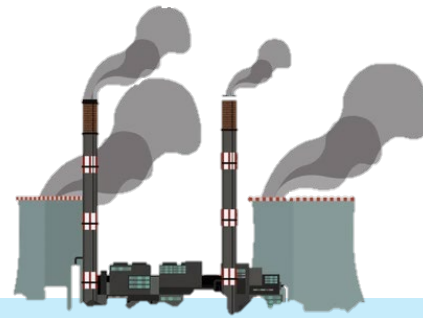
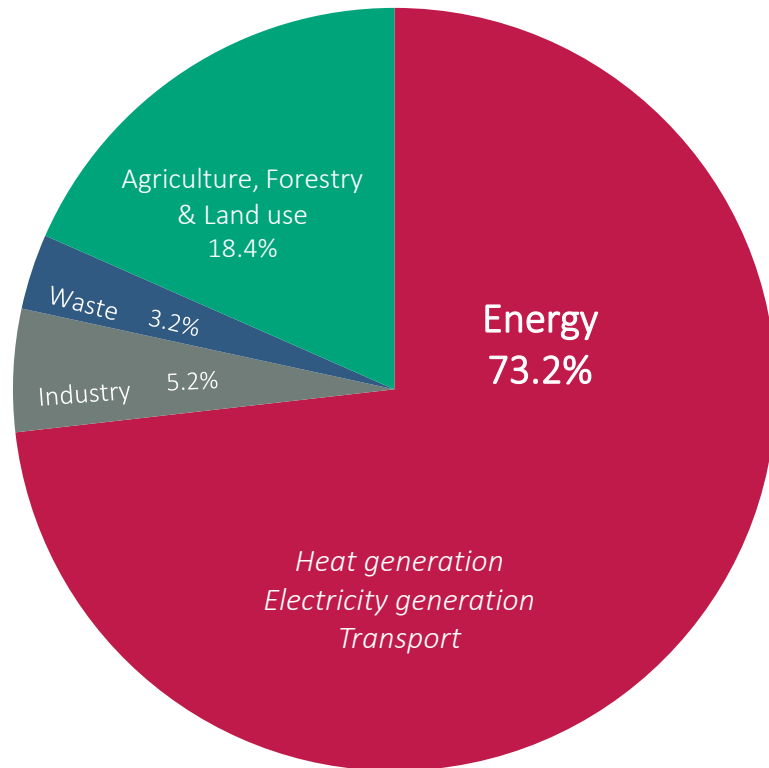


Performance evaluation of structured POCS catalysts for hydrogen production via ammonia decomposition

V. Cechetto, A. Vita, and F. Gallucci

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



- 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

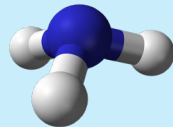
Renewable energy



*Energy storage in
the form of
dispatchable
energy carriers*

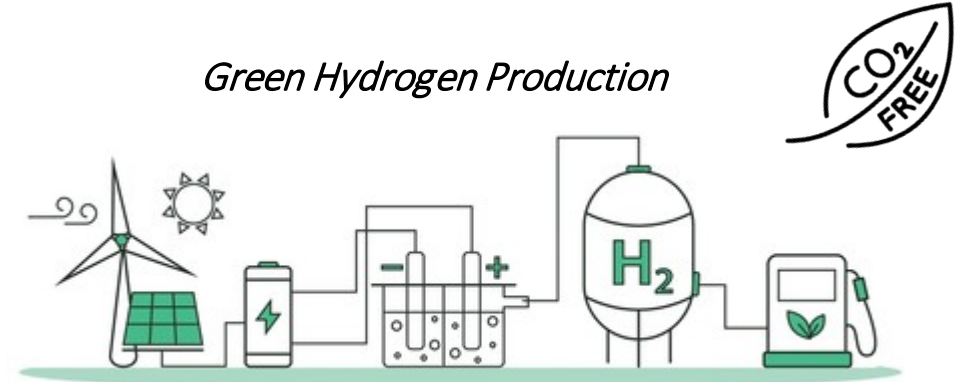
Challenges:

- Intermittency
- Availability far from end-use point



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

Green Hydrogen Production



Challenges:

- storage
- transportation

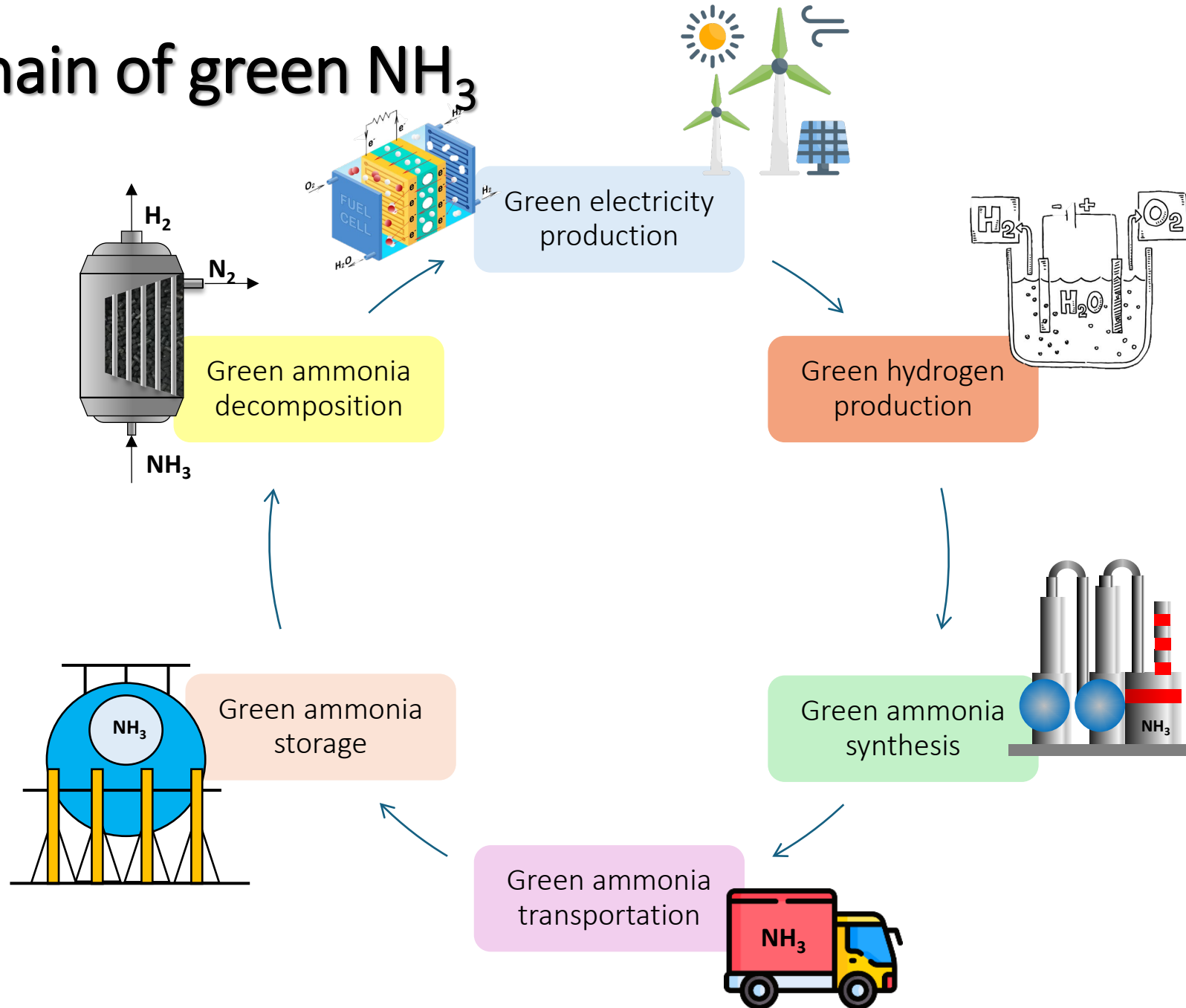
H₂ storage in liquid carrier compounds

Advantages

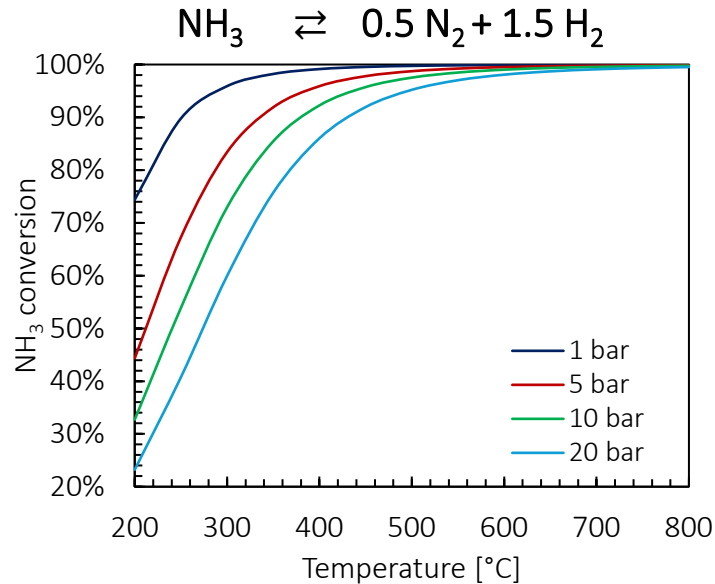
- Easy transport over long distances
- Easy storage for long time
- Possible in-situ decomposition to produce H₂ when required



Value chain of green NH_3



Ammonia decomposition



- Endothermic reaction → Favored at high temperatures
- Molar expansion → Favored at low pressures

Efficient catalytic decomposition of ammonia challenging due to:

- thermodynamic limitations
- the strongly endothermic nature of the reaction
- the need for high hydrogen throughput with minimal reactor volume

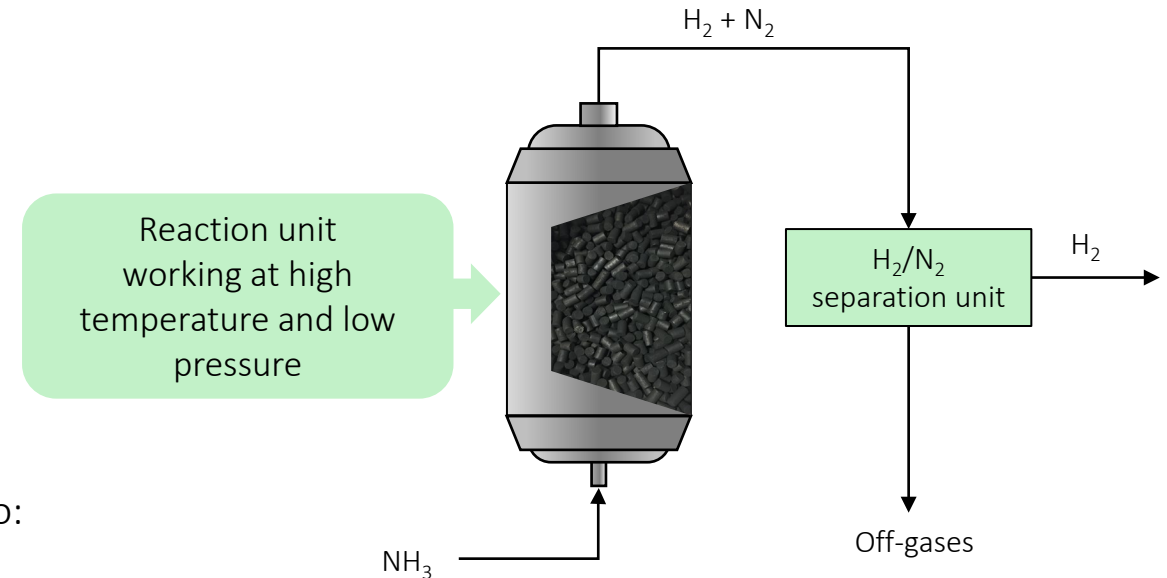
NH_3 decomposition is usually performed catalytically on Ni- or Ru-based catalysts.



- Not abundant in nature
- Expensive
- Operating $T > 400^\circ\text{C}$

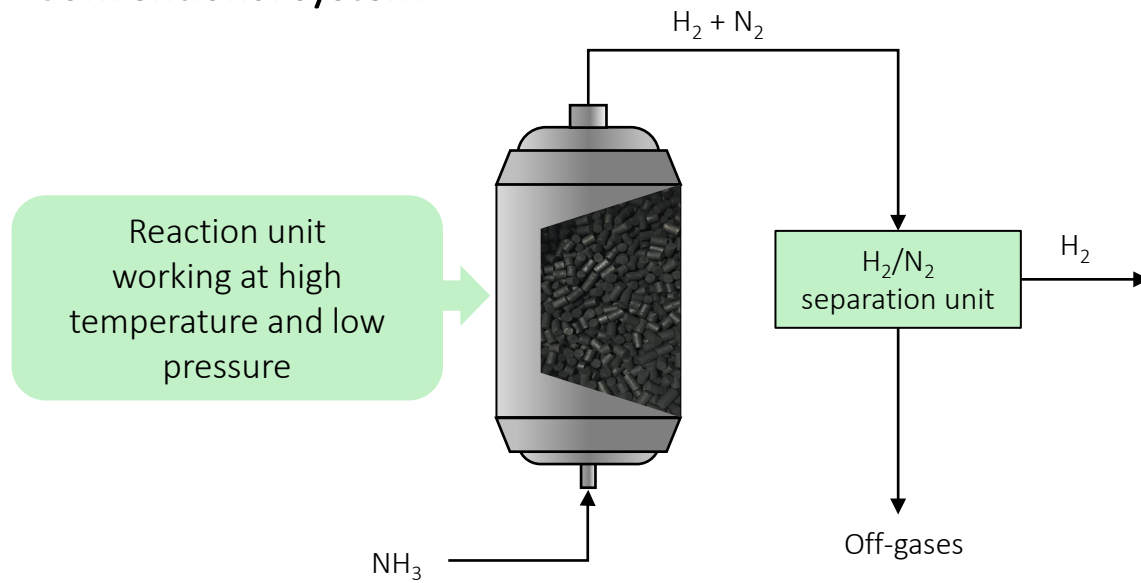


- Abundant in nature
- Relatively inexpensive
- Operating $T > 600^\circ\text{C}$

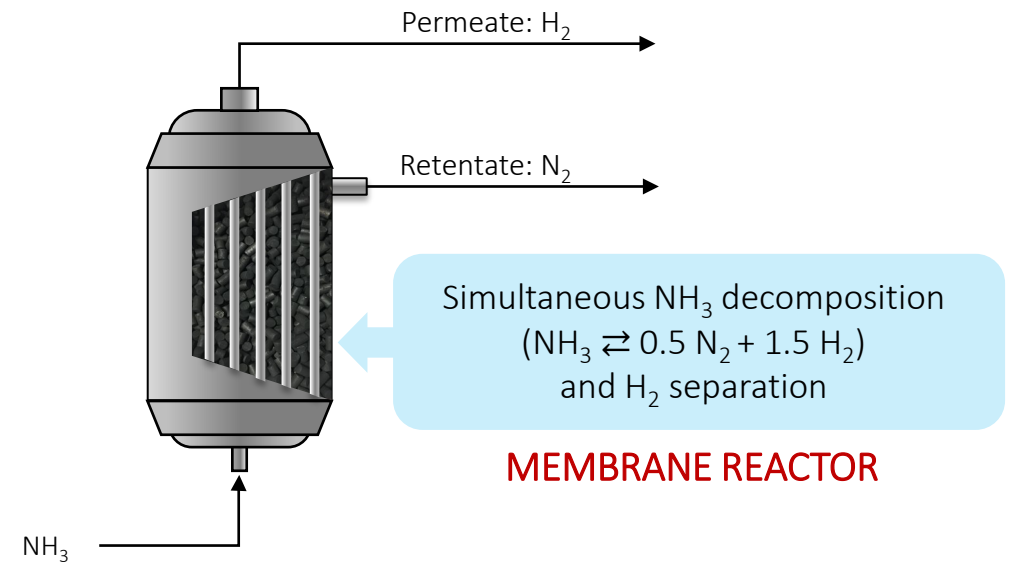


Ammonia decomposition

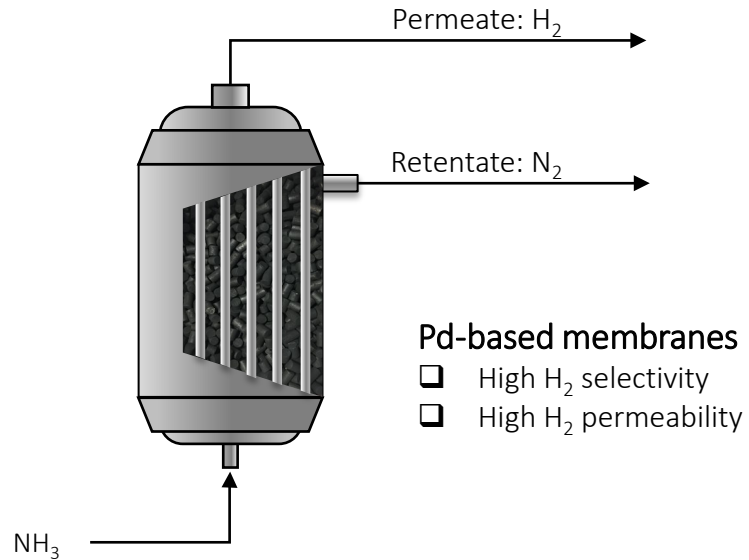
Conventional system



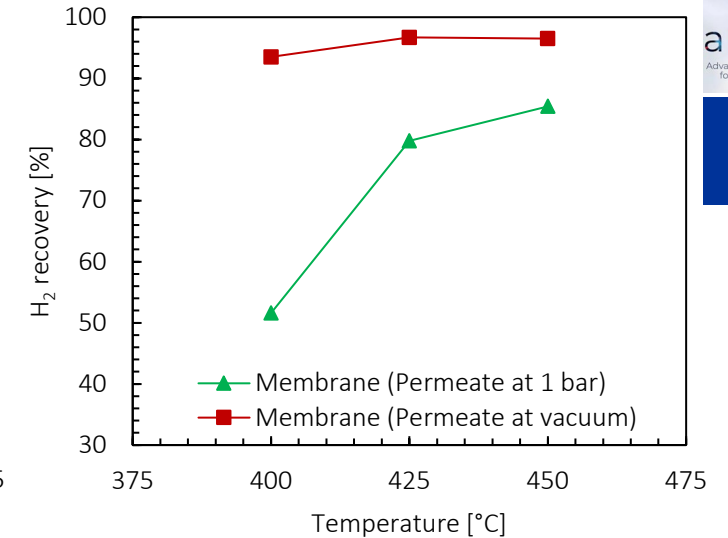
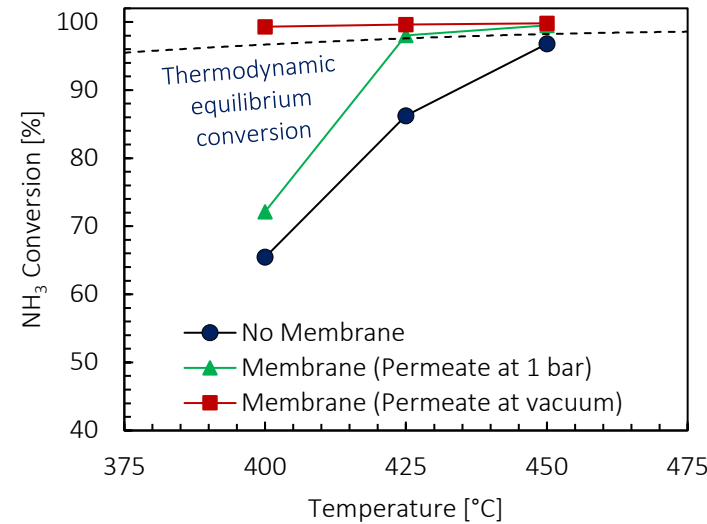
Novel system



Membrane reactors for ammonia decomposition



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

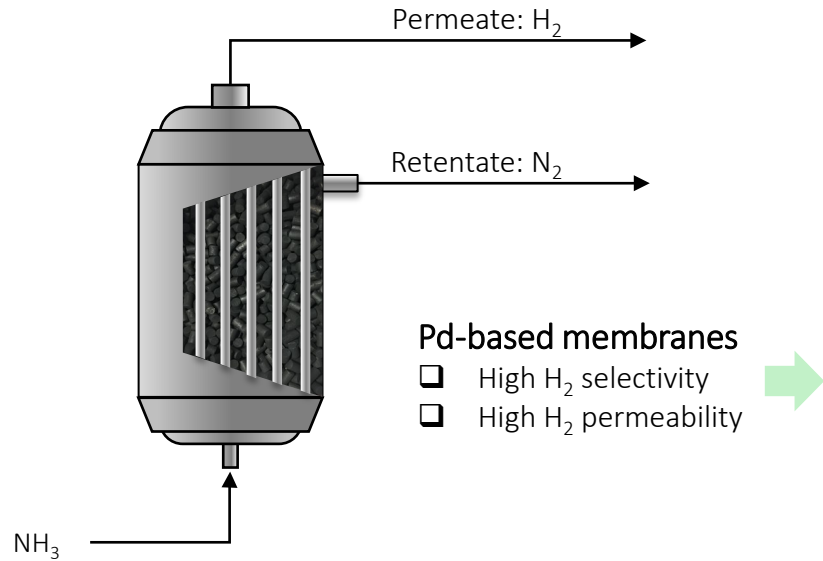


Compared to conventional systems, a MR allows comparable or higher NH_3 conversion at lower temperature
Higher efficiency

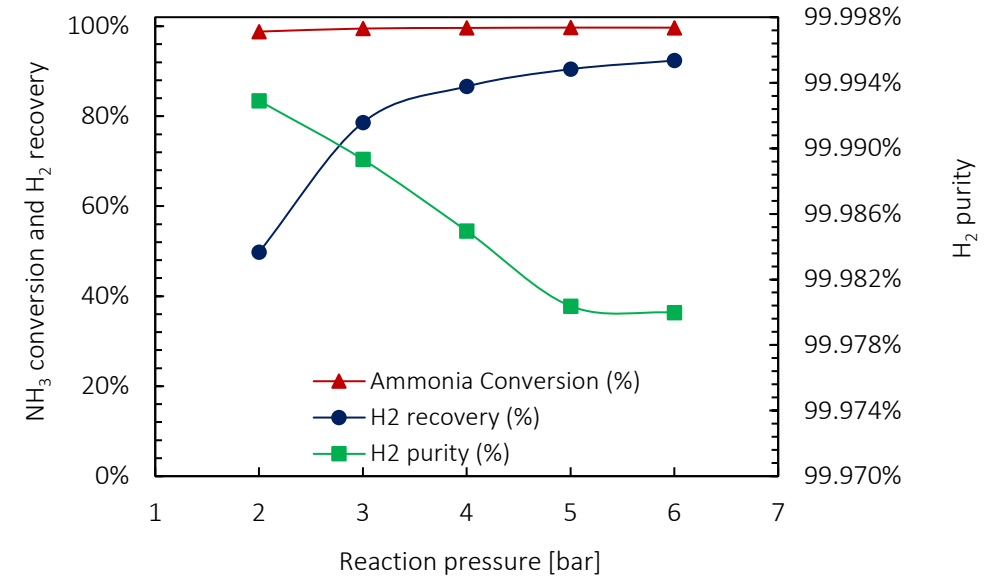
Experimental conditions	
ΔP [bar]	3
Permeate pressure [bar]	0.01-1
Feed flow rate [$\text{L}_\text{N}/\text{min}$]	0.5
Membrane	Double-skinned Pd-Ag
Thickness selective layer [μm]	~ 4.61



Membrane reactors for ammonia decomposition



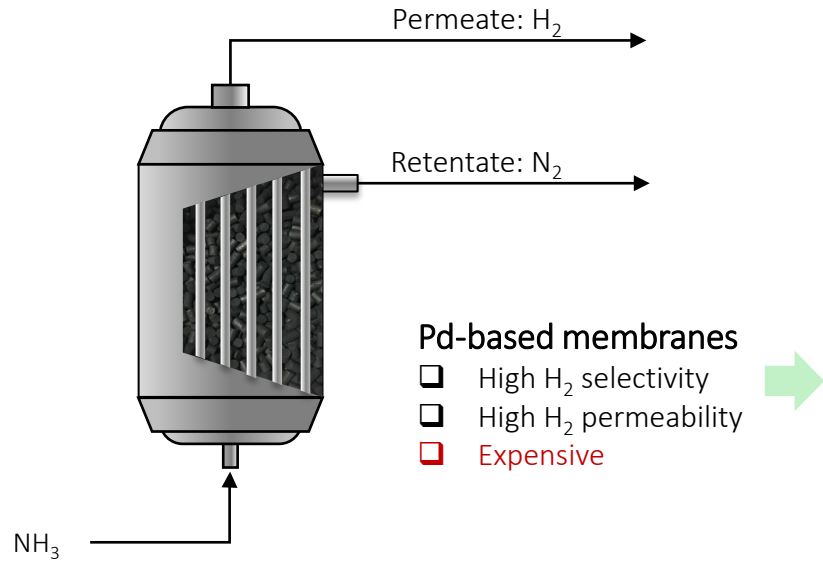
Proof of concept of membrane reactor technology for hydrogen production from ammonia



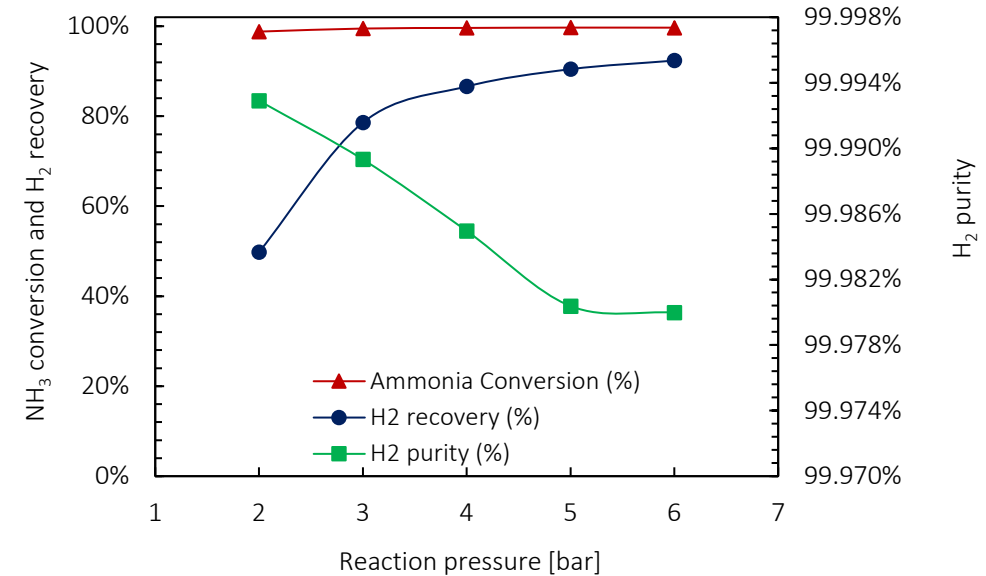
Compared to conventional systems, a MR allows higher NH_3 conversion at comparable pressures
Higher compactness

Experimental conditions	
Temperature [°C]	450
Permeate pressure [bar]	1
Feed flow rate [$\text{L}_\text{N}/\text{min}$]	0.5
Membrane	Double-skinned Pd-Ag
Thickness selective layer [μm]	~4.61

Membrane reactors for ammonia decomposition



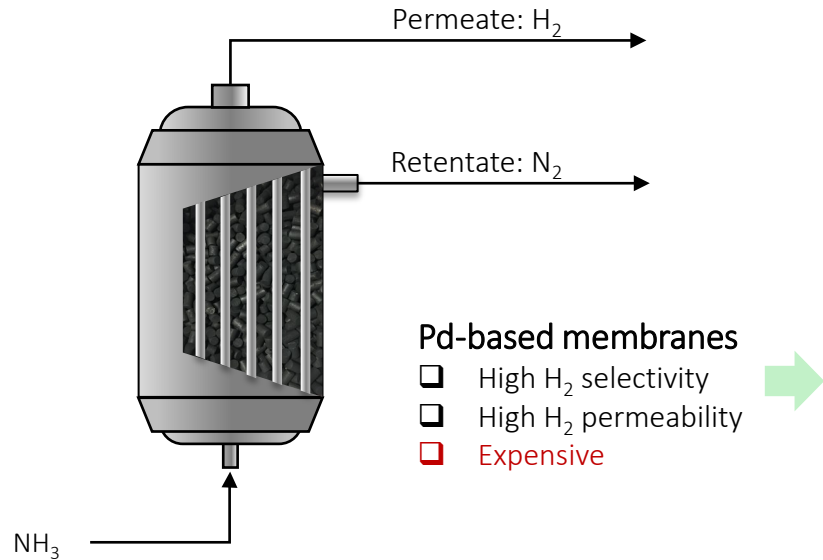
Proof of concept of membrane reactor technology for hydrogen production from ammonia



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

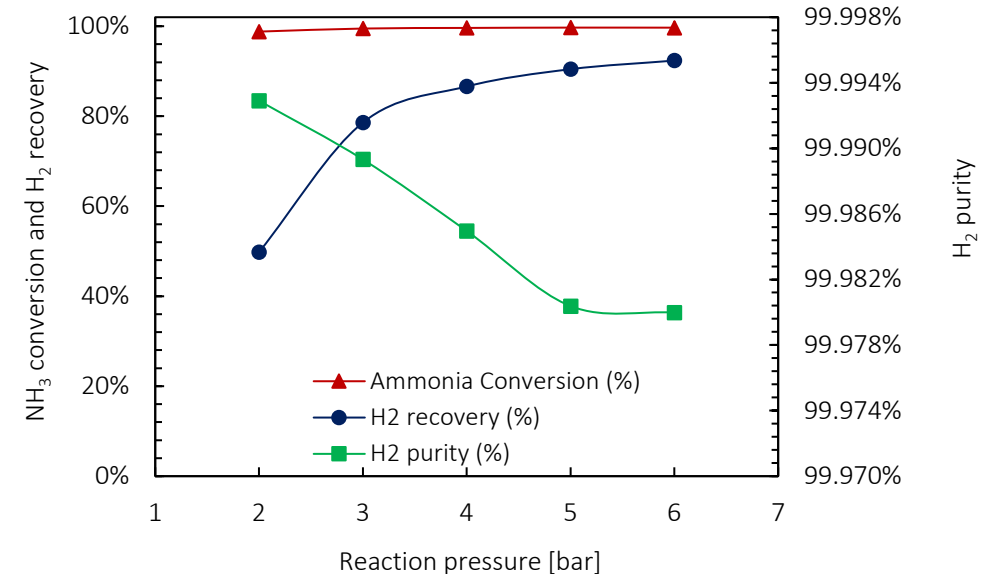
Experimental conditions	
Temperature [°C]	450
Permeate pressure [bar]	1
Feed flow rate [$\text{L}_\text{N}/\text{min}$]	0.5
Membrane	Double-skinned Pd-Ag
Thickness selective layer [μm]	~4.61

Membrane reactors for ammonia decomposition



Use of **Carbon Membranes** due to their **lower fabrication cost**

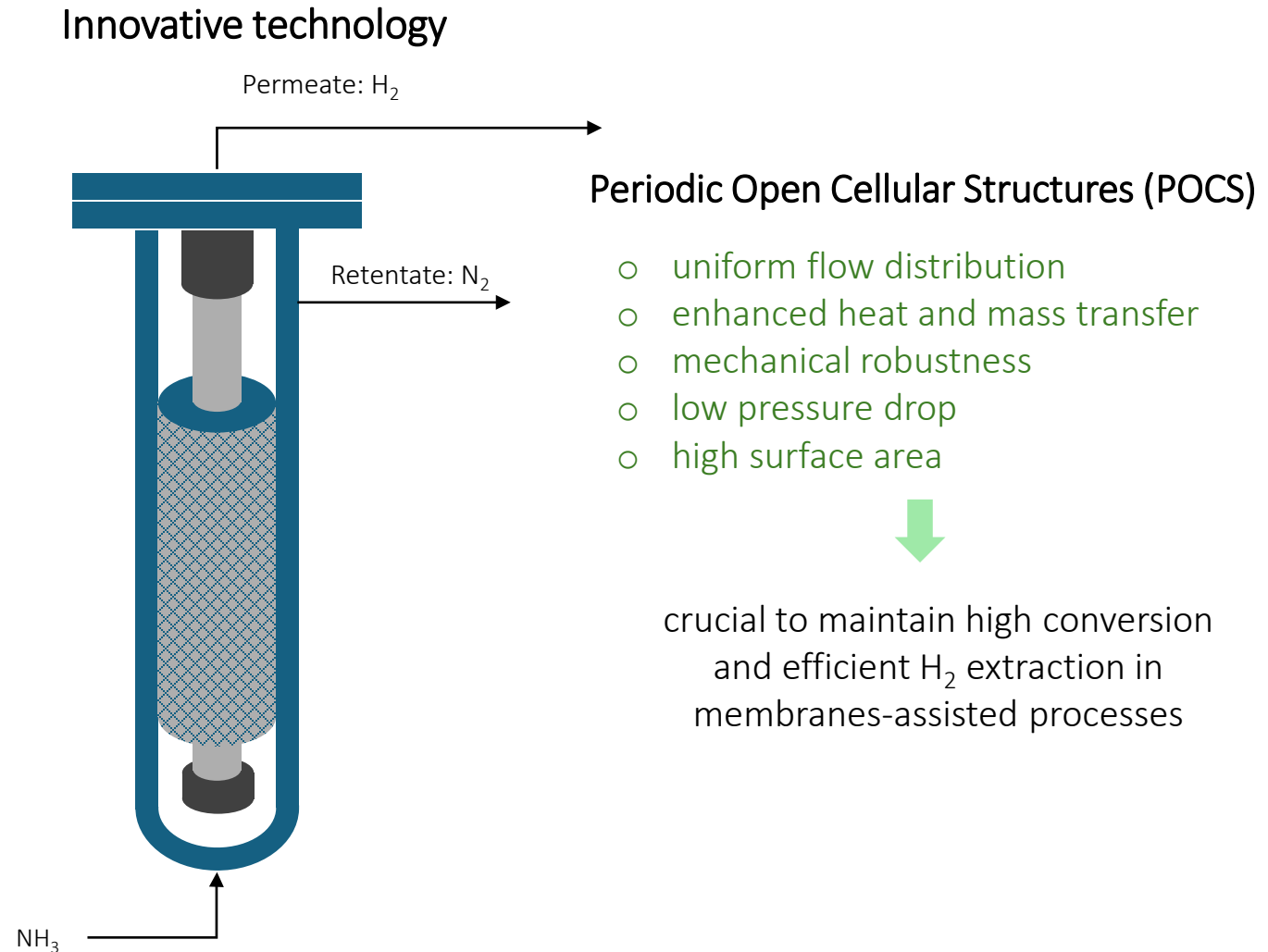
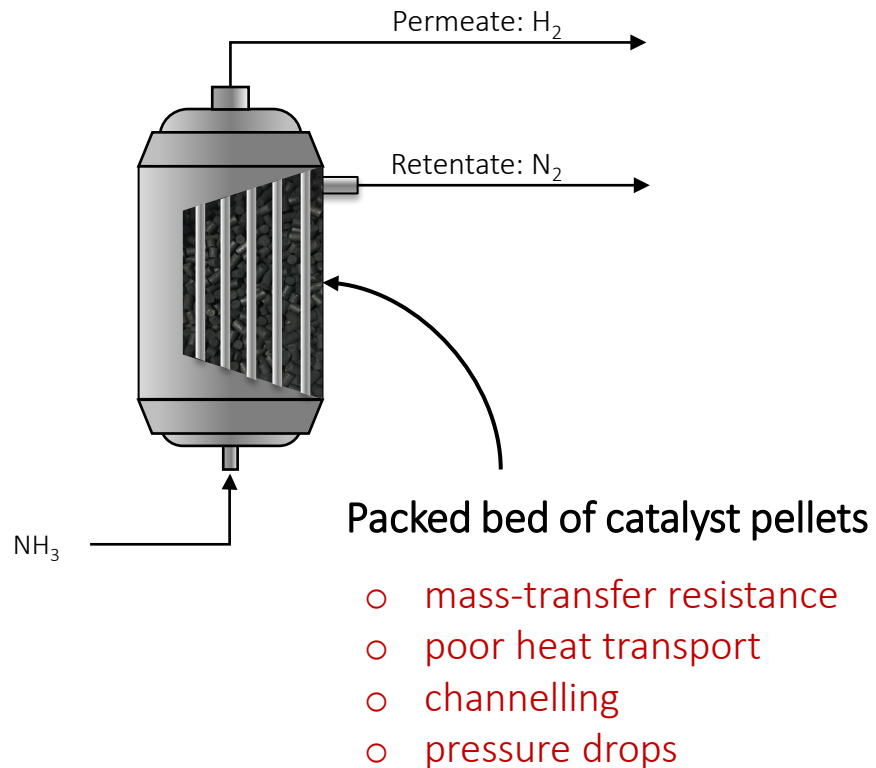
Proof of concept of membrane reactor technology for hydrogen production from ammonia



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

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

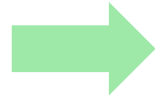
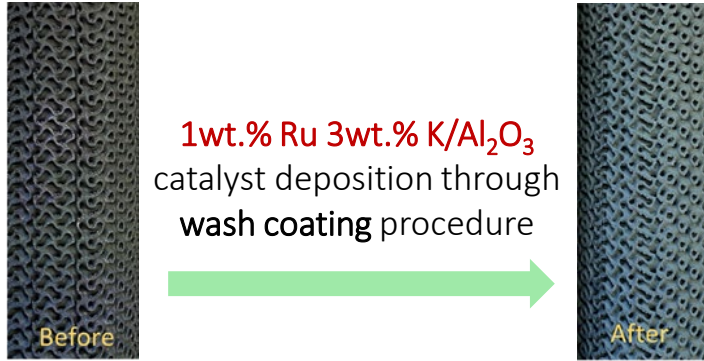
Reactors for ammonia decomposition



This work

Investigation of the intrinsic catalytic performance of **Ru-K-based POCS** structures in standalone configuration.

POCS fabrication



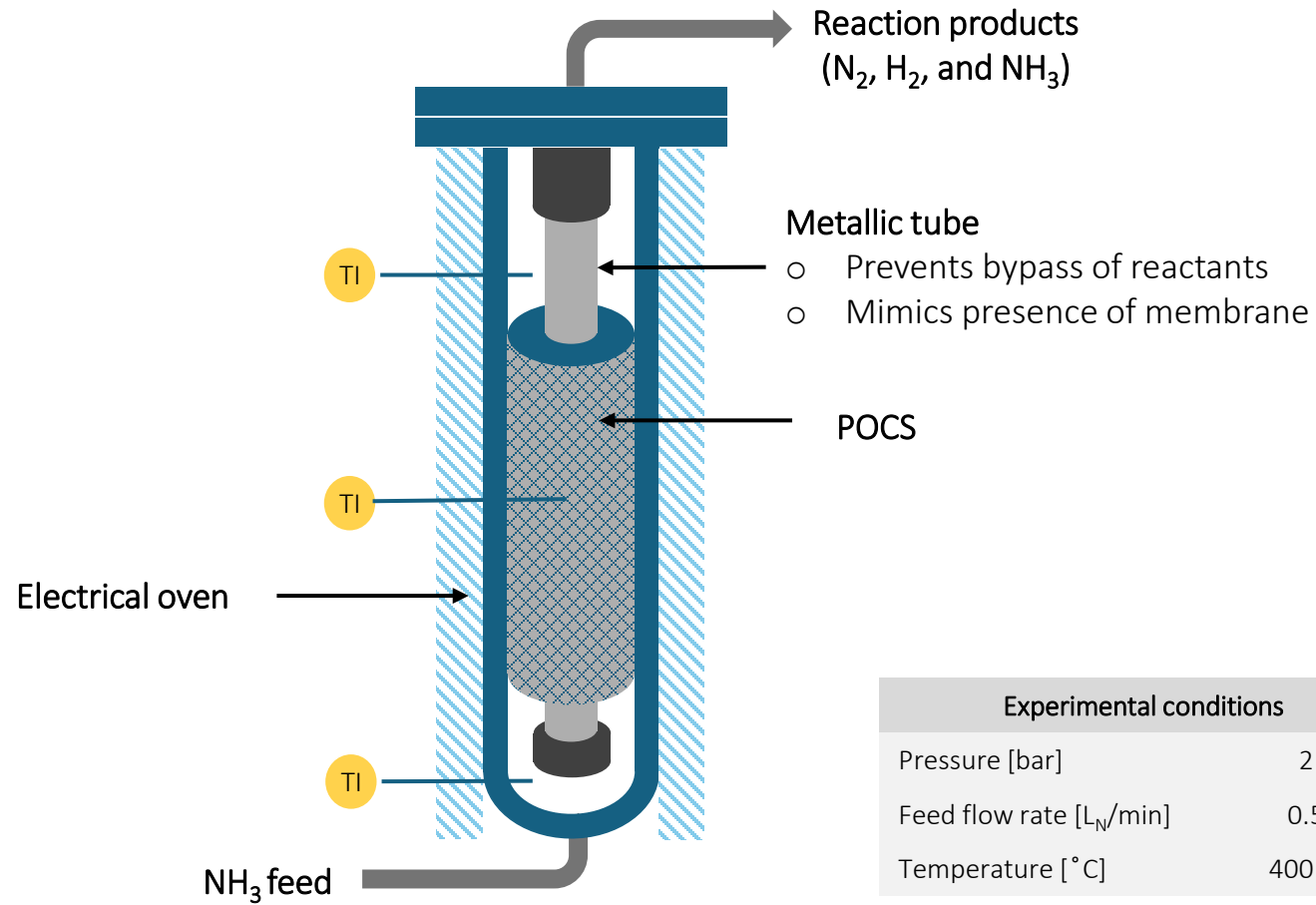
$L = 0.01 \text{ m}$

$D_{\text{external}} = 0.027 \text{ m},$

$D_{\text{central internal channel}} = 0.017 \text{ m}$

POCS	Catalyst weight [g]	Catalyst loading [g/cm ³]
1	4.738	0.15
2	5.059	0.15

Methods



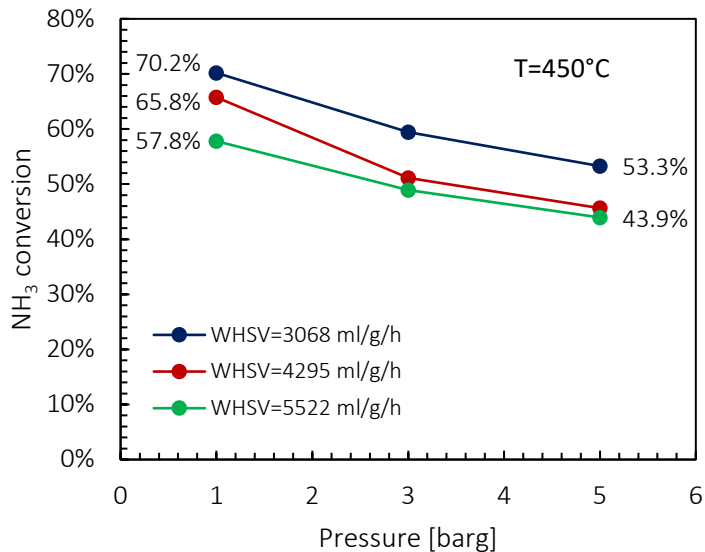
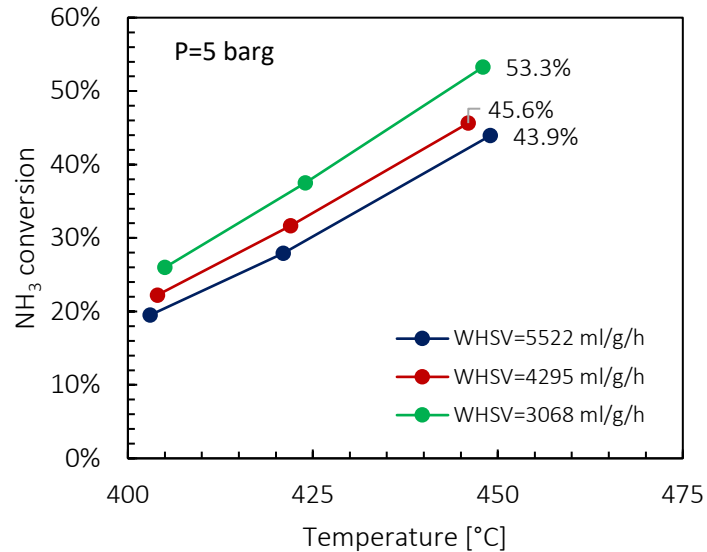
Experimental conditions	
Pressure [bar]	2 – 6
Feed flow rate [$\text{L}_\text{N}/\text{min}$]	0.5 – 1
Temperature [$^\circ\text{C}$]	400 – 450

Testing procedure

- Heating up to 450°C in N_2 atmosphere
- Catalyst activation
- Experimental testing

Exposition of catalyst for 15 hours to an H_2/N_2 mixture containing 75 vol.% of H_2

Results



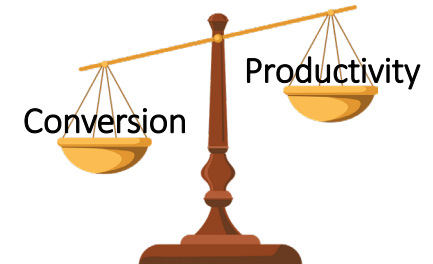
NH_3 conversion increases with:

- Increasing temperature (due to endothermic nature of the reaction).
- Decreasing WHSV (due to higher residence time at lower WHSV).
- Decreasing pressure (due to reaction stoichiometry).

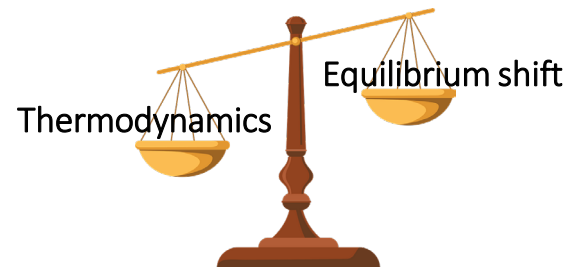
Thermodynamically consistent results

When integrating the POCS with H_2 -selective membrane:

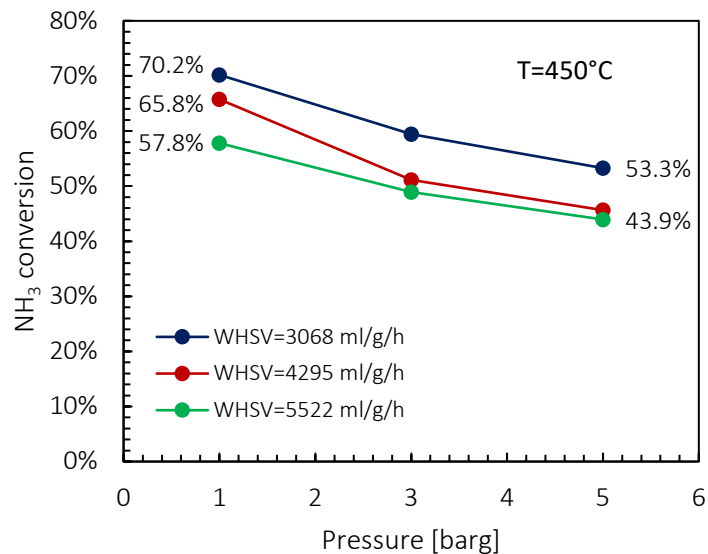
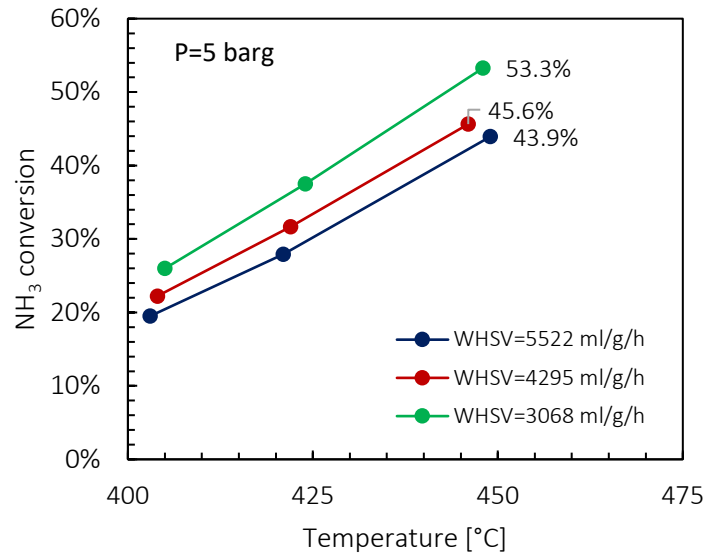
- high WHSV corresponds to larger throughput per catalyst mass



- High pressure corresponds to larger driving force for H_2 separation



Results



Comparison with literature

2 wt.% $\text{Ru}/\text{Al}_2\text{O}_3$

- NH_3 conversion = 70% at 425 $^{\circ}\text{C}$ and 1 bar with WHSV = 21600 ml/g/h
- NH_3 conversion = 90% at 450 $^{\circ}\text{C}$ and 1 bar with WHSV = 21600 ml/g/h

Catalyst with higher Ru content and tested at different operating conditions

Conclusions and Outlook

- Assessment of the intrinsic **performance of a Ru-K/Al₂O₃-coated POCS** for ammonia decomposition under conditions relevant to intensified H₂-production systems.
- The experimental results demonstrate that **the POCS deliver predictable and thermodynamically consistent behaviour.**
- Under the most favourable conditions investigated (450 °C, 2 bar, lowest WHSV), a **maximum conversion of 70.2% was achieved.**
- These standalone results establish the essential baseline required for evaluating the impact of H₂-permeable membranes.
- The next phase will investigate membrane-assisted operation, where selective hydrogen removal is expected to increase conversion beyond the thermodynamic limit of the standalone reactor.

Thank you for your attention



This project receives support from the European commission under grant agreement 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.

