ICCMRI7
INNOVATION AND CHALLENGE OF CATALYTIC MEMBRANE TECHNOLOGY

Nanjing, 28th October 2025

Marine auxiliary power from ammonia: a techno-economic assessment of a membrane reactor-based system

V. Cechetto, S. Iosifidou, and F. Gallucci

TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY

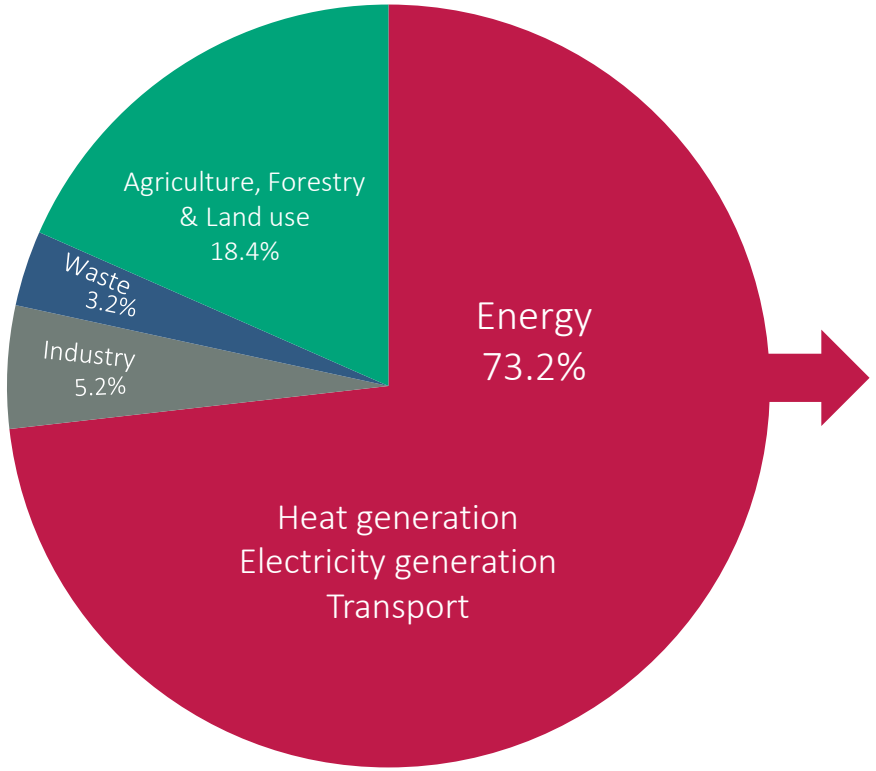
APOLO

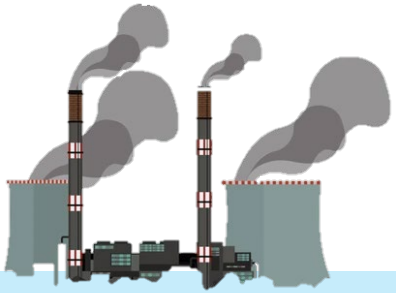
AndreaH

Clean Hydrogen Partnership

Research background

Starting from the **emission challenge** and **energy transition**…





The energy sector mainly relies on the exploitation of *fossil fuels*

The world population is consistently growing alongside the worldwide energy demand

Development of strategies to promote the decarbonization of the energy system

Transportation sector: 24% of the total CO_2 emissions
Shipping: 11% of total CO_2 emissions

Development of strategies to promote the decarbonization of the maritime sector

- *Hannah Ritchie, Climate Watch, the World Resources Institute, 2020*
- "International Energy Agency." [Online]. Available: www.iea.org
- "Alternative fuels outlook for shipping - An overview of alternative fuels from a well-to-wake perspective," Oct. 2022.

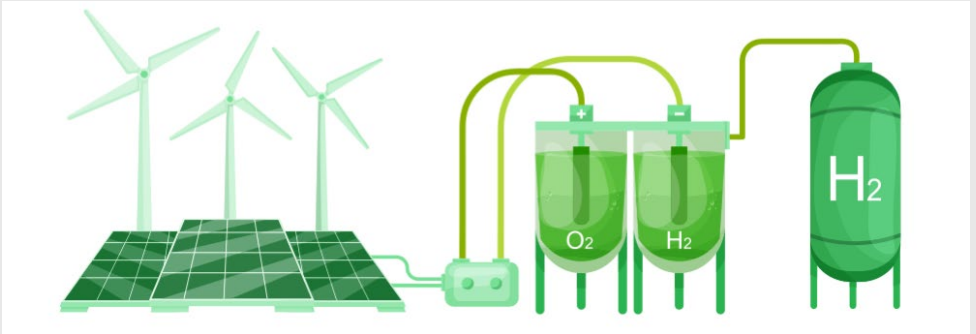
Ammonia as a hydrogen carrier

RENEWABLE ENERGY

Challenge: intermittency

Energy storage in the form of ***dispatchable energy carriers***

Green Hydrogen Production



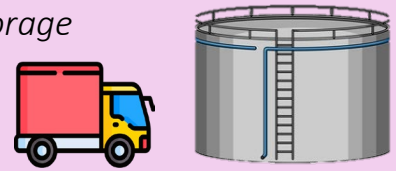
CO_2 FREE

Challenges: storage and transportation

NH_3

- ✓ *Existing infrastructure for transport*
- ✓ *Existing infrastructure for storage*
- ✓ *Carbon free*

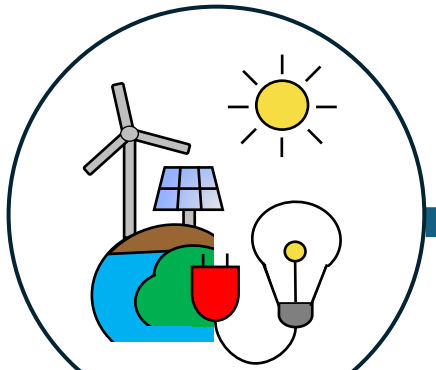
CO_2 FREE



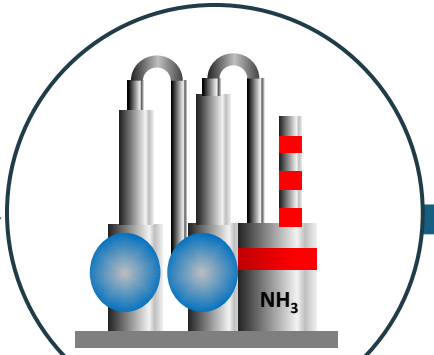
H_2 storage in ***liquid carrier compounds***

- ✓ *Easy transport over long distances*
- ✓ *Easy storage for long time*
- ✓ *Possible in-situ decomposition to produce H_2 when required*

Value chain of green NH_3



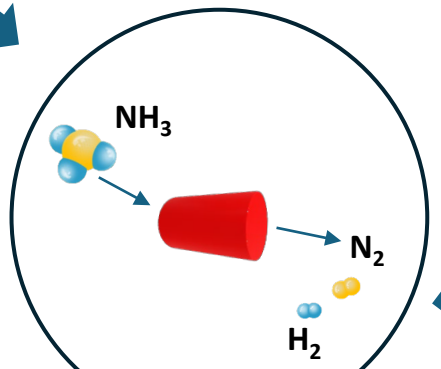
Renewable energy generation



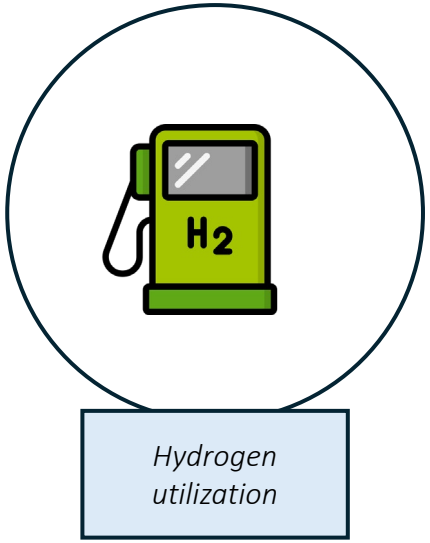
Green ammonia synthesis

Green ammonia transport and storage

Direct green ammonia utilization

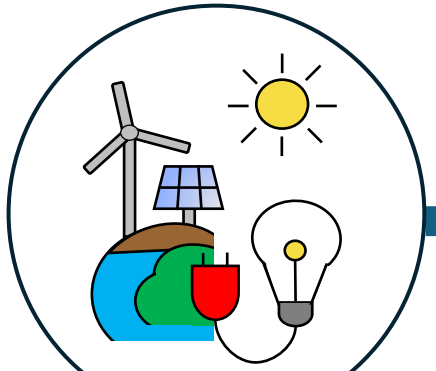


Hydrogen recovery from green ammonia

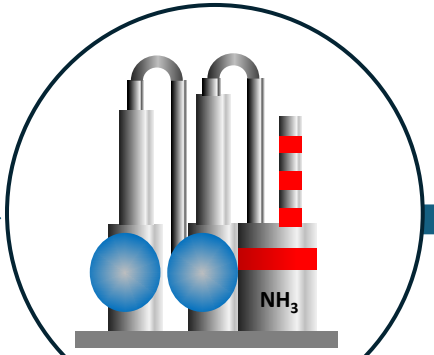


Hydrogen utilization

Value chain of green NH_3



Renewable energy generation



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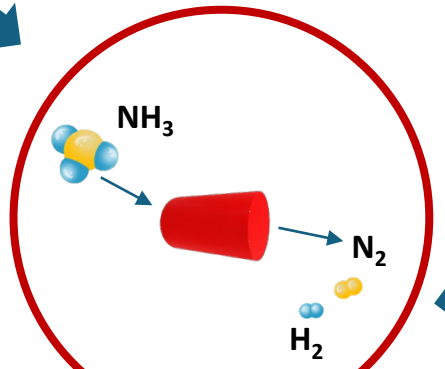

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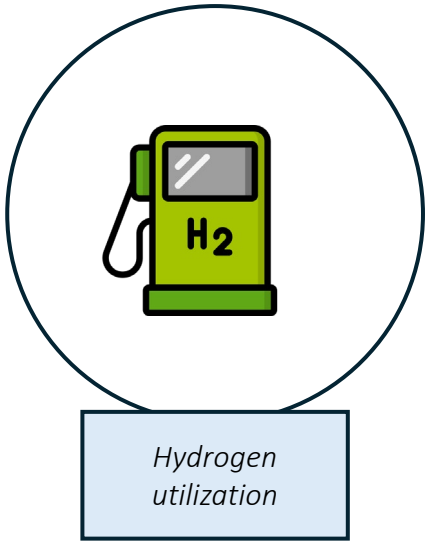


Hydrogen utilization

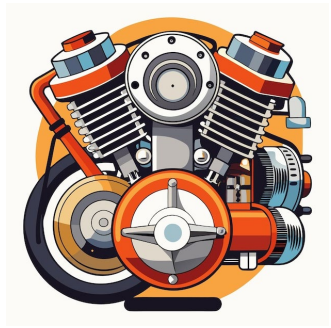
Maritime applications

Ammonia utilization in maritime applications

Applicability:

- ❑ *Auxiliaries*
- ❑ *Propulsion system*

Direct green ammonia utilization



NH_3-based ICEs

Hydrogen recovery from green ammonia

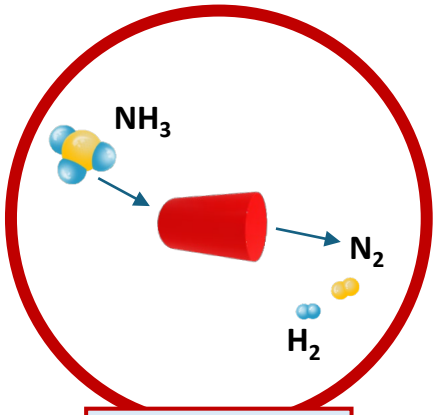
H_2 direct use in PEM fuel cells

Ammonia utilization in maritime applications

Direct green ammonia utilization

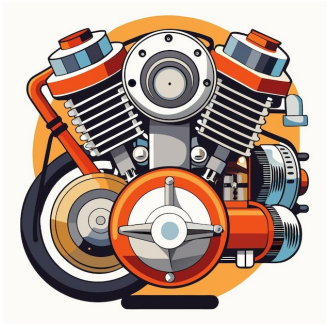
Applicability:

- ❑ *Auxiliaries*
- ❑ *Propulsion system*

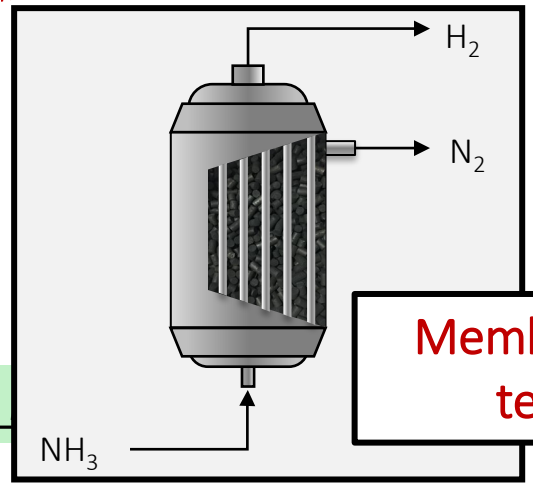


Hydrogen recovery from green ammonia

NH_3 combustion requires H_2 co-fueling



NH_3-based ICEs



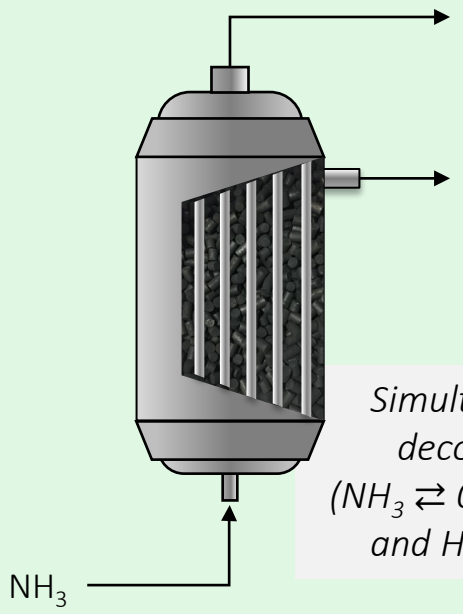
Membrane reactor technology

H_2 direct use in PEM fuel cells

Both the [illegible]

Membrane reactors for H_2 recovery from NH_3

Membrane reactor technology

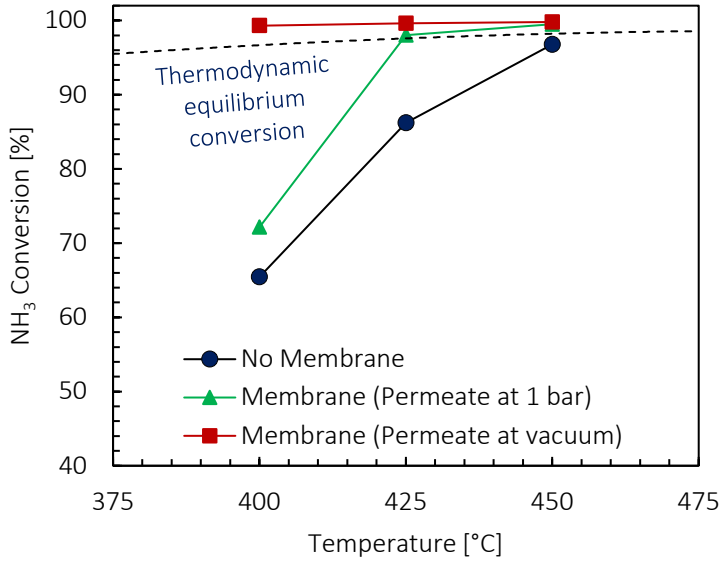


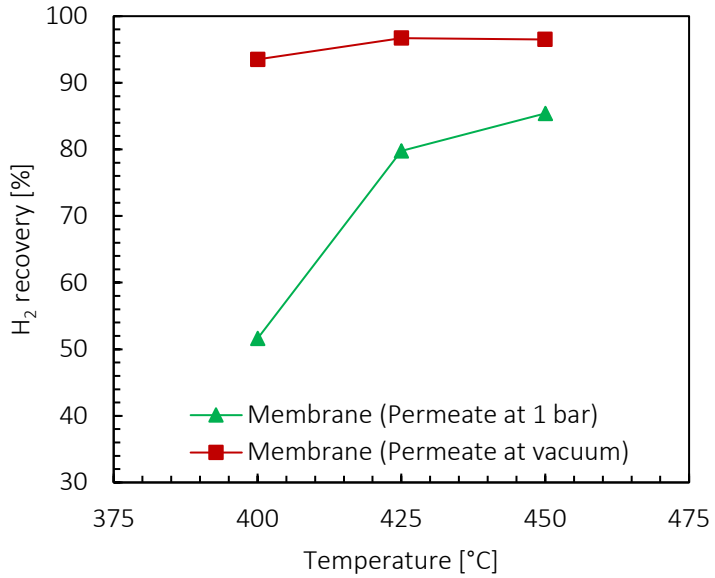
Simultaneous NH_3 decomposition ($NH_3 \rightleftarrows 0.5\ N_2 + 1.5\ H_2$) and H_2 separation

Pd-based membranes

- ❑ High H_2 selectivity
- ❑ High H_2 permeability

***Proof of concept** of membrane reactor technology for hydrogen production from ammonia*





Experimental conditions	
ΔP [bar]	3
Permeate pressure [bar]	0.01-1
Feed flow rate [L_N/min]	0.5
Membrane	Double-skinned Pd-Ag
Thickness selective layer [µm]	~4.61

Compared to conventional systems, a MR allows comparable or higher NH_3 conversion at lower temperature

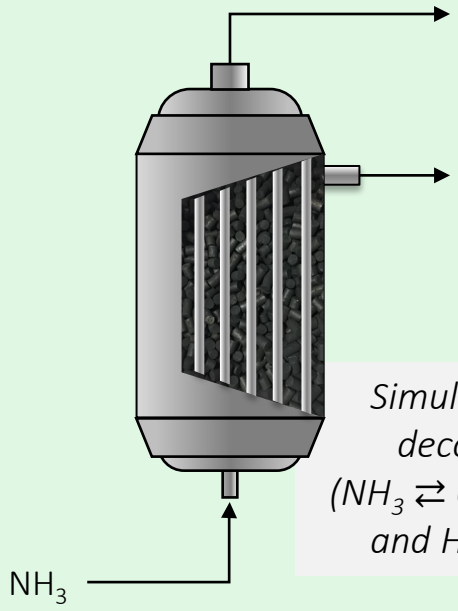
⬇

Higher efficiencies

V. Cechetto, L. Di Felice, J. A. Medrano, C. Makhloufi, J. Zuniga, and F. Gallucci, "H_2 production via ammonia decomposition in a catalytic membrane reactor," Fuel Processing Technology, vol. 216, p. 106772, 2021.

Membrane reactors for H_2 recovery from NH_3

Membrane reactor technology



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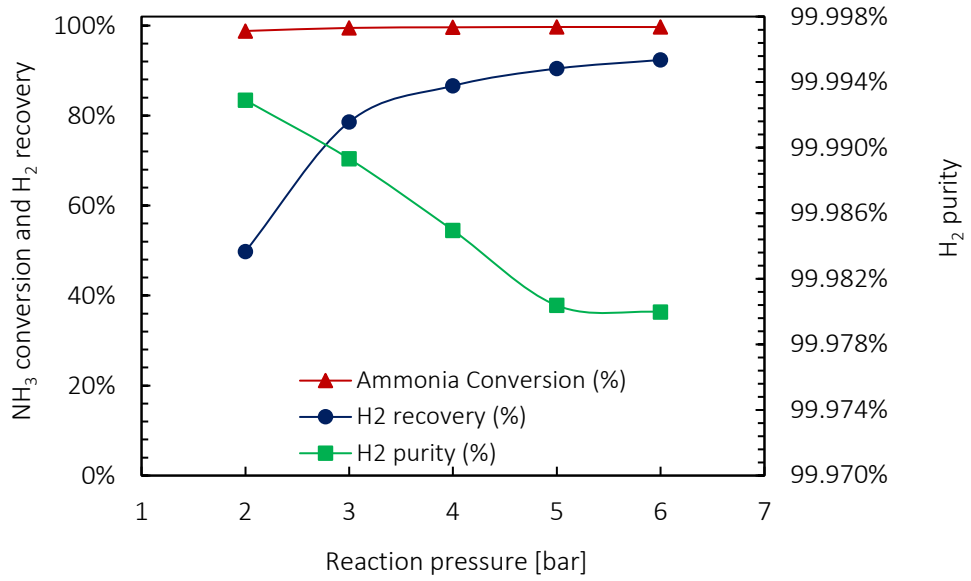


Experimental conditions	
Temperature [°C]	450
Permeate pressure [bar]	1
Feed flow rate [L_N/min]	0.5
Membrane	Double-skinned Pd-Ag
Thickness selective layer [µm]	~4.61

Compared to conventional systems, a MR allows higher NH_3 conversion at comparable pressures

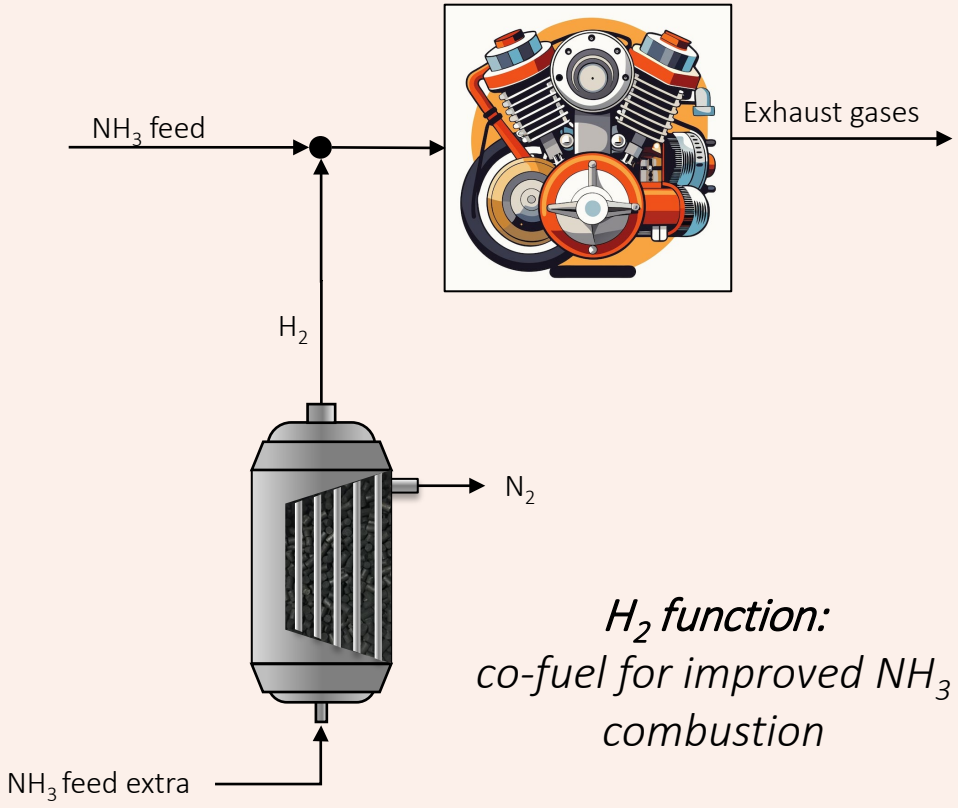
⬇

Higher compactness

V. Cechetto, L. Di Felice, J. A. Medrano, C. Makhloufi, J. Zuniga, and F. Gallucci, "H_2 production via ammonia decomposition in a catalytic membrane reactor," Fuel Processing Technology, vol. 216, p. 106772, 2021.

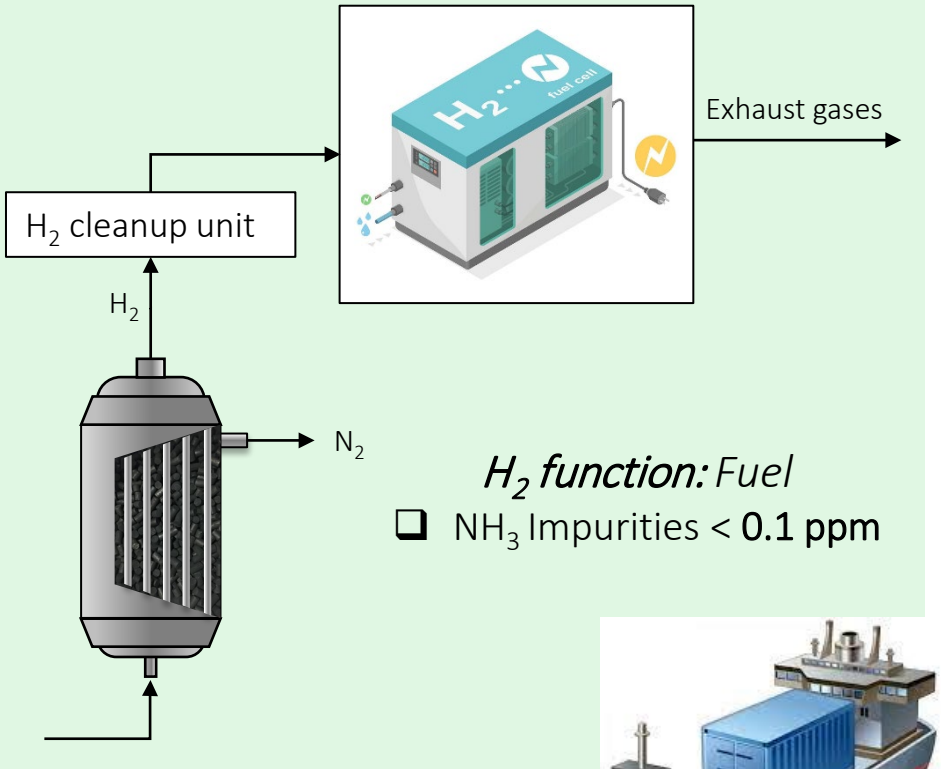
Techno-economic assessment

Alternative 1: ICE-based system



H_2 function:
co-fuel for improved NH_3 combustion

Alternative 2: PEMFC-based system



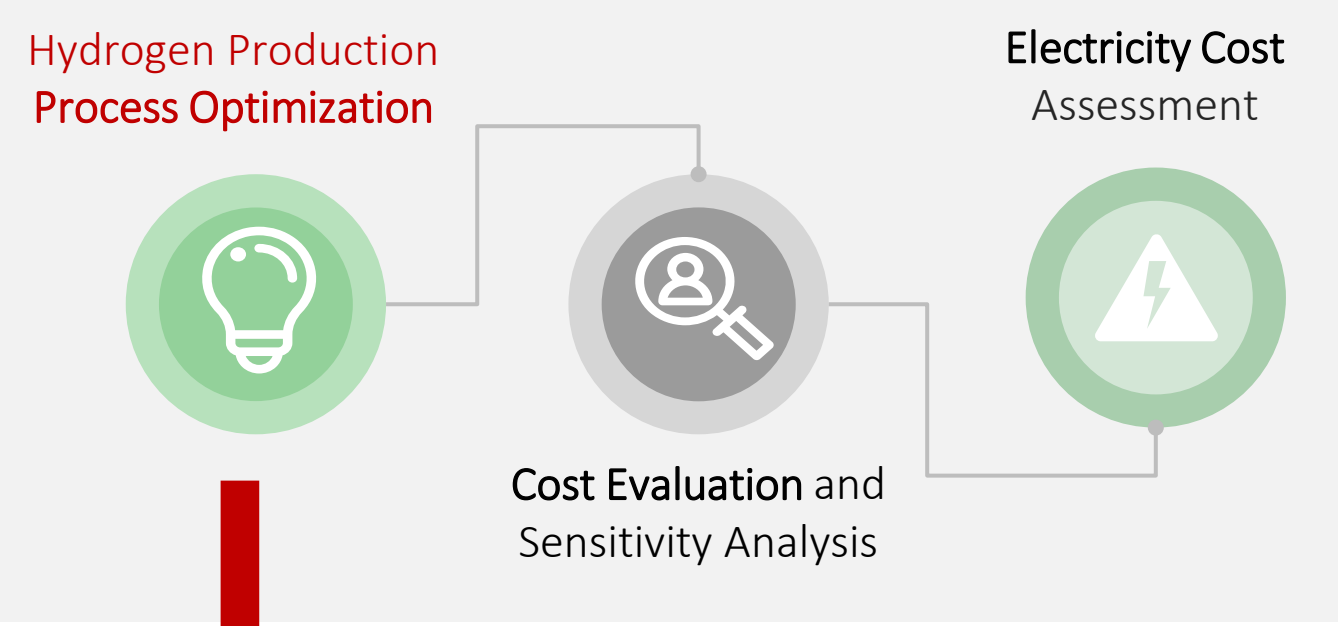
H_2 function: *Fuel*

- NH_3 Impurities < **0.1 ppm**

Which alternative is more economically viable for auxiliary power generation?

Process design and optimization

Methodology



1 **Objective Function**

Minimization of the cost of H_2 production

$$\text{LCOH}\left[\frac{€}{kg_{H_2}}\right] = \frac{TCC \times CCF + C_{O\&M,fix} + C_{O\&M,var} \times h_{eq}}{\text{Production Capacity}\left[\frac{kg_{H_2}}{y}\right] \times h_{eq}}$$

2 **Design Variables**

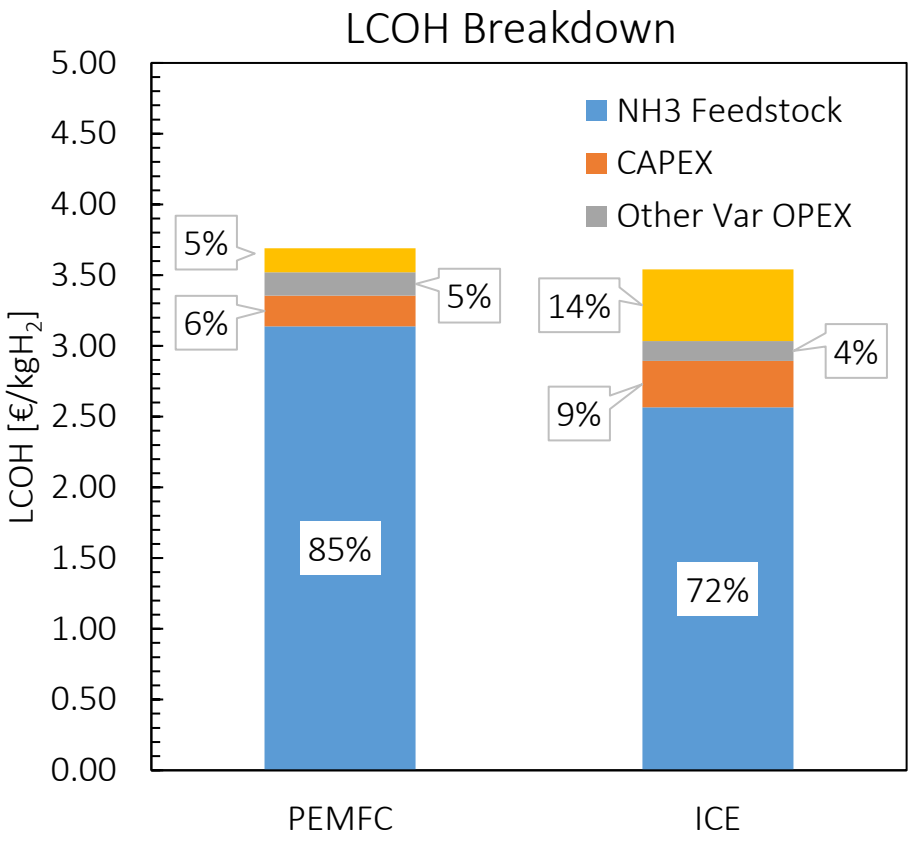
- ❑ Reactor Geometry (L, N_{mem})
- ❑ Ammonia Feedstock
- ❑ Operating pressure and temperature
- ❑ Balance-of-Plant Configuration

3 **Constraints**

- ❑ Hydrogen production target
- ❑ Ammonia Conversion ≥ 99%

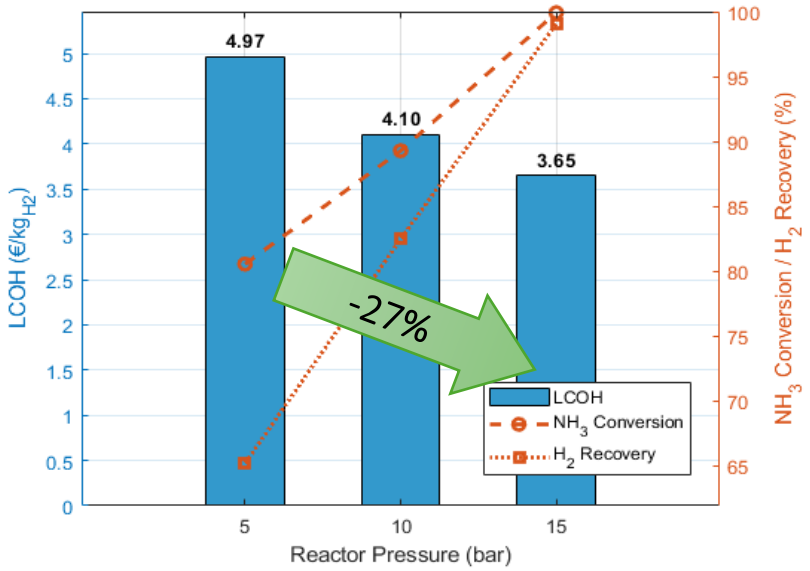
Economic evaluation

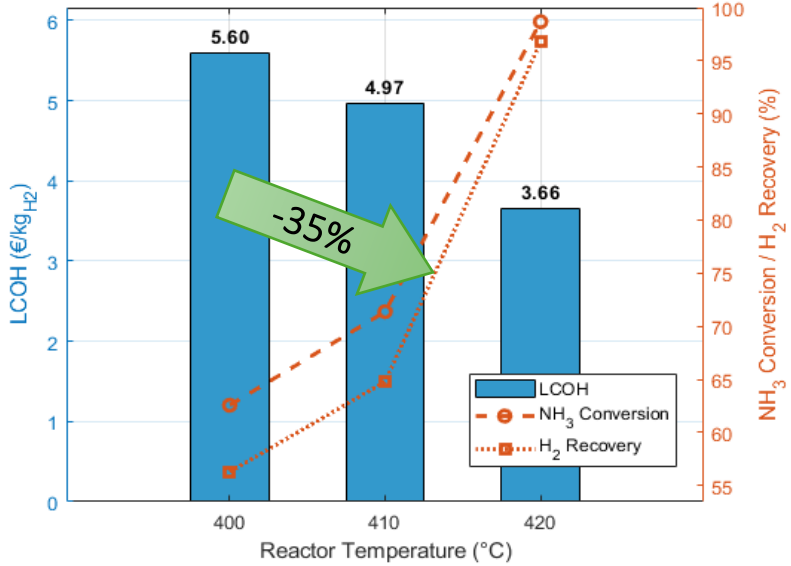
H_2 production process



NH_3 is the main contributor to LCOH

PEMFC-case

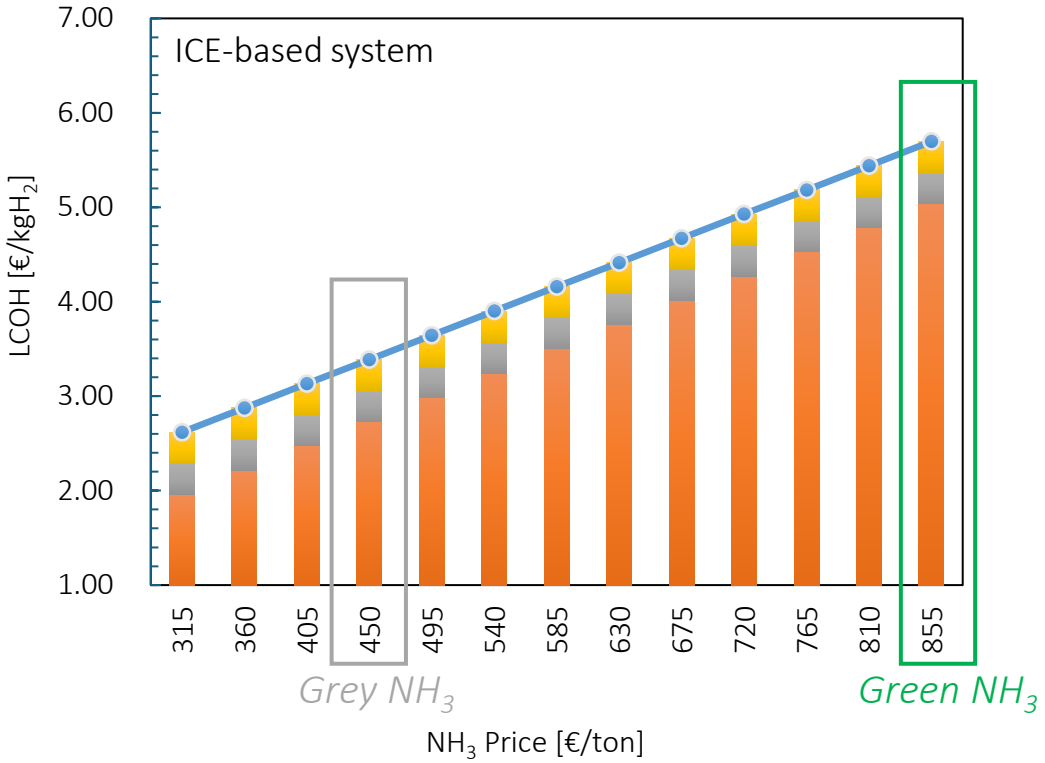




Minimization of LCOH is obtained through **maximization of NH_3 conversion**

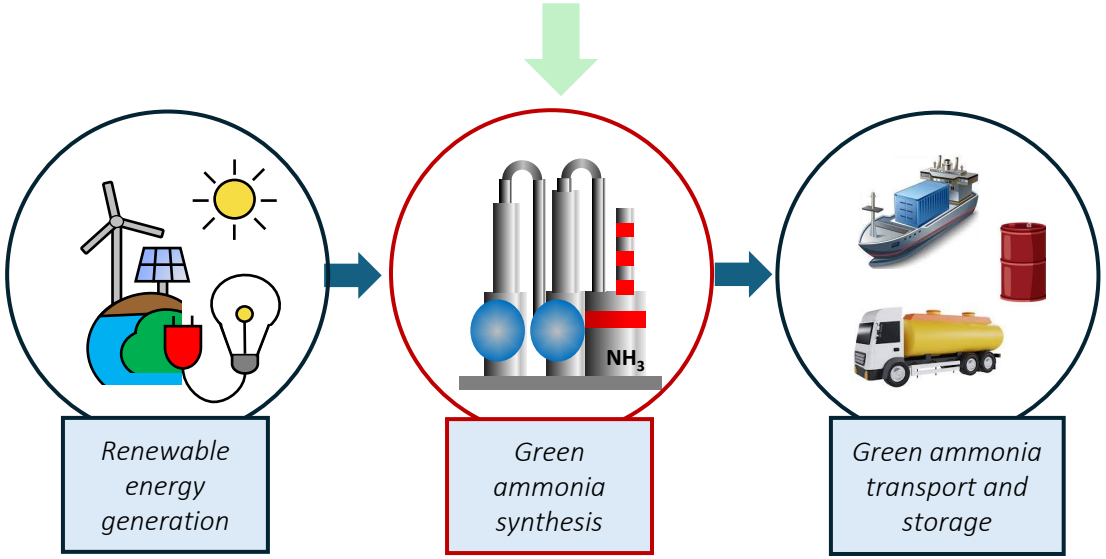
Sensitivity analysis on H_2 production cost

H_2 production process



Var OPEX | Fixed OPEX | CAPEX

NH_3 is the main contributor to LCOH



Urgency to lower the cost of green NH_3 production

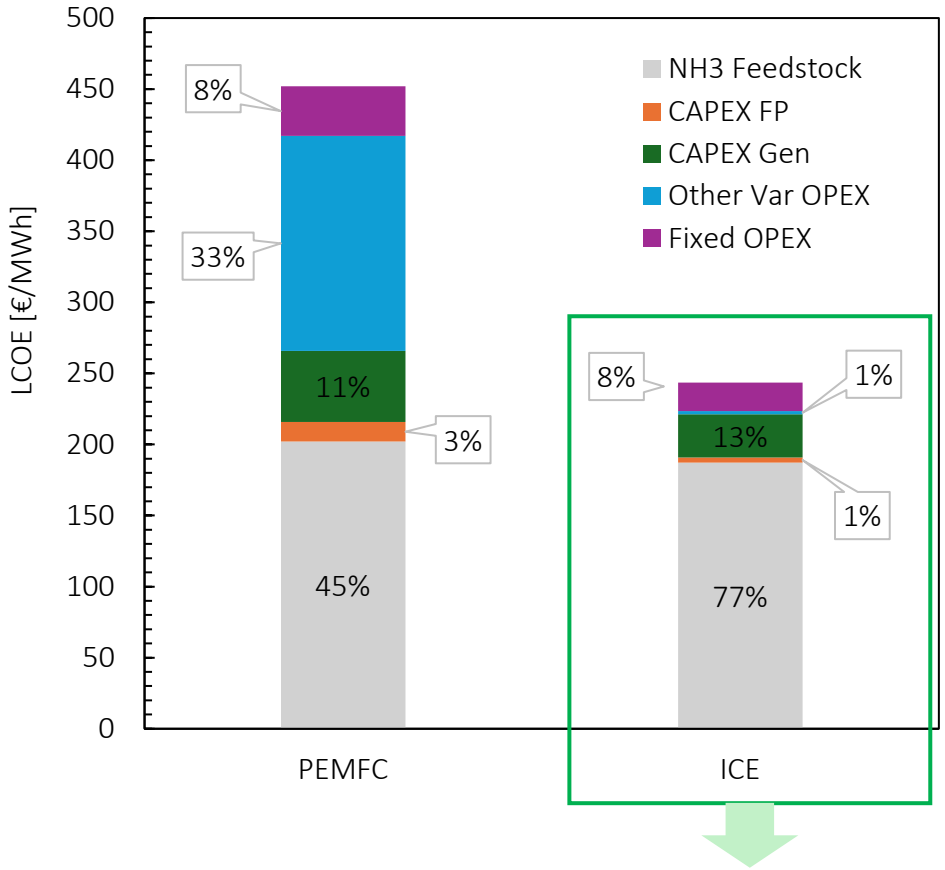
Economic evaluation

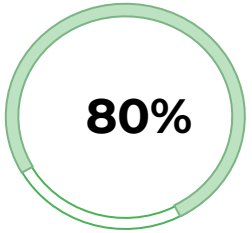
Cost of Electricity

$$\mathrm{LCOE}\left[\frac{€}{\mathrm{MWh}}\right] = \frac{\mathrm{TCC} \times \mathrm{CCF} + \mathrm{C_{O\&M,fix}} + \mathrm{C_{O\&M,var}} \times \mathrm{h_{eq}}}{\text{Production Capacity}\left[\frac{\mathrm{MWh}}{\mathrm{y}}\right] \times \mathrm{h_{eq}}}$$

These are preliminary results!!!

Trends and conclusions of this study may be subject to changes as a result of changes in assumptions

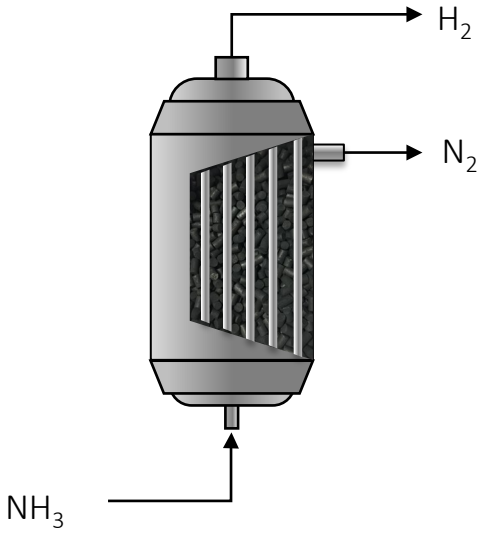




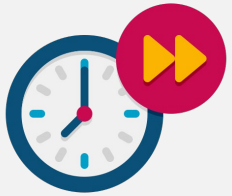
Share of **Variable Costs**

- ❑ Lower LCOE
- ❑ Simultaneous generation of high-pressure steam

Conclusions and outlook



- The **membrane reactor technology** could be integrated in onboard applications contributing to the decarbonization of the **maritime sector** through the utilization of NH_3 as fuel.
- **The cost of auxiliary power generation** in this case is mainly driven by OPEX, and particularly by the cost of the NH_3 feedstock.



Evaluation of the impact on the techno-economics of the process of:

- Partial load functioning of ICE/PEMFC
- ICE/PEMFC efficiencies
- Utilization of membranes different than Pd-based ones
- Different economic assumptions

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Thank you for your attention

TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY

Clean Hydrogen Partnership

APOLO

AndreaH

This project receives support from the European commission under grant agreement No. 101138466 (APOLO project) and No. 101112118 (ANDREAH project). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union.