Technical & Economic aspects related to H2 Fuel Cell Ships

Øystein Ulleberg
Principal Scientist
Institute for Energy Technology
Kjeller, Norway

Japan-Norway Energy Science Week 2015
27 May 2015, Tokyo
Institute for Energy Technology

- Independent foundation est. 1948
- R&D on Energy Technologies
- Laboratory intensive activities
- 600 employees (Kjeller & Halden)
- Turnover: MNOK 950 (15 billion JPY)
- Contract Research
- Internationally oriented
Energy & Environmental Technology

- Main areas
  - Renewable Energy: Solar cells, Wind energy, **Hydrogen**
  - Energy systems analysis
  - Climate technology; CO$_2$-management
  - Battery technology
  - Radioactive waste management
- 70 employees
- Turnover: MNOK 100 (1.6 billion JPY)
Renewable Energy & Hydrogen Research & Development → Demonstration & Innovation

- Fuel Cell Cars (Hynor)
- Passenger Ferries (Rødne)
- Fuel Cell Buses (Ruter)
- Supply Ship (Eidesvik)

Mobile Applications
Hydrogen & Fuel Cells
Maritime Applications
H2-ship Feasibility Study (2014)

Hydrogen as Fuel for Ships – From Renewable Energy to Zero Emission Propulsion

- Project Partners:
  - Ship design: NCE Maritime CleanTech
    Wave Propulsion AS
    Hordaland Maritime Miljøselskap AS
  - Ship building: Brødrene Aa
  - Ship operation: L. Rødne og sønner AS
    Eidesvik Offshore ASA
  - Ship power systems: Westcon Power and Automation AS
    Wärtsilä Norway AS
  - Energy supply: SKL Produksjon AS
  - Fuel Cell systems: CMR Prototech
  - Hydrogen systems: Institute for Energy Technology
  - Funding: Partners & Transnova (now Enova)
H2-ship Feasibility Study (2014)

Scope of Work

• Regulatory issues for use of Hydrogen & Fuel Cells in ships

• Preliminary Design & Costing of a Hydrogen Fuel Cell Passenger Ferry
  → Demonstration Project (short-term perspective)

• Case Study: H$_2$-production & Supply to a Fuel Cell Ship
  → Business Case: Offshore Supply Ship (long-term perspective)
Regulations for Ships

National Laws and Regulations:

International Convention / Codes / Agreements / National Regulations

Technical Codes - Class / Standards / National Regulations

Survey / Inspections / Certificates
Regulations for H2 & FC Ships?

- **Norwegian Maritime Authority**
  - *Regulation on construction & operation of passenger ferries fueled by gas*
  - Liquefied or compressed gas (LNG) for engines, turbines, **and** fuel cells
  - H$_2$ **not** included in regulation

- **IGF Interim Guideline (International Gas Fuel)**
  - *Int’l Code of Safety for Ships using Gases or other Low flashpoint Fuels*
  - Code for LNG, ready for methanol and ethanol, but H$_2$ **not** included in code

- **Classifications, Codes & Standards**
  - GL: *Guidelines for the Use of Fuel Cell Systems on Board of Ships & Boats*
  - DNV: *Fuel Cell Installations*
  - The Norwegian Maritime Authority is **not** using DNV GL Codes & Standards
Recommended Approval Process for Hydrogen & Fuel Cells in Ships

- Follow the IMO-guideline (International Maritime Organization):
  - Guidelines for the Approval of Alternatives ...(24 June 2013)

- Case-by-Case Approval Process:
  1. Development of a Preliminary Design
  2. Approval of Preliminary Design
  3. Development of Final Design
  4. Final Design Testing & Analyses
  5. Approval
Hydrogen Fuel Cell Passenger Ferry Preliminary Design

- **Main Specifications**
  - 4 × 2-hour trips per day (55 km/h)
  - Electric Motors: 2 × 750 kW
  - PEMFC modules: 8 × 200 kW
  - Li-ion battery: 50-100 kWh
  - GH2-storage: 330-660 kg
Hydrogen Fuel Cell Passenger Ferry
Preliminary Design & Costing

• H2 FC sub-systems
  • PEMFC modules & BoP
  • Li-ion Batteries & BMS
  • DC/DC converters
  • DC/AC inverters
  • Safety & Control Systems
  • AC motors, Gears & Propellers

• Key Features:  
  H2 Fuel Cell vs. Diesel ICE  
  Weight:  ca. 18 tonnes  13 tonnes  
  Volume:  ca. 30 m³  8.5 m³  
  CAPEX:  ca. 28 MNOK  3.75 MNOK  
  CAPEX + OPEX:  ca. 450 million JPY  60 million JPY  
  CAPEX + OPEX:  ca. 131 MNOK  80 MNOK
H2-Production & Supply to a Fuel Cell Ship
Case Study: Water Electrolysis + H2 Liquefaction

Hydro Electric Power → Regional Grid → Water Electrolysis → Hydrogen Liquefaction → Fuel Cell Ship (4 MWel)
Techno-Economic H2 Production Simulator
Data based on Standard Industrial H2 Technology
H2-infrastructure for FC Supply Ship Design & Assumptions

• **Overall System Design**
  - Average H₂-consumption: 1800 kg/day 12 500 kg/week
  - Alkaline Water Electrolyzer: 850 Nm³/h 4.2 MW
  - LH₂-production: 850 Nm³/h 0.9 MW
  - LH₂-storage: 12 500 kg
  - LH₂-pump: 175 000 liter/h 0.8 MW

• **Main Assumptions**
  - Power demand water electrolysis: 4.9 kWh/Nm³
  - Power demand overall LH₂-plant: 1.1 kWh/Nm³
  - Electricity costs: 0.5 NOK/kWh (8 JPY/kWh)
  - O&M costs: 4% of Annual CAPEX
  - Life time & interest rate: $n = 20$ years, $i = 5\%$
H2-infrastructure for FC Supply Ship

Main Results

- **Capital Costs (CAPEX):** 112 MNOK (1.8 billion JPY)
  - Water Electrolyzer: 36 MNOK (32%)
  - LH$_2$-production: 51 MNOK (46%)
  - LH$_2$-storage: 14 MNOK (13%)
  - LH$_2$-pump: 10 MNOK (9%)

- **Annual Costs:** 32 MNOK/year (512 million JPY)
  - CAPEX: 9 MNOK/year (28%)
  - OPEX (mainly electricity): 23 MNOK/year (72%)

- **Hydrogen Cost:** 50 NOK/kg (800 JPY/kg)
Supply Ship – Sensitivity Analysis
CAPEX & OPEX vs. Electricity Cost

![Graph showing the relationship between Relative Costs (%) and Electricity Cost (NOK/kWh). The graph has two curves, one for OPEX and another for CAPEX. As the electricity cost increases, the relative costs of both CAPEX and OPEX decrease.]
Business Case for a FC Supply Ship?
LH₂-production costs normalized wrt. FC power on ship

![Chart](image)

- **Today**
- **0.20 NOK/kWh**
- **5 x Ships**
- **No electricity tax**
- **No grid fee**
- **LNG**

- **NOK per kWh**
- **LNG cost (max)**
- **LNG cost (min)**
- **CAPEX Liquefaction**
- **CAPEX Electrolyzer**
- **OPEX**
- **Electricity Fees**
- **Electricity Cost**
Conclusions & Recommendations

• **New national & international regulations** for H2 FC ships need to be established

• A passenger ferry could be designed, built & demonstrated in Norway, with the aim to **validate H2 FC system design and technology**

• The Western part of Norway has favorable conditions for establishing RE/H2-infrastructure for FC ships, but **tax incentives are needed**

• Hydrogen & Fuel Cell Ships is an **excellent opportunity for collaboration between Norway & Japan**!
Urban Water Shuttle
A New Norwegian Patented Concept
Thank you for your attention!

**IFE, Research for a better future**