Fuel Cells and Hydrogen in Maritime Applications

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National association with approx. 75 members, and 20 partners from public sector
Background information

- Part of Christian Michelsen Research group
- Prototype development – from idea to product
- 25 years experience with research, development and testing of hydrogen and fuel cell technology
- Expertise in advanced design and manufacturing, system design and integration, and stack/complete system testing

Development of Closed-loop Regenerative Fuel Cells Systems for space applications
Solid Oxide Fuel Cells
Solid Oxide Electrolysis
PEM fuel cells
High Temperature PEM fuel cells
High pressure PEM electrolysis
Regenerative Fuel Cell Systems
Reforming

BioZEG - 20 kW SOFC

100 bar PEM electrolyser

RSOFC stack

Methane pyrolysis reactor
Space to Ocean Space

Light-weigh FC and ELY stacks for Space Applications.
15 years development for European Space Agency

Advanced manufacturing
- Ariane 5 structures

Fuel cell systems for offshore power supply

H2 Viking – Zero emission Sunseeker Predator 95

H2 fueled 12,5 kW FC system incl batteries and electric propulsion installed on MF Vågen (2009-2011)
Maritime electric power systems

• Maritime - obvious case for electrification

• Potential - significant reductions in energy consumption, emissions and total cost of ownership

• Optimization of zero emission electric powertrains
  • Aim is to design the most (cost) efficient solutions for a diversified energy scenario
Why Fuel Cells?

Battery Charging

- Anode (-)
- Electrolyte
- Cathode (+)

Li Ion Battery

Battery Discharging

- Anode (-)
- Electrolyte
- Cathode (+)

Proton Exchange Membrane FC
Why Fuel Cells?

- Enables zero emissions energy intensive applications with limited time/access to charging
- Low energy consumption $\eta_{FC} \sim 50 - 65\% +$ rest heat
- High part load efficiency
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- Low energy consumption $\eta_{FC} \sim 50 - 65\% + \text{rest heat}$
- High part load efficiency
- No (significant) noise and vibrations
- Low complexity
- High level of redundancy
- High performance at low temperature
- Utilization of variable renewable energy sources – stabilizing power grids
- Fuel flexibility
  - Hydrogen, bio(m)ethanol, natural gas/biogas, ammonia
Fuel cell stack

Proton Motor PEM automotive FC stack

MEA
Bipolar plate

Prototech Space PEMFC stack
Fuel cell system – stack + Balance of Plant

Ballard FC module

Toyota Mirai FC system
Proton Exchange Membrane and Solid Oxide Fuel Cells most relevant for maritime operations
Fuel cell efficiency

- Theoretical efficiency varies with temperature
- Actual efficiency depends on
  - Activation polarization
  - Ohmic polarization
  - Concentration polarization
- Less losses for high temperature fuel cells

\[ \eta = \frac{\text{Useful Energy}}{\Delta H} \]

\[ \eta_t = \frac{\Delta G}{\Delta H} \]

\[ \Delta G = \Delta H - T \Delta S \]
Polarization curve describes the performance of a fuel cell stack.

The diagram shows the polarization curve with the following regions:

- **Theoretical EMF or Ideal Voltage**
- **Region of Activation Polarization (Reaction Rate Loss)**
- **Region of Concentration Polarization (Gas Transport Loss)**
- **Region of Ohmic Polarization (Resistance Loss)**
- **Operation Voltage, V, Curve**

The graph plots **Cell Voltage** against **Current Density (mA/cm²)**.
Overall efficiency assessment

- Power conversion efficiency higher for batteries than hydrogen FC
- However:
  - Efficiency of non-utilized VRE = 0%
  - Heat ≠ lost energy
  - Ship power need $\sim v^3$
    - Charging time may have significant implication on ship energy consumption
  - Ship power need dependent on weight
- Fuel cells and batteries are complementary technologies – need both to achieve emission free maritime sector
- Total cost of ownership and overall emissions probably more important than efficiency
<table>
<thead>
<tr>
<th></th>
<th>Specific energy (kWh/kg)</th>
<th>Energy density (kWh/l)</th>
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<tbody>
<tr>
<td>Diesel (genset)</td>
<td>4,80</td>
<td>4,00</td>
</tr>
<tr>
<td>LNG (genset)</td>
<td>5,00</td>
<td>2,26</td>
</tr>
<tr>
<td>LNG (FC)</td>
<td>6,82</td>
<td>3,08</td>
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<tr>
<td>NH3 (FC)</td>
<td>3,11</td>
<td>2,39</td>
</tr>
<tr>
<td>250 bar GH2</td>
<td>1,32</td>
<td>0,30</td>
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<tr>
<td>350 bar GH2</td>
<td>1,16</td>
<td>0,41</td>
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<tr>
<td>700 bar GH2</td>
<td>0,99</td>
<td>0,66</td>
</tr>
<tr>
<td>LH2</td>
<td>1,65</td>
<td>1,07</td>
</tr>
<tr>
<td>Batteries</td>
<td>0,07</td>
<td>0,10</td>
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</table>
Maritime fuel cells - selected projects
Maritime hydrogen projects in Norway

• NPRA hydrogen car ferry
  – In operation from 2021
  – Hjelmeland – Nesvik – Skipavik
  – 50% energy delivered by H2
  – Norled, Fjord1, Boreal qualified to bid

• Trondelag FK – Zero emission high speed vessel

• Norwegian value creation
A wide range of Norwegian initiatives

Aquaculture vessels

Fjord tourism

Viking Cruises

Karoline

Hydrogen Viking – Sunseeker Predator 95

Osterøy ferry

Supply vessels

LMG Marin, CMR Prototech

GKP7H2
Potential market – all vessels

- Work boat 0.2-1.2 MW
- Hydrogen ferry 0.5 – 2 MW
- Sunseeker Green Cruises 3 MW
- Seasight ~1.5 MW
- Urban Water Shuttle

- Develop fuel cell power systems for high energy demand vessel types
- Various fuel types
  - GH2
  - LH2
  - Methanol
  - LNG
  - Ammonia
- Marine CHEOP
Main barriers – research needs

- Fuel cost and infrastructure
- Maritime adaption of fuel cell technology – optimization
- Rules and regulations

Figure: Waitbutwhy
Hydrogen Viking

- 100 ft Sunseeker
- ~40 knots
- Demonstration of zero-emission hybrid propulsion
- Education/meetings
Thank you for your attention!

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