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FME
CENTRE FOR ENVIRONMENT-FRIENDLY ENERGY RESEARCH

The Research Council of Norway

Preliminary design of hydrogen-driven high speed passenger ferry

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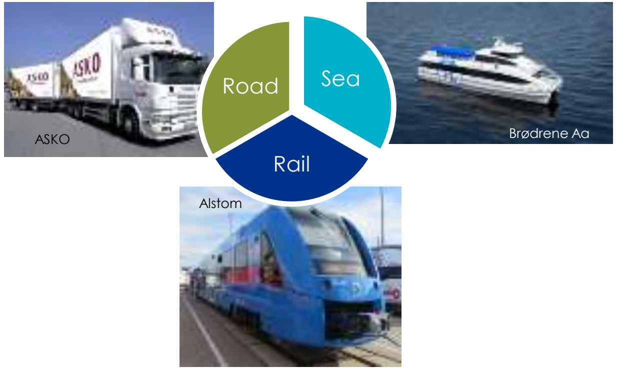
MoZEES – Norwegian Research Center for Zero Emission Transport

- **Established in 2017**
- **260 MNOK, 8 years and 19 PhD and postdocs**



Research Partners

IFE Institute for Energy Technology
NTNU Norwegian University of Science and Technology
SINTEF
UiO University of Oslo
TØI Institute of Transport Economics, Norwegian Centre for Transport Research
FFI Forsvarets forskningsinstitutt
HSN University College of Southeast Norway

Public Partners

AKERSHUS County Council
Statens vegvesen Norwegian Public Roads Administration
ENOVA
Jernbanedirektoratet
Port of Oslo
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Private and industrial partners

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Battery and hydrogen – technology value chains

Materials → Components → Batteries and fuel cells → Modules → Systems

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Task 3.5 – Design specifications for selected applications

RA3 Annual Work Plan:

1. Maritime case study (2017-2018)
2. Heavy-duty road case study (2019-2020)
3. Rail case study (2022-2023)

Objective:

Derive design specifications of the fuel cell and battery hybrid systems on a selection of specific heavy duty applications

H2 Maritime Case Study – Research Team

- Øystein Ulleberg, IFE
- Fredrik Aarskog, IFE
- Frederico Zenith, SINTEF
- Sepideh Jafarzadeh, NTNU
- Trond Strømgren, Maritime Association Sogn & Fjordane
- Olav Roald Hansen, Lloyd's Register

Selection of case:
GKP7H2 – Pre-Project (Green Coastal Shipping Program)

- Length: 30 meters
- Installed motor power: 2 × 600 kW
- Speed: 28 knots (52 km/hour)
- Passenger capacity: 100 persons
- Reference route:
  - Florø-Måløy, 1 trip per day: 68.4 nm
  - Nordre rute, 2 trips per day: 45.0 nm
  - Total 113.4 nm (210 km) per day (on weekdays)
- Estimated max. daily hydrogen consumption: ca. 380 kg
- H2-storage: 3 × 150 kg @ 250 bar

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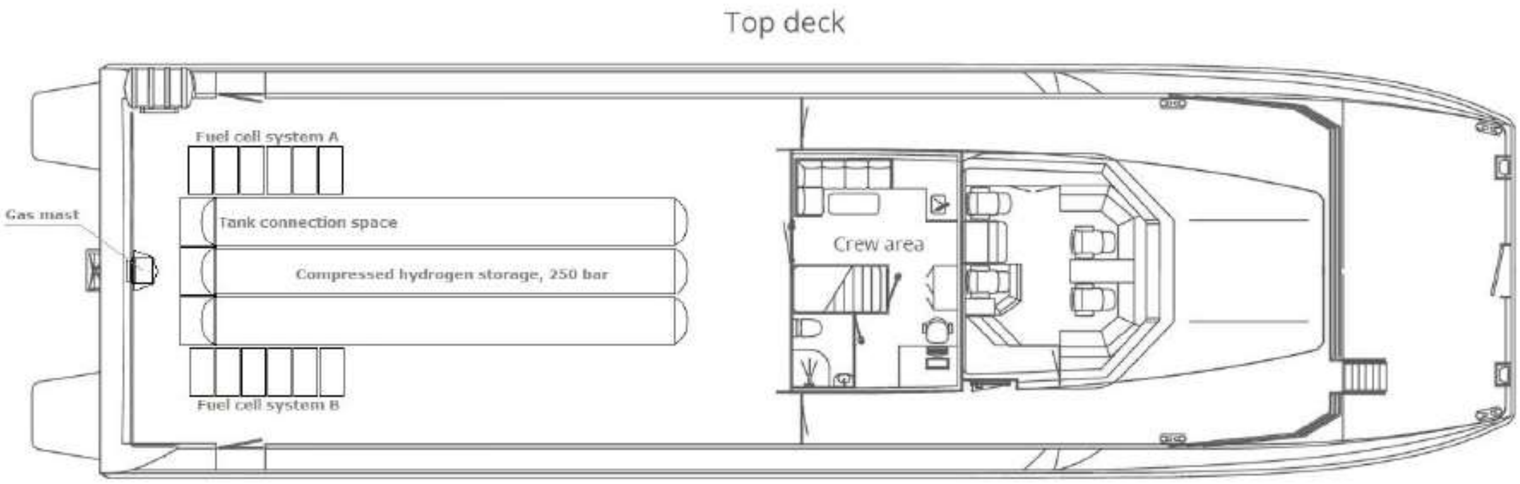
Source: https://www.dnvgl.no/maritime/gront-kystfartsprogram/rapporter.html

H2 Maritime Case Study – Scope of Work

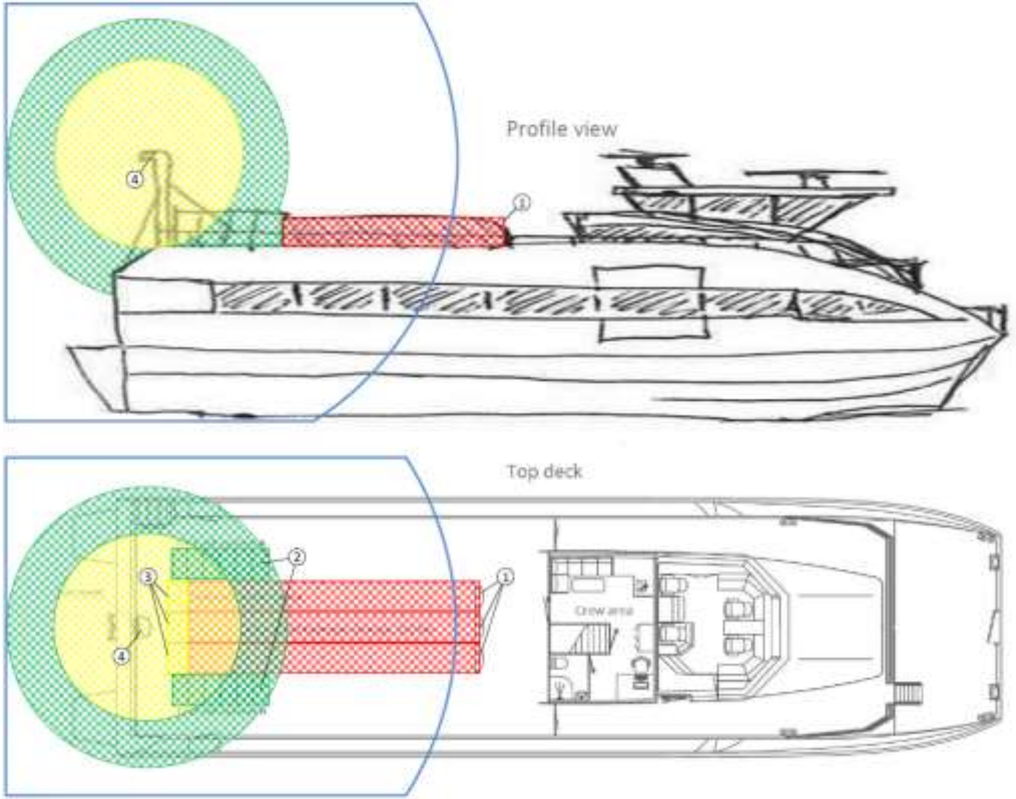
- Duty cycle of this ship in normal route (NTNU, IFE)
  - GKP7H2 pre-project: Estimation of fuel consumption
  - Measurements/data logging by Brødrene Aa
- Fuel cell energy system design (IFE, SINTEF)
  - Battery and FC capacities (kWh, kW) and dimensions (kg, m^3)
  - Hydrogen storage capacity (kg H_2) and dimensions (kg, m^3)
- Economic evaluation (SINTEF, IFE)
  - OPEX/CAPEX; limit study to this exact ship on this exact route
  - Economic parameters (FC: $/kW, tanks: $/kWh, etc.)
- Safety & Risk analysis (LR, IFE)
  - Pre-HAZID on simplified P&ID
  - Risk analysis on preliminary mechanical design (with safety zones)
- H2-bunkering not part of the study

Preliminary Design – General arrangement and system schematic

- H2-storage (250 bar) on top of roof
- Preliminary hydrogen system schematic created



Preliminary Hazardous Areas and Safety Zones



○	Zone where air intake, air outlet or other opening to non-hazardous area is not allowed. Exhaust outlet from machinery or furnace not allowed. (5.2.2.6)

Hazardous areas according to DNV GL Rules Pt.6 Ch.2 Sec.5		
Legend	**Zone**	**Description**
(red)	0	Area in which an explosive gas atmosphere is present continuously or is present for long periods.
(yellow)	1	Area in which an explosive gas atmosphere is likely to occur in normal operations.
(green)	2	Area in which an explosive gas atmosphere is not likely to occur in normal operation and, if it does occur, is likely to do so only infrequently and will exist for a short period only.

A more detailed assessment per IEC60079-10-1 should conclude that hazardous zone should only extend upwards from vent mast (due to buoyancy), will be influenced by solid fences, and no zone should be necessary inside high pressure storage tanks

Source: DNV GL Rules for classification – High speed and light craft – Pt.6 Ch.1
DNV GL Rules for classification – Ships – Pt.6 Ch.2

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Results – Pre-HAZID & Concept Risk Assessment reports


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Working together for a safer world

Memo

Pre-HAZID October 31, 2017 - Maritime case study GKP7H2 MoZEES

To: MoZEES RA3 Cc:

From: Lloyd's Register Date: 14 November 2017 CONFIDENTIAL

1 Introduction

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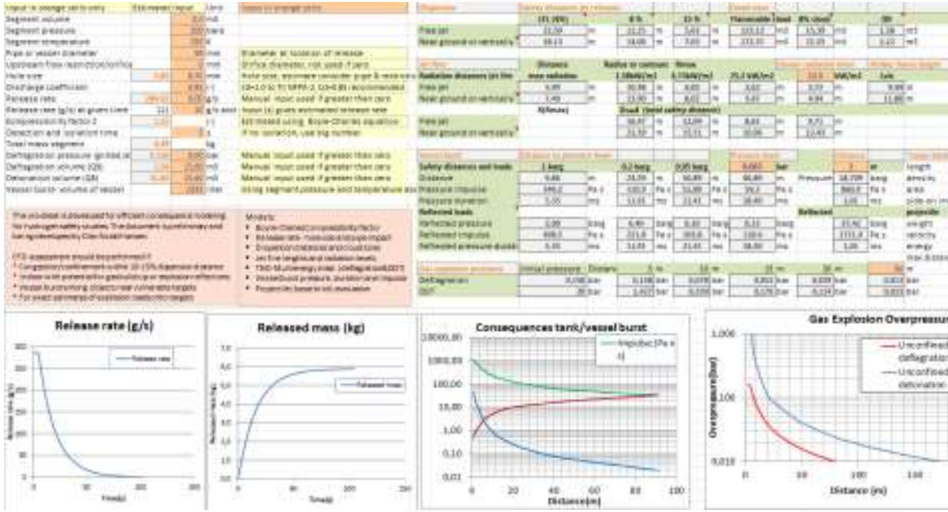
Hydrogen Risk Assessment Approaches

Screening assessment using xls-sheet formulas

- ❑ Segment inventory and outflow (real gas)
- ❑ Dispersion distances and cloud volumes
- ❑ Jet fire radiation distances
- ❑ Pressurized vessel burst - projectiles
- ❑ TNO multi-energy explosion loads
- ❑ Ignition probability



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Hydrogen Risk Assessment Approaches

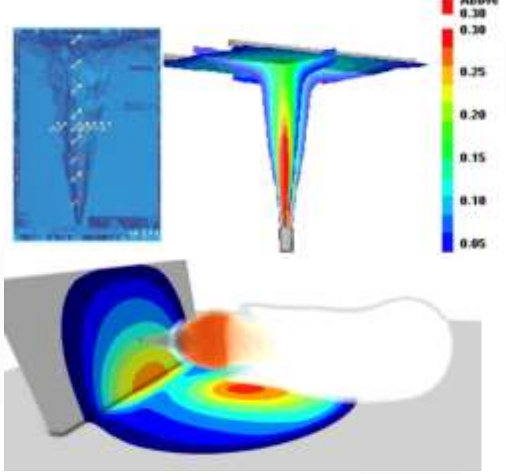
CFD Required in some cases:

- Concentration > 10-15% AND congestion or confinement (including recirculation potential)
  - Release and explosion effects
  - Pre-ignition (jet-) turbulence
  - Geometry effects at explosion source
  - Blast waves detailed loading (3D) – durations, reflections & shielding etc.

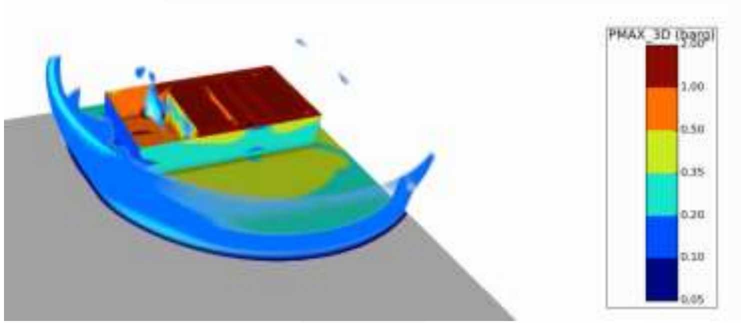
- Liquid hydrogen scenarios…

- Most indoor scenarios….
  - What detection time can be expected?
  - Is emergency ventilation effective?
  - What is actual release rate from pipe?
  - Is there a potential for DDT, if so…

- Vessel burst scenarios near targets



Hydrogen release and ignition scenarios



Worst case tank rupture (onshore example):

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Concept Risk Assessment – IGF Requirements

Requirements; IGF – equivalent safety to conventionally fuelled vessel (diesel)

Challenge 1:

- What is equivalent safety level? To what? How to demonstrate?
  - TØI (2001) – 0.6 dead per 1E9 passenger km 1970-1994
  - NMA (2002) – new technology 1.0 dead per 1E9 km OK
  - ➔ < 0.5-1.0 fatalities per 1E9 km from H2 systems likely OK

- Vessel may spend significant time in harbour
  - ➔ Decided to evaluate against DSB land planning regulations (not required, but may support case)

Challenge 2:

- Early stage, many design details unclear
  - ➔ Need to take numerous assumptions

  E.g. general best practice to minimize pipe diameters, limit jet flame risk, ensure leaks vented upwards etc.

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Risk Assessment Approach

Systems generally sorted and evaluated by pressures and volumes, typical choice will be

Hydrogen systems	**Hazard**	**Fatality potential**	
Storage tanks	vessel burst (w/wo ignition)	significant	(very low frequency)
HP piping/equipment	leak, jet fire, explosion	limited	(with good design)
LP piping/equipment	leak, jet fire, explosion	marginal	(with good design)
Fuel cells	leak and explosion	marginal	
Emergency vent	radiation/explosion	must be designed safe	

Good design may limit consequences from most scenarios

Catastrophic tank rupture may be exception, expected frequency 1E-6 to 1E-7/y (?)

⇒ Very high pressures (of short duration) – should consider measures to limit likelihood and mitigate

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Concept Risk Assessment – Conclusions

Estimated of passenger risk:

- For all identified scenarios fatality distances and frequencies were estimated
- Fatality risk to passengers and crew was estimated and compared against 0.5-1.0 per 1E9 passenger km

DSB consultation distances (hensynssoner) if fixed installation

- Inner zone: ??m
- Middle zone: ??m (no shops or homes allowed)
- Outer zone: ??m (no hotels, schools, shopping malls)
- Based on this it was concluded whether there should be any concerns mooring the vessel in a busy harbour

Preliminary assessment indicates that the fatality risk will not be significantly higher than for a conventionally fueled vessel

Estimates were approximate and depend on

- Provided preliminary information available
- LR assumptions on pipe dimensions and mitigation methods

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