Hydrogen and Fuel Cells in Ports and Shipping Workshop

The Path to Hydrogen Shipping

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CALIFORNIA HYDROGEN BUSINESS COUNCIL

Hydrogen Means Business in California!
Our vision: global impact for a safe and sustainable future
Global reach – local competence

150+ years
100+ countries
100,000+ customers
12,500 employees
Industry consolidation
1600 employees and 75 offices in North America
Agenda

1. Intro - Motivation Drivers
2. Technology overview
3. Regulation update
4. Maritime Fuel Cell Development /Projects
Introduction

Motivation

- Improvement of Ship Energy Efficiency
- 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
Enhancement of Ship’s emissions, efficiency and comfort

- **Fuel option**
  - HFO + scrubber
  - 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
Towards zero emissions in shipping

**HYBRID**
- “Vision of the Fjords” – The ship of the year 2016 – Flom-Gudvangen
- Diesel hybrid 2 * 150 kW el- engines, 600 kWh batteries
- Fastest ever - 14 months from contract to delivery 18.july 2016

**BATTERIES**
- “Future of the Fjords”
- 100% electric 2 * 450 kW el- engines, 1.8 MWh batteries
- Delivery 1.april 2018

**HYDROGEN – FUEL CELLS**
- Next generation
- Increased range
- Reduced weight possible
- More flexible charging/bunkering
Technology Overview

Complexity of Fuel Cell SYSTEMS

Fuel Storage

Fuel Processing (Reformation)

Air / O₂

Hydrogen

Fuel Cell

Water Heat

Exhaust

Consumer Heat

Battery

H₂ Storage

Inverter

Consumer Electricity

To be integrated onboard
Technology overview - Fuel Cells types

<table>
<thead>
<tr>
<th>Fuel Cells types</th>
<th>Maturity and Relevance</th>
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<tbody>
<tr>
<td>Electro-galvanic fuel cell (EgFC)</td>
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<td>Enzymatic Biofuel Cells (EnzFC)</td>
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<td>Magnesium-Air Fuel Cell (Mg-AFC)</td>
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<td>Metal hydride fuel cell (MHFC)</td>
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<td>Protonic ceramic fuel cell (PCFC)</td>
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<td>Microbial fuel cell (MFC)</td>
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<td>Alkaline fuel cell (AFC)</td>
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<td>Direct borohydride fuel cell (DBFC)</td>
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<td>Direct carbon fuel cell (DCFC)</td>
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<td>Direct formic acid fuel cell (DFAFC)</td>
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<td>Molten carbonate fuel cell (MCFC)</td>
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<td>Phosphoric acid fuel cell (PAFC)</td>
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<td>Solid oxide fuel cell (SOFC)</td>
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<td>PEMFC</td>
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<td>High Temperature PEM</td>
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<td>Reformed methanol FC (R-MFC)</td>
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<td>Regenerative fuel cell (ReqFC)</td>
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<td>RFC – Redox</td>
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<td>Solid acid fuel cell (SAFC)</td>
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<td>Upflow microbial fuel cell (UMFC)</td>
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<td>Zinc-air battery</td>
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<tr>
<td>Electro-galvanic fuel cell (EgFC)</td>
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<tr>
<td>Molten Carbonate FC</td>
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<td>Phosphoric Acid FC</td>
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<tr>
<td>HT PEM fuel cell</td>
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<tr>
<td>Alkaline fuel cell</td>
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<tr>
<td>PEM fuel cell</td>
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<tr>
<td>Direct Methanol FC</td>
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<tr>
<td>Safety aspects</td>
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<td>Physical size</td>
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<td>Flexibility towards type of fuel</td>
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<td>Sensitivity for fuel impurities</td>
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Tolerance for cycling | Lifetime
Efficiency | Emissions
Relative cost | Modular power levels (kW)
Maritime FC- Developments

- Start with first maritime FC applications in the early 2000
- Mostly based on European and US development programmes
- Technology readiness was proven: SOFC and PEMFC Technology are most promising for maritime
- Recent development projects focusing on a common rule frame work for maritime Fuel Cells
Regulation overview - status

Requirements for on-board energy generation systems

Fuel specific requirements

Maritime Fuel Cell Systems

IGF code entered into force Jan. 1st 2017

Contains detail requirements for natural gas as fuel only, and internal combustion engines, boilers and gas turbines

Work started on technical provisions for methyl-/ethyl- alcohols as fuel and fuel cells

Alternative Design Approach

Most classification societies have established Rules covering fuel cells and to some extent low flashpoint liquids
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
Regulation overview - DNVGL Fuel Cell Rules

- DNVGL Rules for Classification – Ships
  - Part 6 Chapter 2 Section 3 – **Fuel Cell Installations – FC**
  - The Rules offer two class notations:
    - **FC(Power)**
      - Given to ships that fulfils design requirements in the Rules, where the FCs are used for essential-, important- or emergency services.
    - **FC(Safety)**
      - Given to ships that fulfils the environmental- and safety requirements in the Rules, where the FCs are not used for essential-, important- or emergency services.
Maritime Fuel Cell Product Certification/Type Approval – under development

- DNVGL has initiated the development of a class program CP for Fuel Cell Power Installations, describing the procedures and technical requirements for the approval and certification of such systems (similar to the DNV GL CP-0418 for Lithium Batteries)

- Technical basis will be e.g. the draft of the IGF-Code for fuel cells, the DNVGL CG-0339 'Environmental test specification for electrical, electronic and programmable equipment and systems'

- Since the technical requirements for fuel cell power installations are equivalent for case-by-case or type approval (only the procedure is different) and due to the very different kinds of fuel cells (PEM, HTPEM, HTFC etc.) the procedures and the technical requirements for approval and certification (CbC or TA) of such systems will be developed together with manufacturer and class until the above mentioned Class Program is available.
Maritime FC- Noteable Projects

<table>
<thead>
<tr>
<th>Maritime FC- Noteable Projects</th>
<th>FellowSHIP</th>
<th>320 kW MCFC system for auxiliary power of Offshore Supply Vessel</th>
<th>Eidesvik Offshore, Wärtsilä, DNV</th>
<th>2003-2011</th>
<th>MCFC</th>
<th>320 kW</th>
<th>LNG</th>
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<tbody>
<tr>
<td>ZemShip - Alsterwasser</td>
<td>100 kW PEMFC system developed and tested onboard of a small passenger ship in the area of Alster in Hamburg, Germany</td>
<td>Proton Motors, GL, Alster Touristik GmbH, Linde Group etc.</td>
<td>2006-2013</td>
<td>PEM</td>
<td>96 kW</td>
<td>Hydrogen</td>
<td></td>
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<tr>
<td>E4Ships - SchiBZ MS Forester</td>
<td>100 kW containerized SOFC system developed and tested for the auxiliary power supply of commercial ships. Scalable up to 500 kW units.</td>
<td>Thyssen Krupp Marine Systems, DNV GL, Leibniz University Hannover, OWI, Reeder Röd Braren, Sunfire</td>
<td>Phase 1: 2009-2017, Phase 2: 2017-2022</td>
<td>SOFC</td>
<td>100 kW</td>
<td>Diesel</td>
<td></td>
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<tr>
<td>E4Ships - Pa-X-cell MS MARIELLA</td>
<td>60 kW modularized HT-PEM fuel cell system developed and tested for the decentralized auxiliary power supply onboard passenger vessel MS MARIELLA</td>
<td>Meyer Werft, DNVGL, Lürssen Werft, etc</td>
<td>Phase 1: 2009-2017, Phase 2: 2017-2022</td>
<td>HT-PEM</td>
<td>60 kW (each stack is 30 kW)</td>
<td>Methanol</td>
<td></td>
</tr>
<tr>
<td>Nemo H2</td>
<td>Small passenger ship in the canals of Amsterdam</td>
<td>Rederij Lovers etc</td>
<td>2012-present</td>
<td>PEM</td>
<td>60 kW</td>
<td>Hydrogen</td>
<td></td>
</tr>
<tr>
<td>RiverCell</td>
<td>250 kW modularized HT-PEM fuel cell system developed and to be tested as a part of a hybrid power supply for river cruise vessels</td>
<td>Meyer Werft, DNVGL, Neptun Werft, Viking Cruises</td>
<td>Phase 1: 2015-2017, Phase 2: 2017-2022</td>
<td>HT-PEM</td>
<td>250 kW</td>
<td>Methanol</td>
<td></td>
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<tr>
<td>SF-BREEZE</td>
<td>Feasibility study of a high-speed hydrogen fuel cell passenger ferry and hydrogen refueling station in San Francisco bay area</td>
<td>Sandia National Lab., Red and White Fleet</td>
<td>2015-present</td>
<td>PEM</td>
<td>120 kW per module. Total power 2.5MW</td>
<td>Hydrogen</td>
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</tbody>
</table>

Zero/V - Hydrogen Fuel-Cell Coastal Research Vessel

Sandia partnered with the Scripps Institution of Oceanography, the naval architect firm Glosten and the class society DNV GL to assess the technical, regulatory and economic feasibility of a hydrogen fuel-cell coastal research vessel.

## Maritime Hydrogen Projects

<table>
<thead>
<tr>
<th>Customer</th>
<th>Scope</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Norwegian Public Roads Administration</strong></td>
<td>H2 Ferry 2020 - Study of technical, regulatory and financial feasibility of hydrogen fuel cell ferry by 2020. Frame agreement supporting NPRA in their process for the hydrogen electric ferry that shall be built from dec 2018 – sept 2020, then tested and start normal operation with passengers in 2021.</td>
<td>2016-2021</td>
</tr>
<tr>
<td><strong>Green Coastal Shipping Programme – Hydrogen Pilot</strong></td>
<td>Hybrid hydrogen fuel cell powered high speed passenger ferry in Flora. DNV GL contributions are feasibility of concept, cost estimates, emissions savings, regulatory and safety aspects. Launch planned for 2021.</td>
<td>2017</td>
</tr>
<tr>
<td><strong>Fiskerstrand HYBRIDskip</strong></td>
<td>Hybrid hydrogen (700 – 100 kg H2/day) fuel cell ferry with batteries. Ferry to start operation by 2020. DNV GL contribute with safety and classification competence and experience. 2017-2018 activities supported by PILOT-E.</td>
<td>2017-2018</td>
</tr>
<tr>
<td><strong>Sogn og Fjordane County Authority</strong></td>
<td>Potential for hydrogen production, utilisation and value creation in Western Norway. Hydrogen value chains including maritime use. Technologies, market, potential production sites, scenarios for future hydrogen demand, regional competence. (Source <a href="https://www.dnvgl.no/publications/index.html">https://www.dnvgl.no/publications/index.html</a>)</td>
<td>2016</td>
</tr>
<tr>
<td><strong>Eidesvik JIP</strong></td>
<td>FellowSHIP/Viking Lady 330 kW molten carbonate FC for auxiliary power. Hybrid supply vessel with DNV GL class notation – Fuel Cell Safety</td>
<td>2009</td>
</tr>
</tbody>
</table>
**DNV GL’s services on Fuel Cell / Hydrogen**

| R&D | **•** Applied research and development including *experimental* setups  
• Explosion and fire experiments and research |
| Innovation & demonstration | **•** Realization of *demonstration* projects  
• Techno-economic *road mapping* for technology or solutions  
• System integration with renewables/electricity/.. |
| Implementation support | **•** Technology qualification  
• Explosion and fire safe design analysis  
• *Recommended practice* and standards development  
• Guideline for HRS user interface improvement process |
| Realisation support | **•** Consortium initiation/execution  
• *Safety assessments* (HAZOP, HAZID, QRA, RRR, CFD modeling) |
| Operational excellence | **•** Custody transfer?  
• Performance validation  
• Process optimization  
• H2 Incident and accident database (HIAD) |

*Safer, Smarter, Greener...*

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