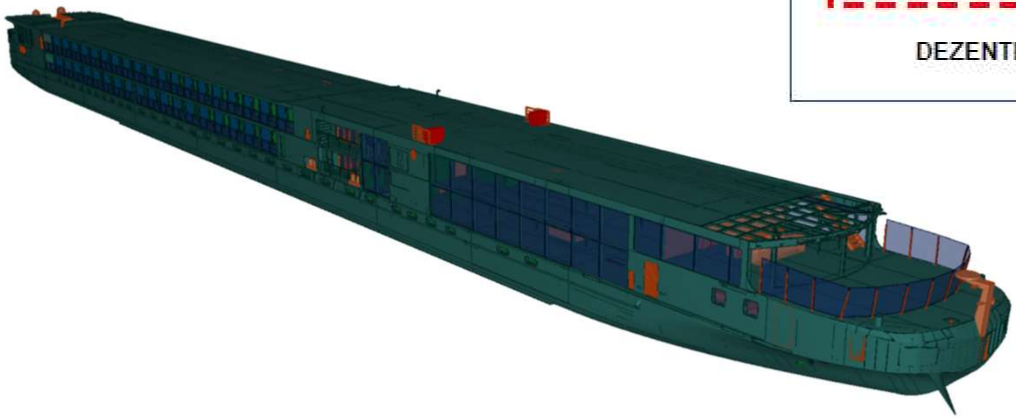


Ongoing developments

RiverCell2 (2017 -2021)

- Final design for HT-PEM system, 240 kW_{el}
- Methanol as fuel
- Detail-design of River cruiser demonstrator
- Construction of Demonstrator until 2020
- Testing until 2022





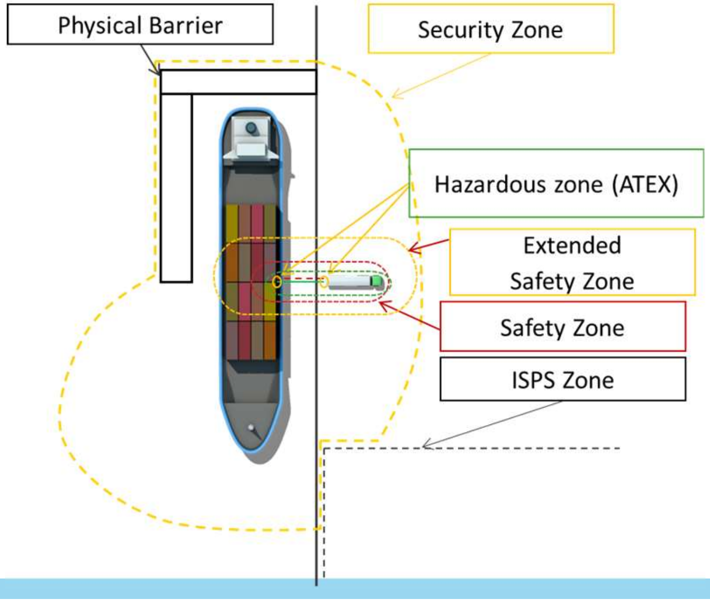
MEYER WERFT
PAPENBURG 1795

Ongoing developments

Fuel Bunkering

- Requirements for Natural Gas only (ISO 20519)
- Definition of Safety Zone and Security Zone
- Suitable standards for equipment and processes



DNV·GL

Summary & outlook

Summary

- Technology readiness of FC for maritime application has been proven
- Studies are showing that PEM FC and HT-FC systems are most suitable for maritime applications
- Maritime applications with up to 330 kW are already tested and a number of FC-vessel are still in operations
- Different fuels have been applied: Diesel, LNG, Methanol and Hydrogen
- Fuel Cells can be approved by the given rule framework (IGF-Code); prescriptive international requirements for alternative fuels and fuel cells are still in development
- Technology and rule development are driven by ongoing projects as e.g. the lighthouse project e4ships nip Brennstoffzellen im maritimen Einsatz

Outlook Rules, Regulations and Guidelines

IGF Code:

- use of fuel cells - use of other low flashpoint fuels than LNG/CNG - bunkering of gaseous H_2, other low flashpoint fuels and LH_2	Further development of IGF code needed. Detailed safety studies. Use existing standards for non-maritime applications as input.

Bunkering:

Rules for bunkering of liquid hydrogen	Review of applicable land based standards. Risk studies and a qualification process to develop rules and bunkering procedures.
Gaseous hydrogen	Review of applicable land based standards. Risk studies and a qualification process to develop bunkering procedures.
Low Flashpoint Liquids	Bunkering procedures for LFL's Safety zones for gas vapour from tanks

On-board storage:

Storage of compressed hydrogen	Qualification of pressure tanks for maritime use with compressed hydrogen gas. Safety studies considering hydrogen pressure tanks and requirements for safe solutions. Development of provisions for possible high pressure storage technologies in enclosed areas.
Storage of liquid hydrogen	Possible storage related failure modes need to be understood, and land based solutions adjusted if necessary for safe application.

Fuel cell System:

Safe handling of hydrogen releases	Review of and update of fuel cell rules and regulations. Risk studies to improve understanding of possible safety critical scenarios including fire and explosion to recommend risk controlling measures.
Ventilation requirements	The fuel specific properties must be considered. Relevant and realistic hydrogen dispersion simulations needed to evaluate and/or update ventilation requirements.
New arrangement designs	Need for improved understanding of system design issues, new technology challenge existing regulations
Piping to fuel cell system	Knowledge and safety assessments needed to identify needs to adjust LNG requirements for the use of LH.
Reforming of primary fuel	Reformer safety issues should be explored and documented

Ship life phases:

Best practices/Codes for hydrogen, LFL fuels and fuel cell installations	Procedures should be developed for commissioning, docking, maintenance to reflect the properties of hydrogen and other LFL fuels.

Fuel specific:

Hydrogen	Comprehensive safety studies considering hydrogen specific properties, behaviour and conditions needed for the use of hydrogen in shipping applications

Outlook technology development

Short term view (next 5 years)

- Development of proven maritime FC systems ready for mass production
- Reach Fuel Cell system lifetimes > 20,000h
- Decrease of dimensions and weights
- Reduction of investment costs
  - Comparable with diesel engines at 400 $/kW, and the lifetime costs of the installation must be compared (investments and operation).
  - Fuel Cell system prices by 5,000 $/kW
  - A target of 1,500 $/kW has frequently been used
- Development of Natural Gas – fuelled FC systems for maritime use
- Development of DC board nets

Outlook New buildings

Cruise shipping industry

- Increasing interest for Fuel Cell applications
- Several cruise shipping lines announced fuel cell developments for New buildings
  - AIDA cruises
  - Royal Caribbean Cruises
  - Viking Cruises
- For the next 5 years FC test installations from 100 kW up to full power supply with more than 20 MW are planned

More on Fuel Cells in Shipping

- e4ships lighthouse project for the development of maritime fuel cell applications
- http://www.e4ships.de/

- EMSA: Study on the use of fuel cells in shipping
- http://emsa.europa.eu/emsa-documents/latest/item/2921-emsa-study-on-the-use-of-fuel-cells-in-shipping.html

“water will one day be employed as fuel, that hydrogen and oxygen which constitute it, used singly or together, will furnish an inexhaustible source of heat and light, of an intensity of which coal is not capable”

Jule Verne, the mysterious island, 1874

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