HFC-forum
Human Factors in Control

Det Grønne skiftet - sikkerhet og menneskelige faktorer underveis

19 October 2021

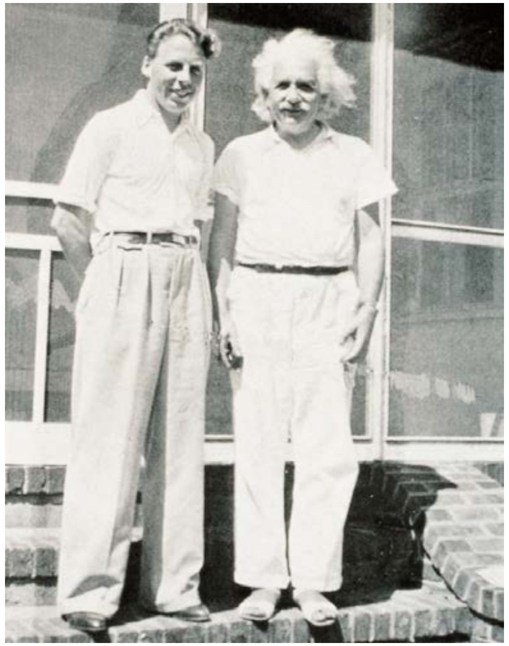
Hydrogen og batterier – Sikkerhetsutfordringer ved anvendelse i nye energisystemer og oppskalering

Øystein Ulleberg
Forskningssjef IFE | Senterleder MoZEES

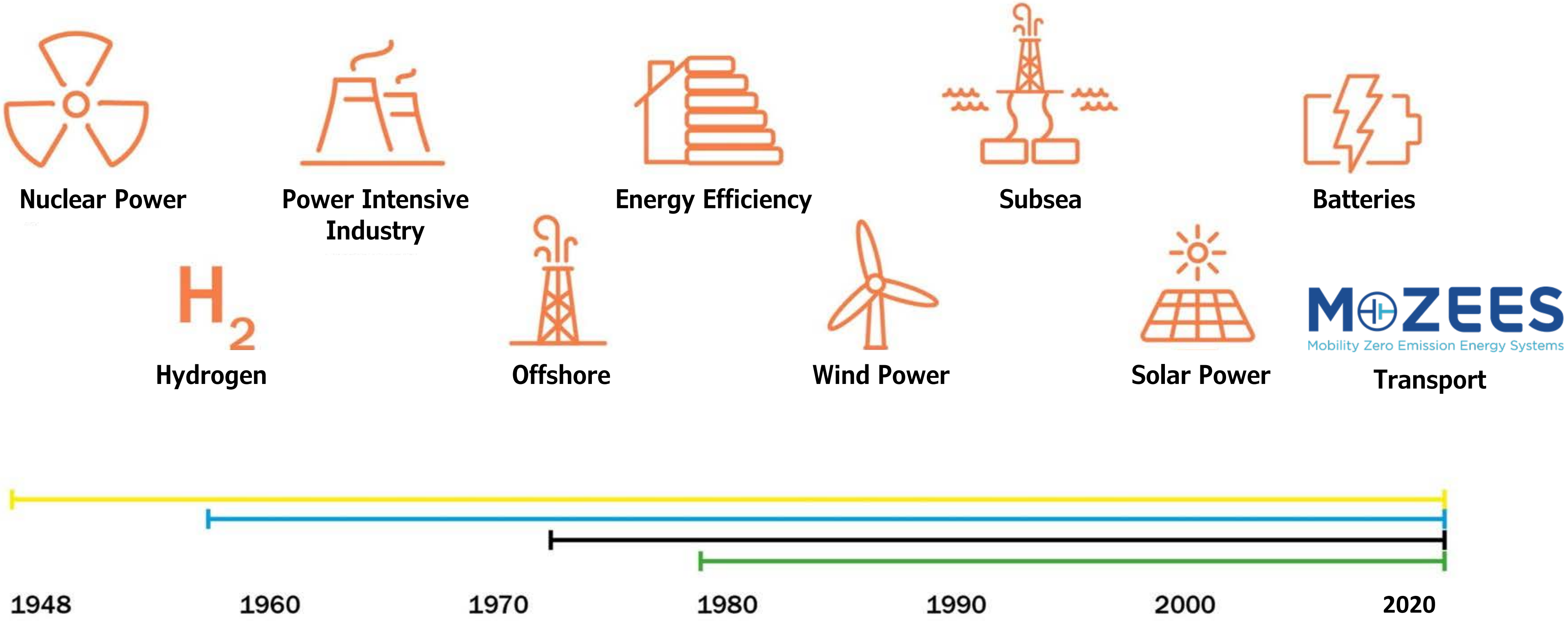
Contents

Institute for Energy Technology

IFE has contributed to the development of Norway as an energy nation for more than 70 years!



Gunnar Randers, IFE's founder



MoZEES – A Research Center on Zero Emission Transport

Battery & Hydrogen
– Technology Value Chains


Illustration: NFR

Materials → Components → Systems

FME MoZEES project: 260 million NOK (2017-2024)

***Heavy Duty* Transport: Road, Rail, Sea**
– Areas for Innovation & New Business


ASKO


Brødrene Aa


Alstom

CENTRE FOR ENVIRONMENT-FRIENDLY ENERGY RESEARCH
The Research Council of Norway

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RA3 – Hydrogen & Battery Systems & Applications

- **Objectives**
  - Optimize design & controls of battery / fuel cell systems
  - Develop safe battery and hydrogen systems
  - Improve water electrolysis systems wrt. costs
- **Focus Areas**
  - Hybrid battery/fuel cell systems for heavy duty applications, with improved lifetime and lower overall costs
  - Li-ion battery cell lifetime and system safety
  - PEM water electrolyzer system operation

PEM Fuel Cells

Li-ion Batteries

PEM Water Electrolysis

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IFE Hydrogen

Research Infrastructure

- IFE Hynor
    1. *Hydrogen Refueling Station (2011 – 2021)*
    2. *Solid oxide fuel cells (2014 – 2016)*
    3. Sorption Enhanced Reforming – ongoing
    4. PEM Fuel Cells & Batteries – ongoing
    5. PEM Water Electrolysis – ongoing
    6. *Liquid Hydrogen storage (2022 –)*

- Norwegian Fuel Cell and Hydrogen Centre*
  *open research infrastructure
    - PEM Fuel Cell System Laboratory
    - PEM Water Electrolysis System Laboratory

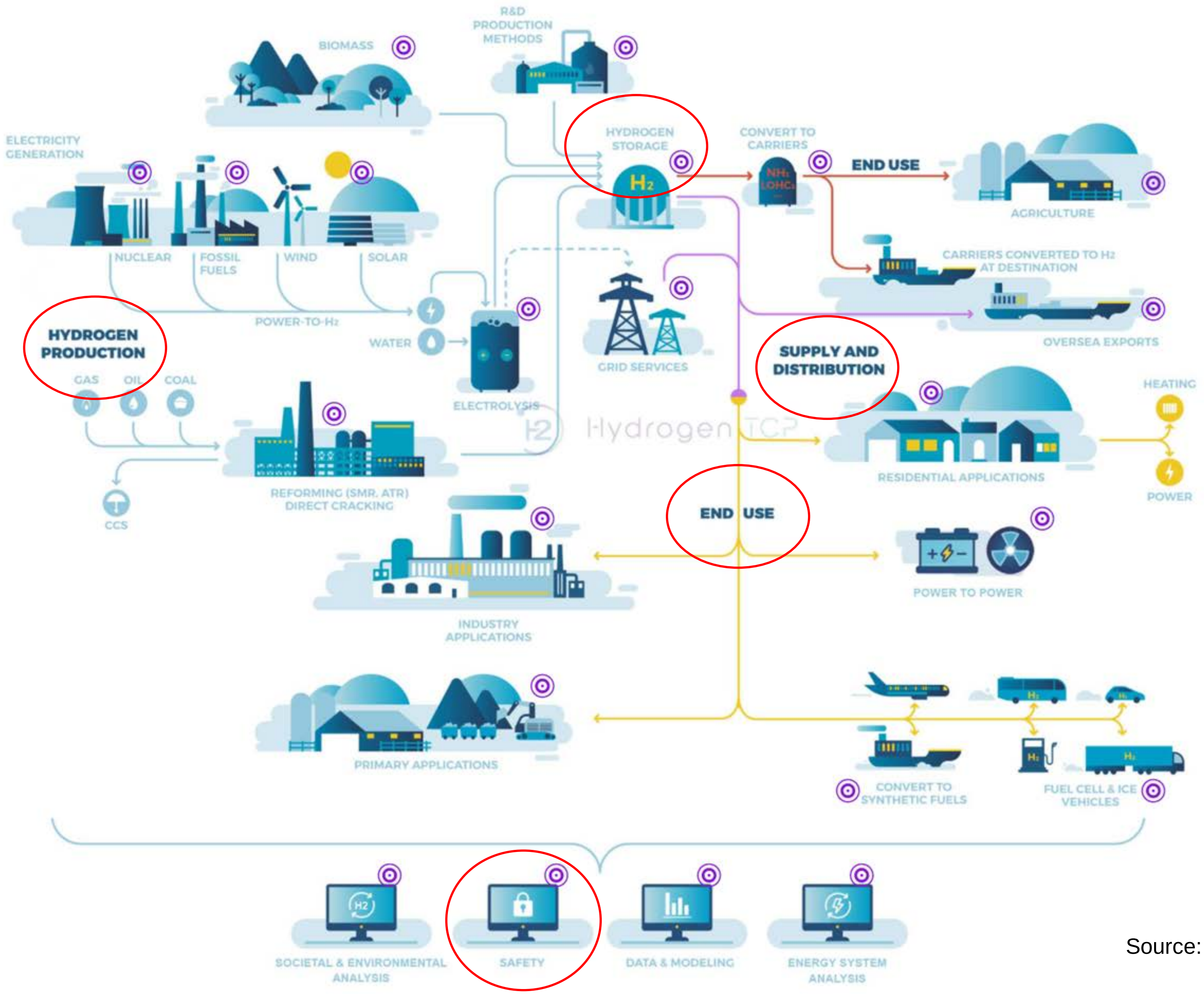
IFE Hynor

Hydrogen Technology Center

NORWEGIAN FUEL CELL AND HYDROGEN CENTRE
FUEL CELL & ELECTROLYSER SYSTEMS

Contents

Safety in Hydrogen Value Chains



Source: IEA Hydrogen TCP (2021)

MoZEES Hydrogen Safety Research – Examples

1. Hydrogen leakages in closed rooms & confined spaces (Task 3.2)

2. Safe design of high pressure water electrolyzers (Task 3.4)

3. Risk assessment of hydrogen & fuel cell driven high speed ferry (Task 3.5)

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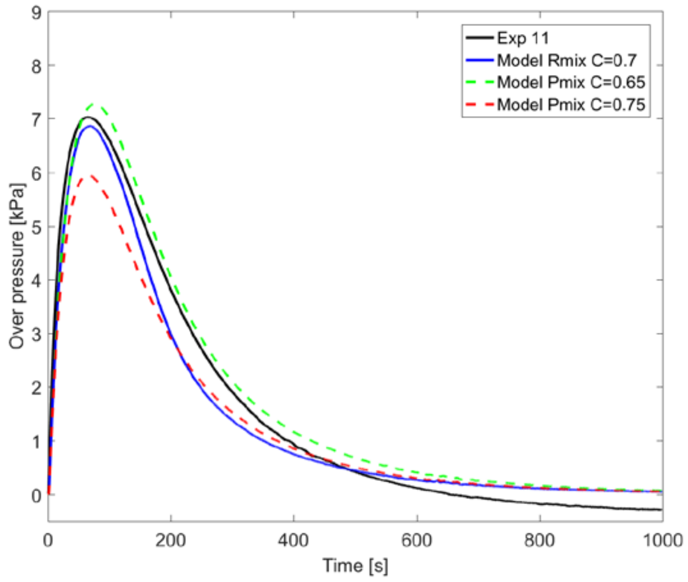
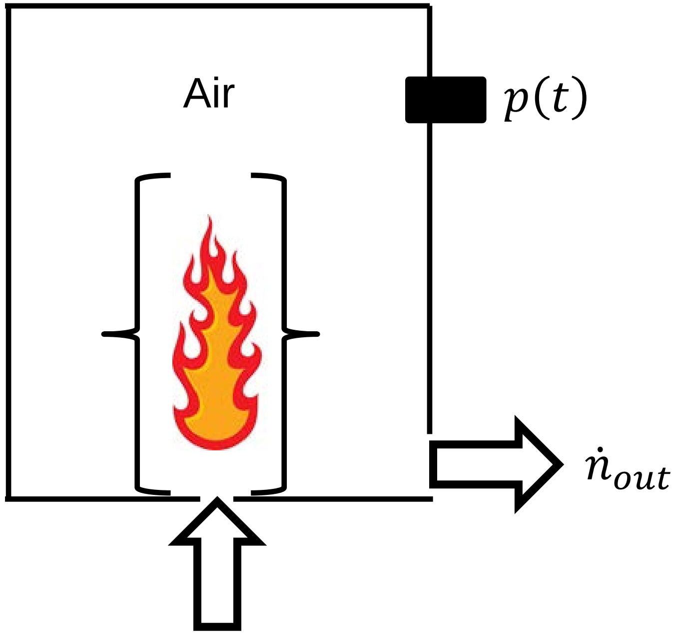
Hydrogen in Closed Rooms & Confined Spaces (1/3)

Pressure Peaking Phenomena

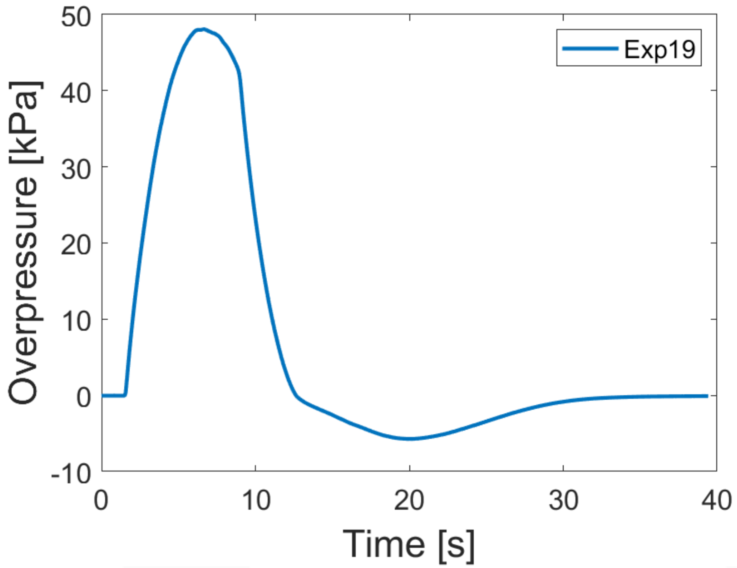
$\dot{m}_{H_2} = 4.85\ g/s$



Unignited



$\dot{m}_{H_2} = 8.62\ g/s$



Ignited

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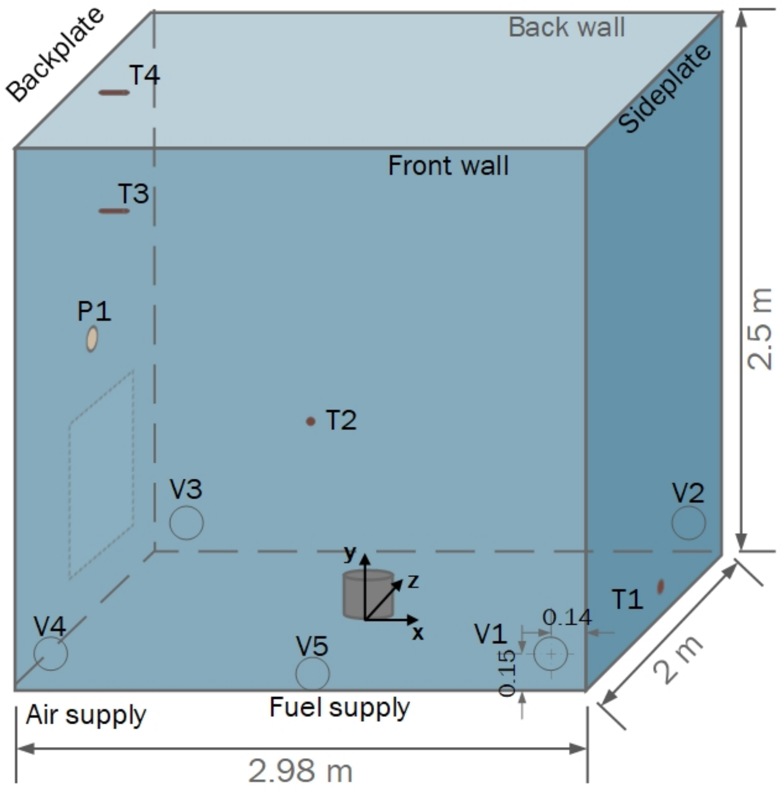
Hydrogen in Closed Rooms & Confined Spaces (2/3)



Number of vents open	Area (m^2)
1	0.0055
2	0.0109
3	0.0164

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Hydrogen in Closed Rooms & Confined Spaces (3/3)

Scope of Work:

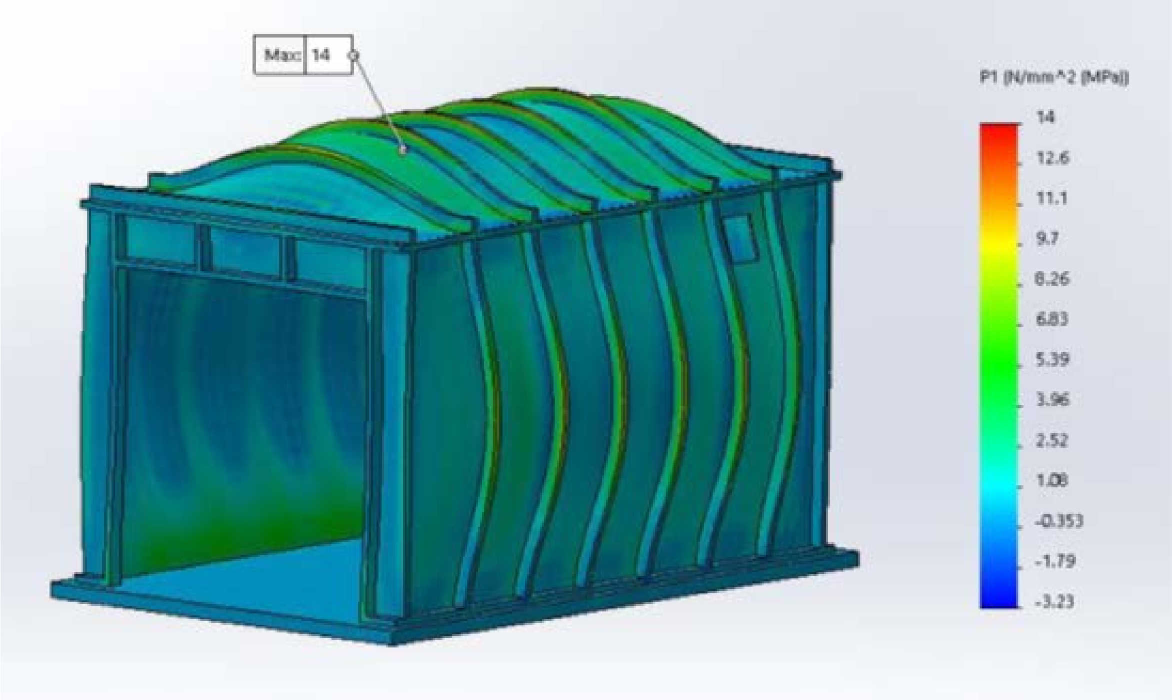
- Experimentation and modeling of H2-leakages in closed rooms and other confined spaces
- Large scale experiments in container (3m × 2m × 2.5m)
- Development of analytical model that captures the physics of the system

Result:

- Modeling tool for design of safe hydrogen rooms and confined spaces

Future Work:

- LH2 releases; including condensation effects
- 700 bar GH2 releases; unignited and ignited



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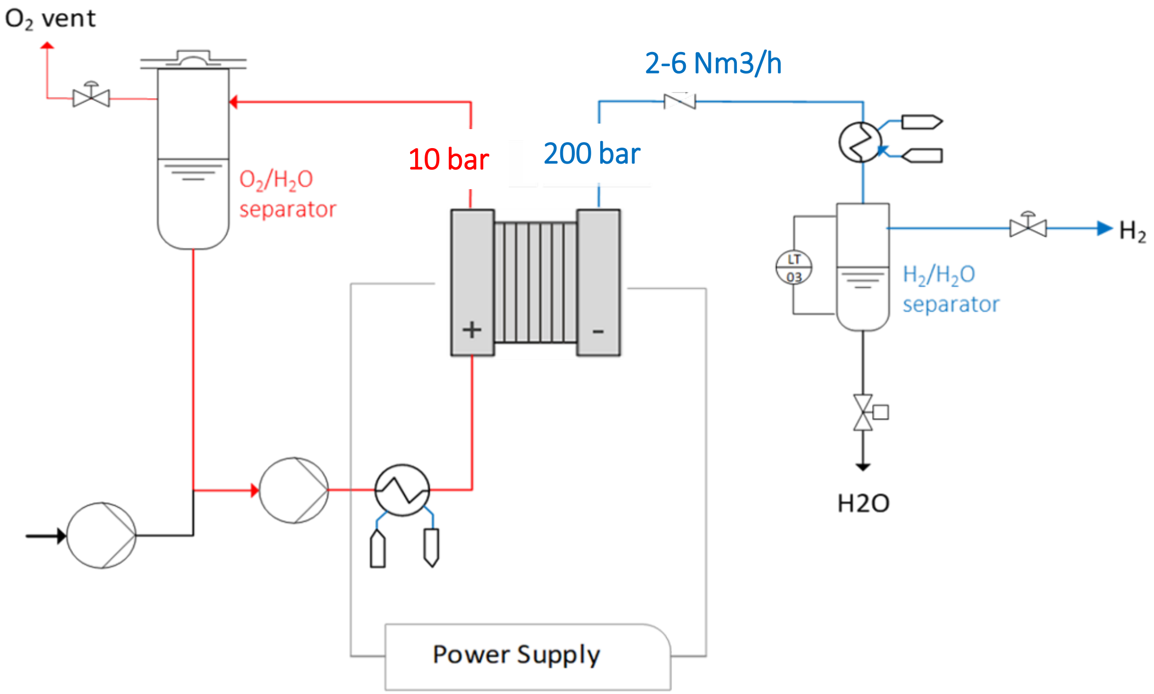
Safe design of High-Pressure Water Electrolyzers (1/3)

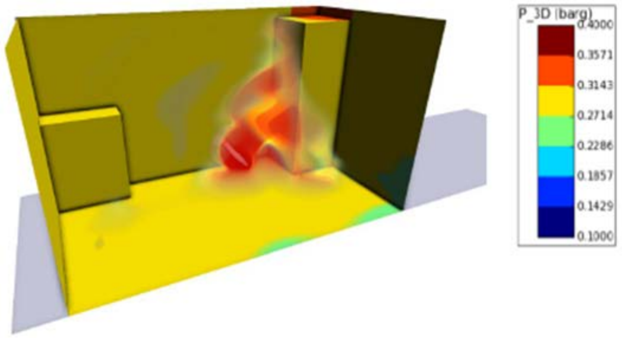
- High-pressure PEM water electrolyzer system at IFE
  - Up to 200 bar differential pressure stacks



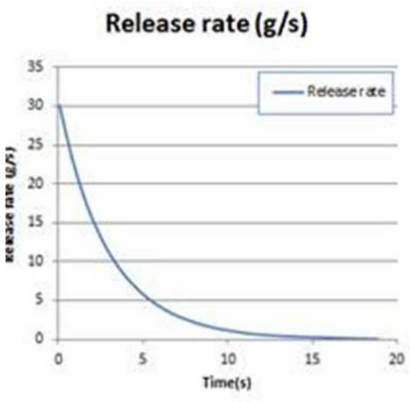
PEM water electrolyzer laboratory system at IFE

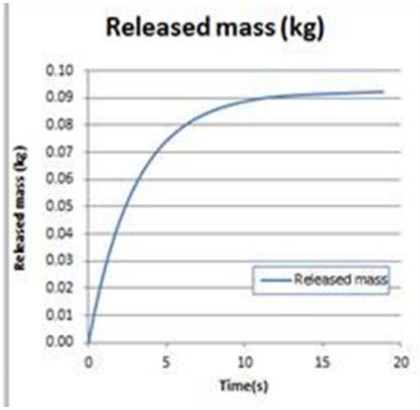
Safe design of High-Pressure Water Electrolyzers (2/3)

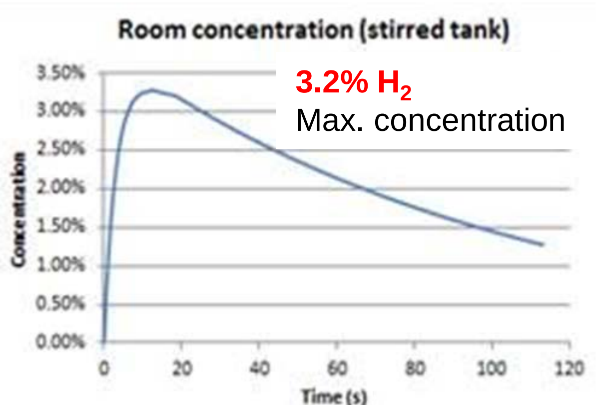
- **Reverse flow of hydrogen into O_2-side**
  - e.g. due to membrane rupture
- **Hydrogen gas cross-over in stack**
  - e.g. H_2 in O_2 > 4% at part load operation
- **Self-ignition Oxygen-rich mixtures on O_2-side**
  - e.g. due to friction or stray particles
- **Hydrogen leakage into container**

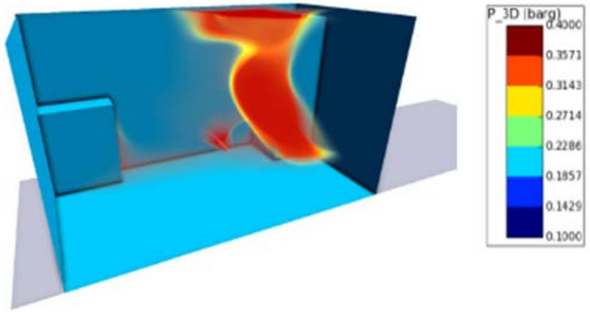


Figur 7.5 - Fullt rørbrudd (initiell lekkasjerate 186 g/s) i konteiner 75 ms etter antenning ved tid for maksimalt overtrykk.









Figur 7.6 – Fullt rørbrudd (initiell lekkasjerate 186 g/s i konteiner 475 ms etter antenning, trykket har nå sunket betraktelig.

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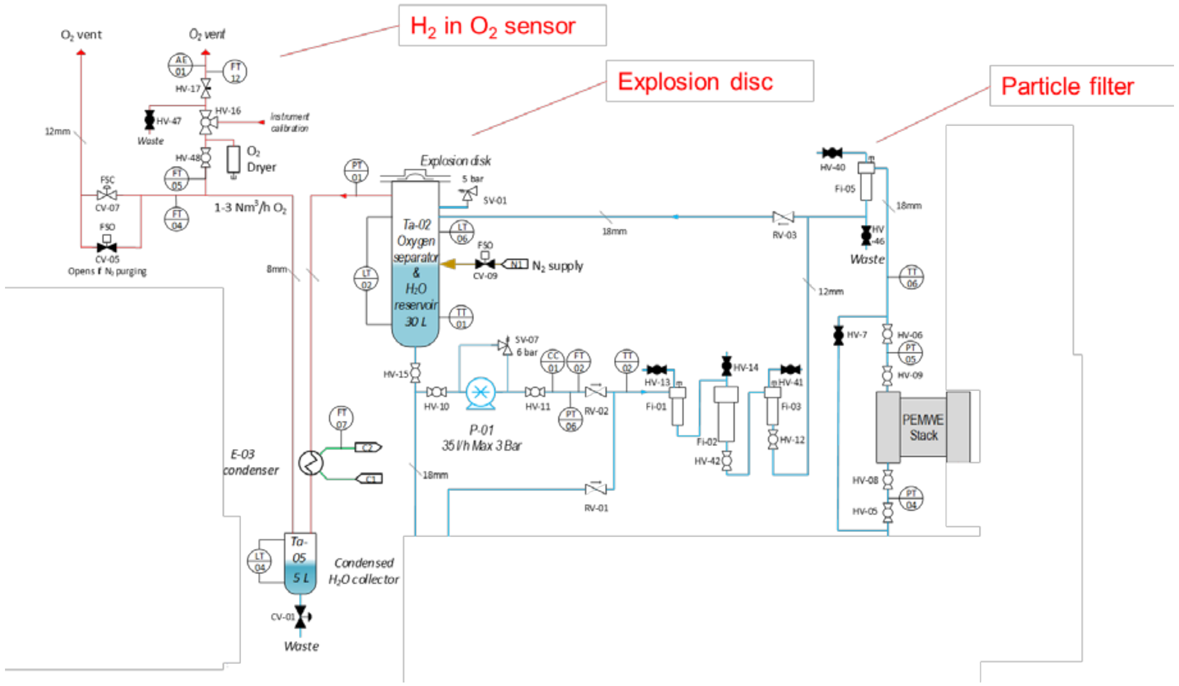
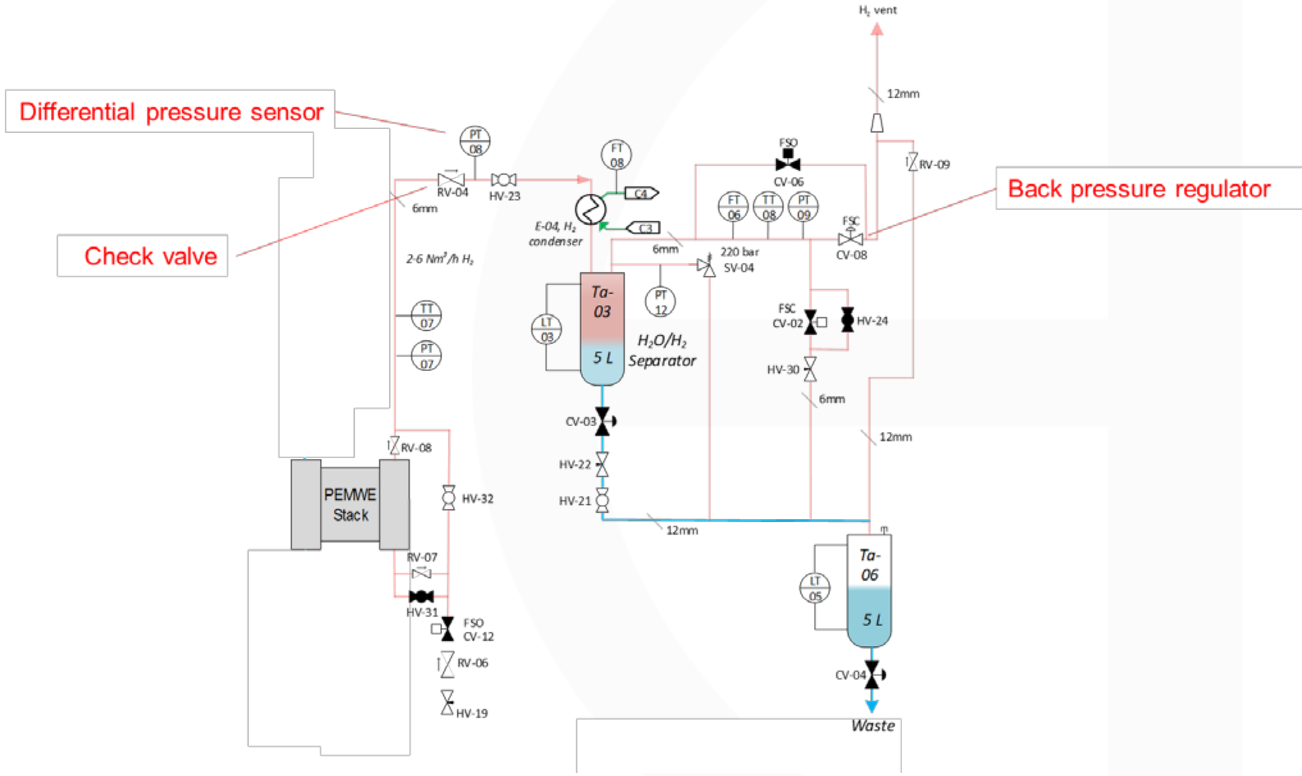
Safe design of High-Pressure Water Electrolyzers (3/3)

Low Pressure Oxygen Side



High Pressure Hydrogen Side



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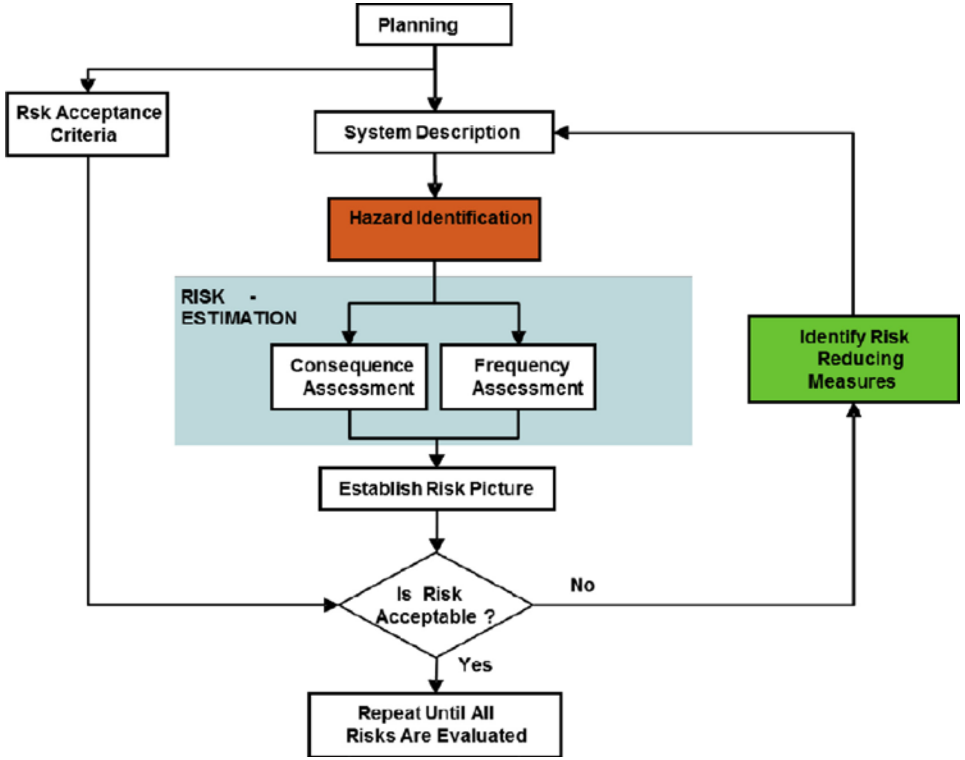
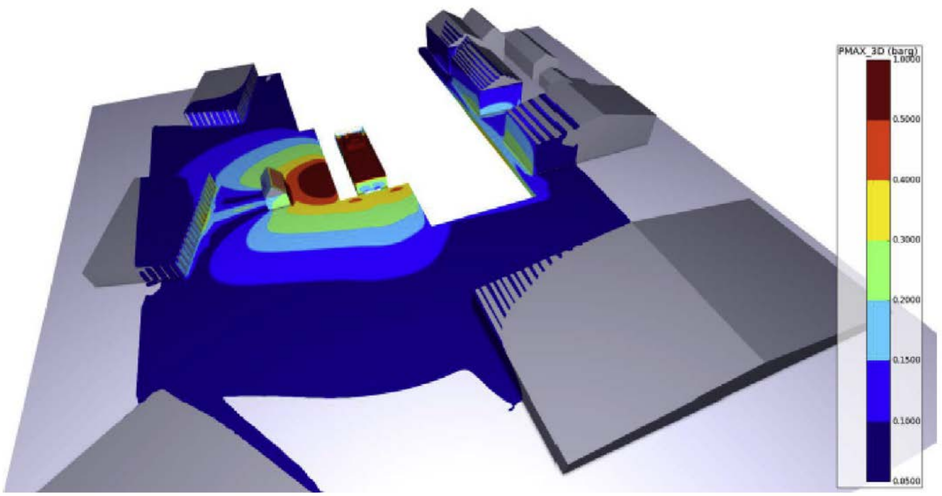
MoZEES Maritime Case Study – Risk Assessment (1/2)





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MoZEES Maritime Case Study – Risk Assessment (2/2)

Scope of Work:

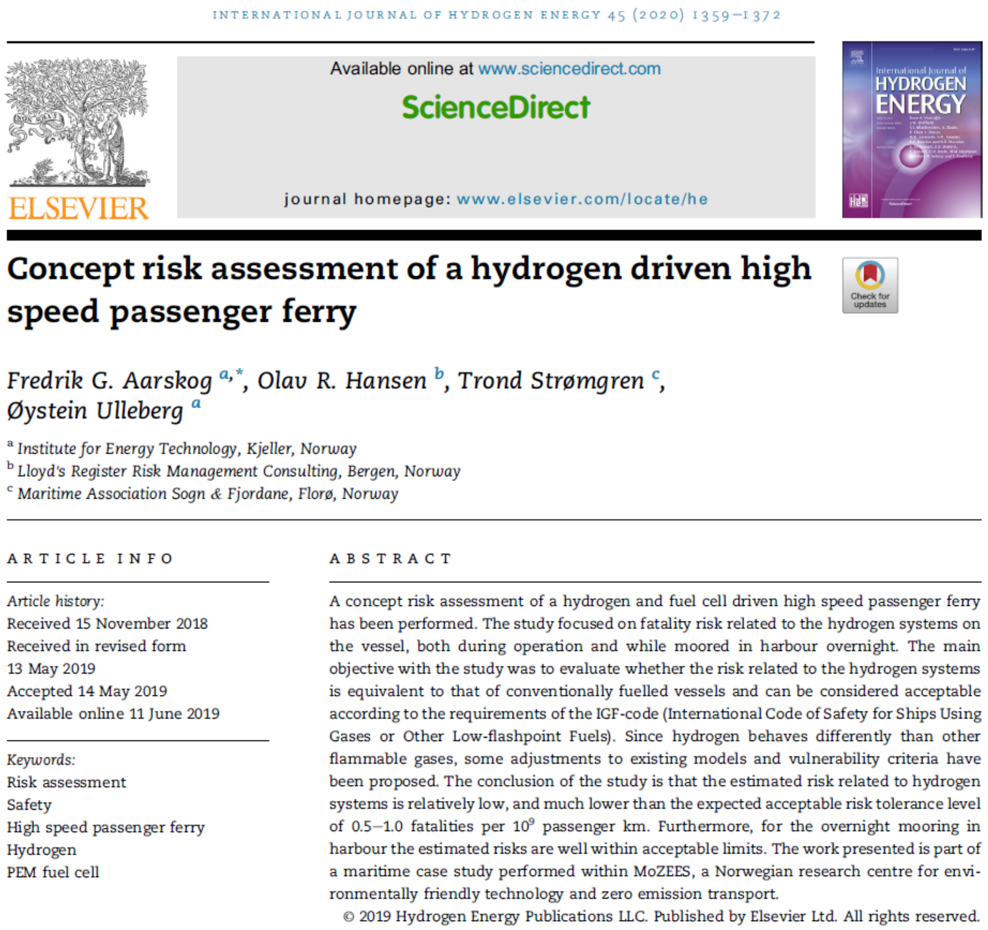
- Approval process for IGF-code – Alternative Design Approach
- New hydrogen ignition probability model
- New vulnerability thresholds
- Vessel design recommendations

Result:

- Risks are well within expected tolerance criteria!

Follow-up:

- KPN H2Maritime-project



INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 45 (2020) 1359–1372

Available online at www.sciencedirect.com

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Concept risk assessment of a hydrogen driven high speed passenger ferry

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ABSTRACT

A concept risk assessment of a hydrogen and fuel cell driven high speed passenger ferry has been performed. The study focused on fatality risk related to the hydrogen systems on the vessel, both during operation and while moored in harbour overnight. The main objective with the study was to evaluate whether the risk related to the hydrogen systems is equivalent to that of conventionally fuelled vessels and can be considered acceptable according to the requirements of the IGF-code (International Code of Safety for Ships Using Gases or Other Low-flashpoint Fuels). Since hydrogen behaves differently than other flammable gases, some adjustments to existing models and vulnerability criteria have been proposed. The conclusion of the study is that the estimated risk related to hydrogen systems is relatively low, and much lower than the expected acceptable risk tolerance level of 0.5–1.0 fatalities per 10^9 passenger km. Furthermore, for the overnight mooring in harbour the estimated risks are well within acceptable limits. The work presented is part of a maritime case study performed within MoZEES, a Norwegian research centre for environmentally friendly technology and zero emission transport.

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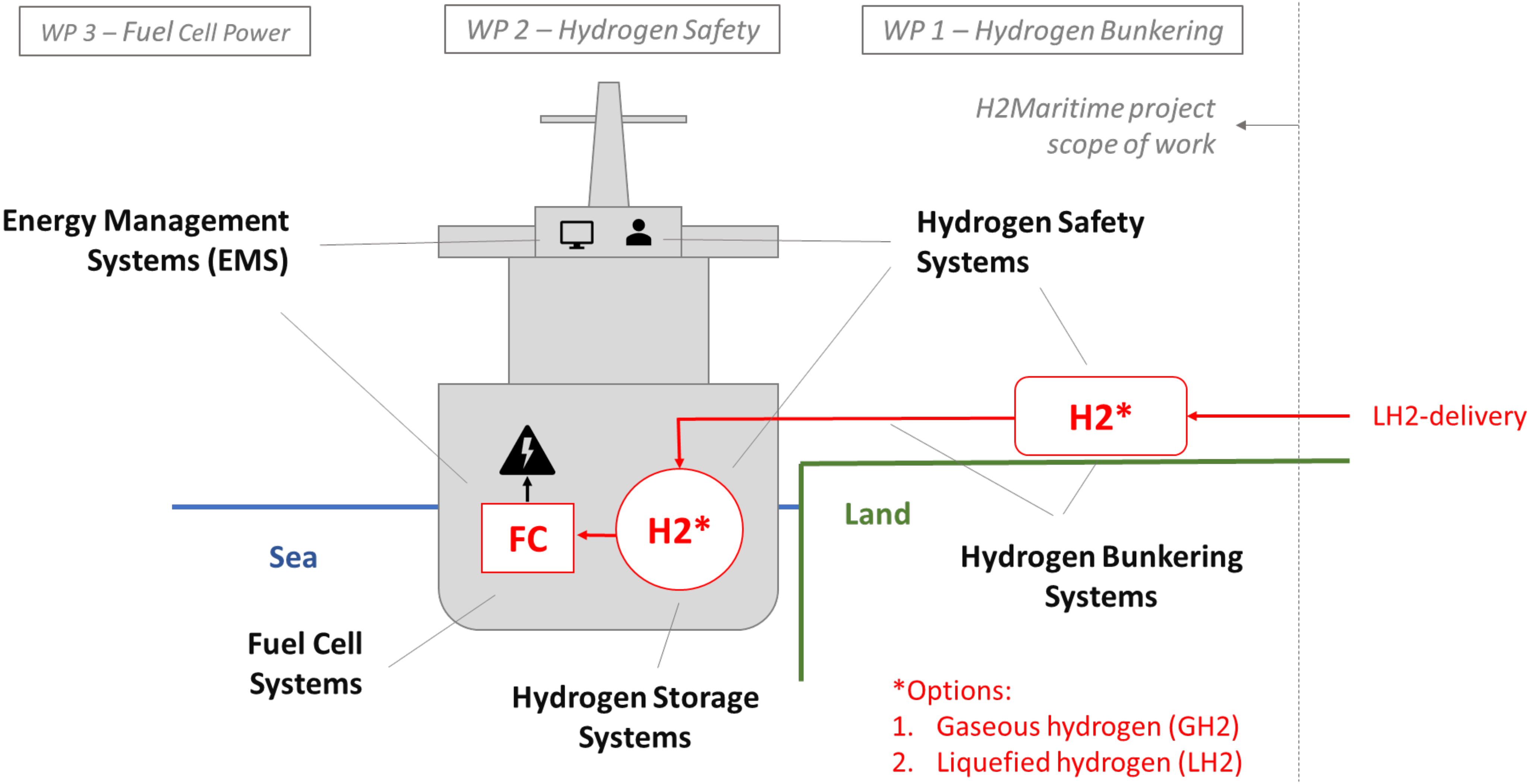
H2Maritime

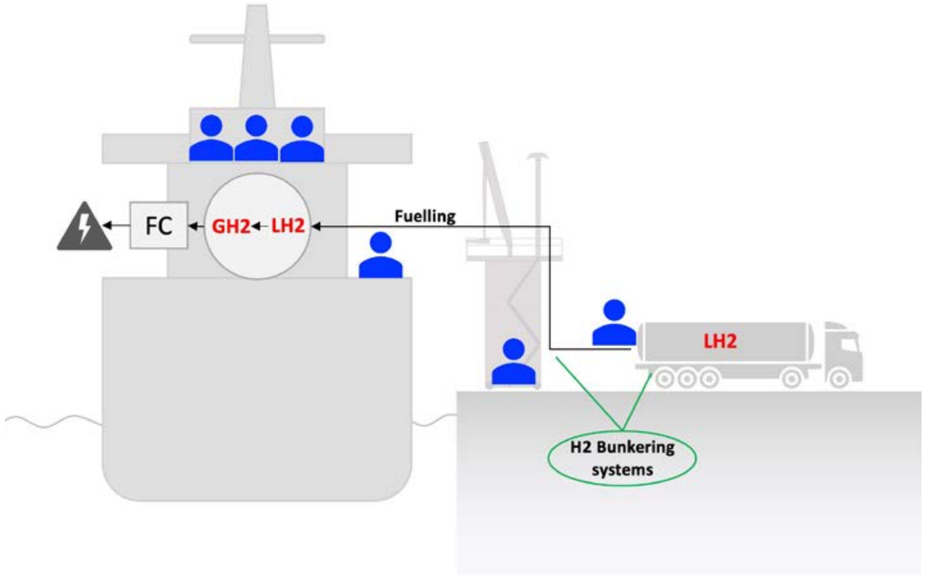
Hydrogen and Fuel Cells for Maritime Applications

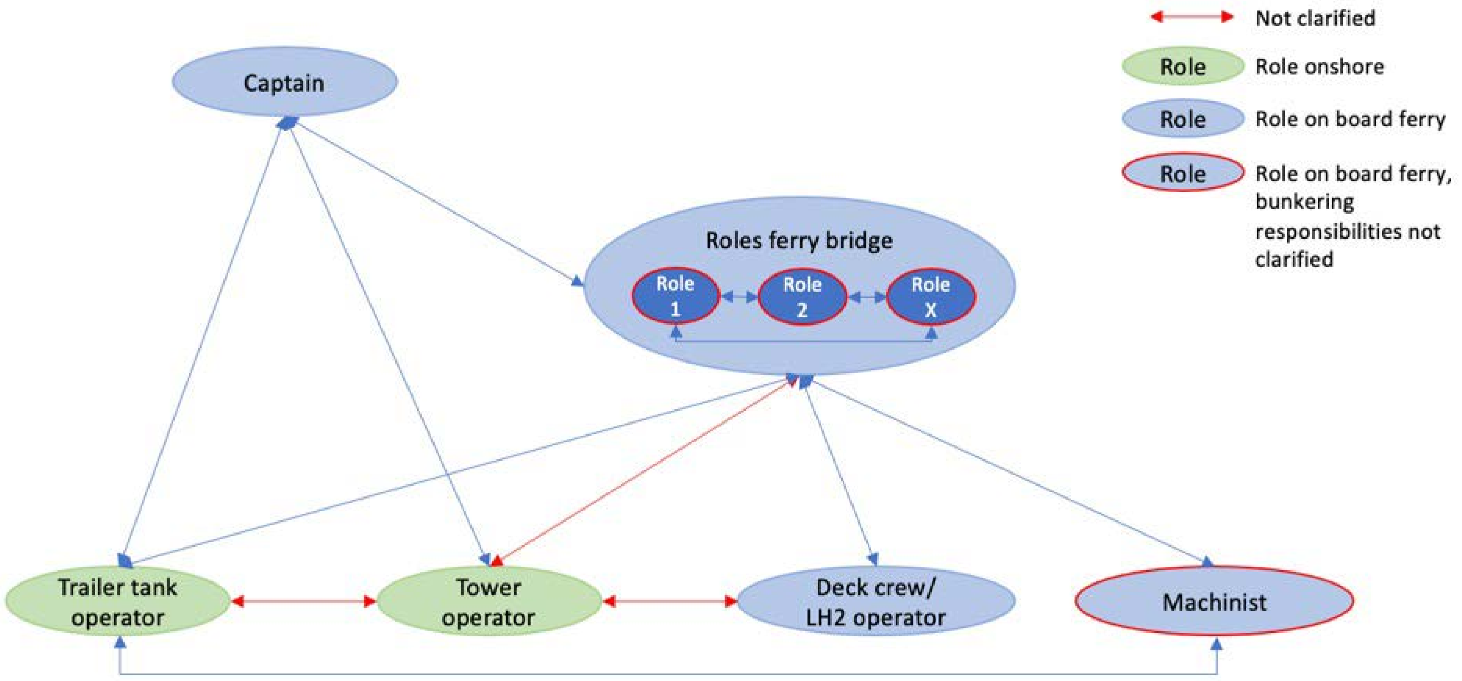


H2Maritime

Hydrogen Safety in Human Operations (WP2)

- How to ensure safe filling and bunkering of hydrogen?
- Use case on LH2-bunkering





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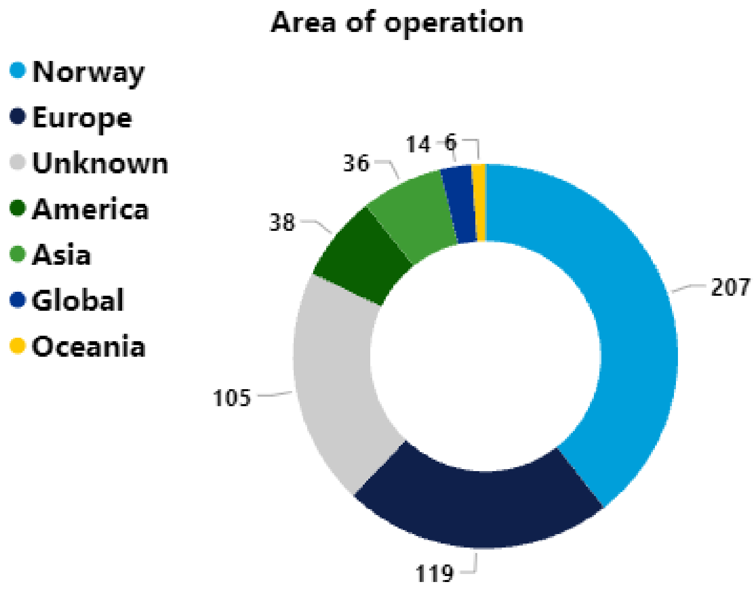
Batteries

Electrification of the Maritime Sector – Norway in the forefront



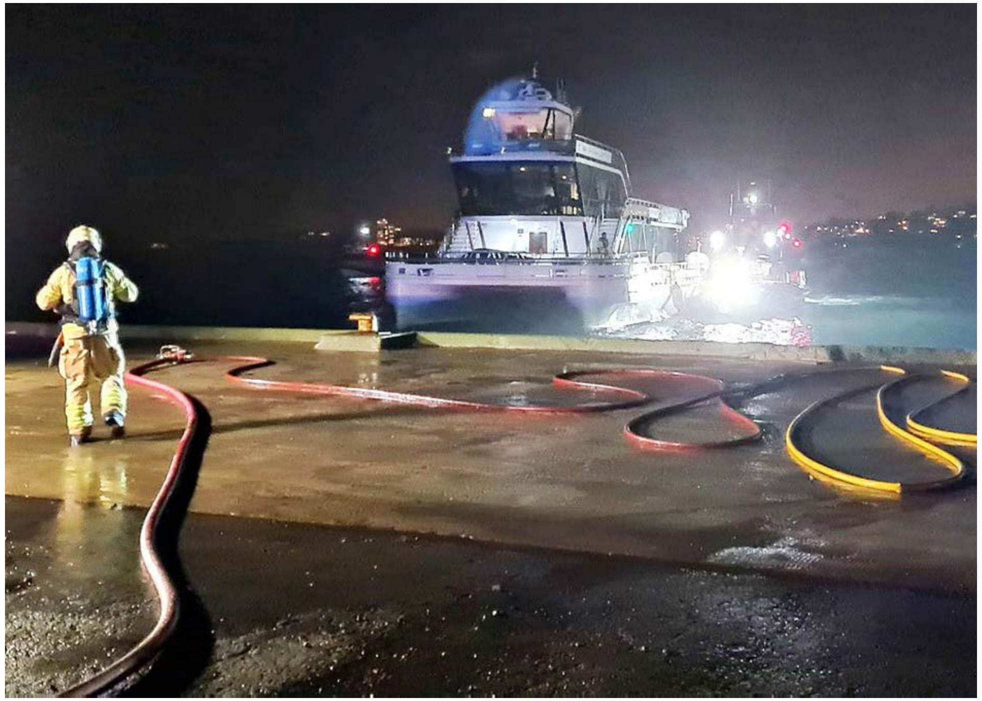
Source: Maritime battery forum ship database 2020

Battery Incidents – Examples

1. MF Ytterøyningen, 10 October 2019
   - Leakage in battery water cooling system → light arch
   - Heating of battery → fire

Source: NRK

2. MF Brim Explorer, 11 March 2021
   - Smoke development and alarm in battery room
   - Fast evacuation of personnel (no passengers)



Source: Vestfold fire department and Corvus Energy

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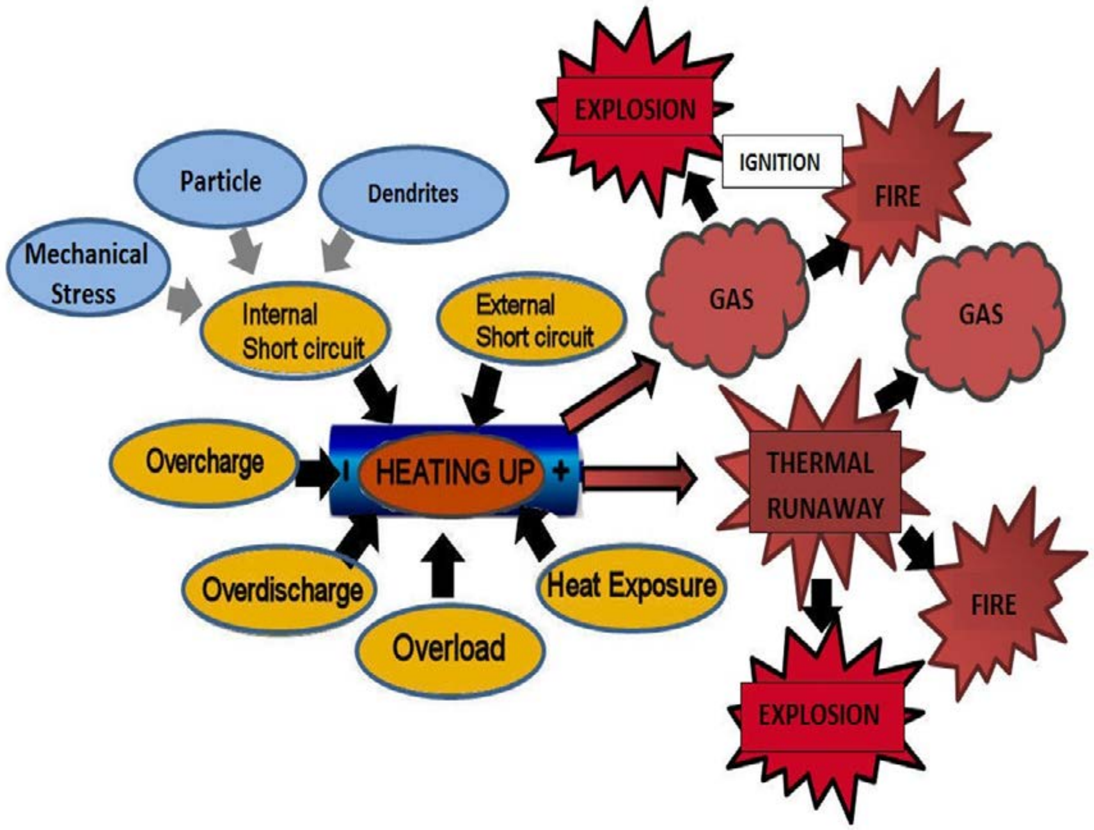
Battery Safety

Standards, regulations & best practice. How to design a thermally robust battery modules

- The Norwegian Maritime Authority (NMA)
  - Administrative and supervisory authority
  - Safety of life, health, material values, and the environment
  - Vessels with Norwegian flag and foreign ships in Norwegian waters
- NMA Circular
  - Detailed description on how to perform battery propagation tests
- Acceptance criteria:
  - No propagation between the modules
  - No propagation between the cells*
    *__Note!__ Requirement for commercial boats < 24 m



MoZEES Battery Safety Research – Examples

1. Explosion characteristics of Li-ion battery electrolytes (Task 3.3)
2. Thermal run-away in Li-ion batteries (Task 3.3)

Battery Safety

Combustion and Explosion Characteristics of Gases Vented from Li-Ion Batteries

Contents lists available at ScienceDirect

Journal of Hazardous Materials

journal homepage: www.elsevier.com/locate/jhazmat

Explosion characteristics for Li-ion battery electrolytes at elevated temperatures

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[b] Norwegian Defence Research Establishment (FFI), Instituttveien 20, 2007, Kjeller, Norway

ARTICLE INFO

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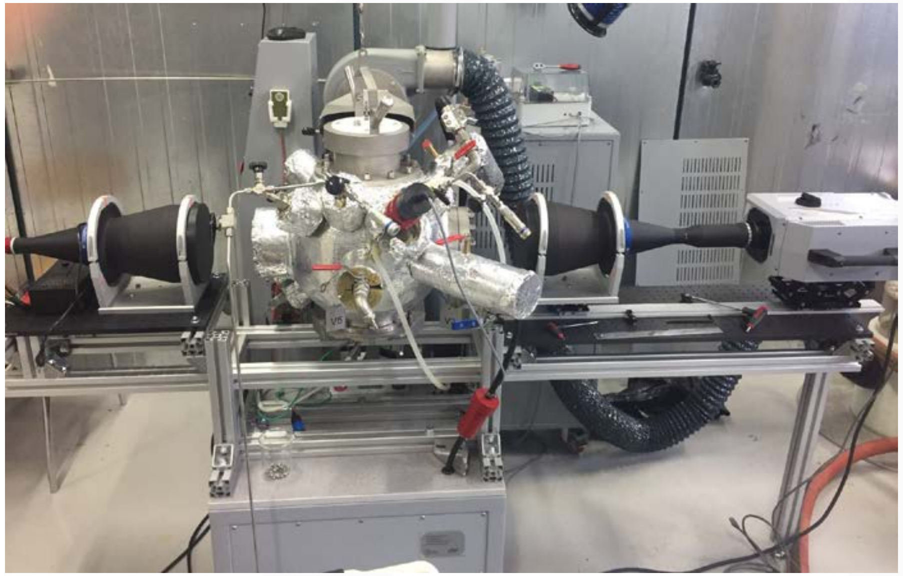
Dimethyl carbonate
Diethyl carbonate
Ethyl methyl carbonate
Maximum explosion pressure
The maximum rate of explosion pressure rise

ABSTRACT

Li-ion batteries are used in electronic devices and electric cars, yet they create safety concerns due to the possibility of the release of combustible materials. The electrolyte, one of the main components in a Li-ion cell, consists of organic carbonates. Venting and thermal runaway release organic carbonates and when mixed with air, it can result in fires and explosions. A 20-liter explosion sphere was used to determine the explosion characteristics for three typical carbonates used in electrolytes, at 373 K, and 100 kPa absolute pressure. The explosion pressure and the maximum rate of explosion pressure rise are presented for the carbonates and for

https://doi.org/10.1016/j.jhazmat.2019.02.108



Explosion Sphere (20 liter) at USN

Safe Battery Design – Requires a Holistic Approach

- Electrically and mechanically robust design
  - including a redundant battery management system
- Responsive surrounding designed to handle a thermal incident in the battery
- Two key research questions:

1. How can we design **thermally robust battery** modules and maintain a **high energy density?**
2. Which method can be used to evaluate the **need for new propagation tests** for batteries with increased cell energy density?

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Battery Safety – Measurement of Thermal Energy

- **Method**
  - Energy released inside battery module during thermal incident can be determined by measuring the increase in temperature for a surrounding enclosure

- **Application of Method**
  - All battery cell types: Cylindrical, prismatic, pouch
  - Different fault conditions: Nail penetration, overcharge, external heating

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Summary

- New battery & hydrogen technology
  → New safety challenges
- Main challenge with hydrogen: Hydrogen leakages
- Main challenge with batteries: Battery fires
- Possible to design safe battery & hydrogen system
  → New standards and regulation required
  → More experience with large systems required
- More **research** required
  → Testing of systems (e.g., LH2-bunkering)
  → Validation of methods (e.g., Li-ion propagation tests)

Sustainable Energy Systems

Source: facebook

Acknowledgements

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Thank you for your attention!

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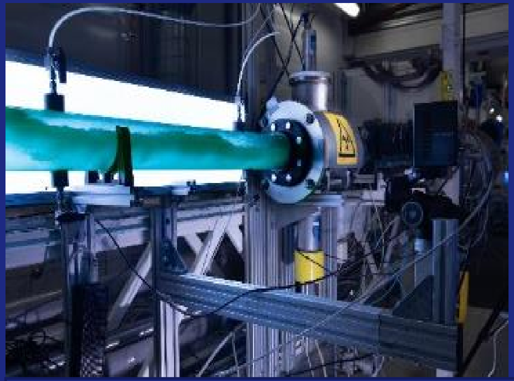
IFE – Advanced Infrastructure & Laboratories


Battery Laboratory

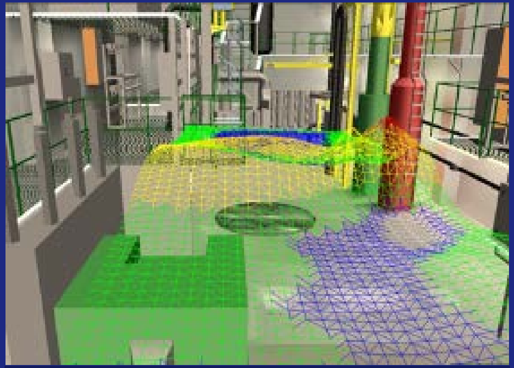

Solar Energy Laboratory


Hydrogen Laboratory


Tracer Tech Laboratory


3-phase Flow Laboratory


Sensor Laboratory


VR Laboratory


Human Behavior Laboratory