# Performance evaluation of structured POCS catalysts for $H_2$ production via $NH_3$ decomposition

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ICSET 2026

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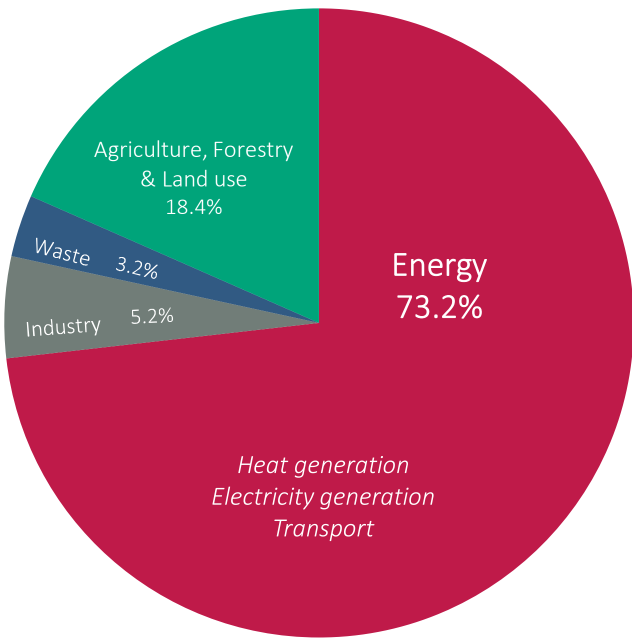
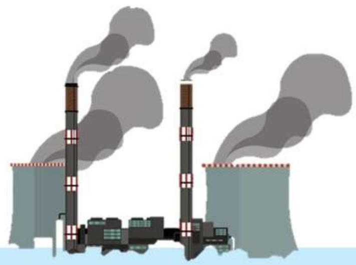
# Research background

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.

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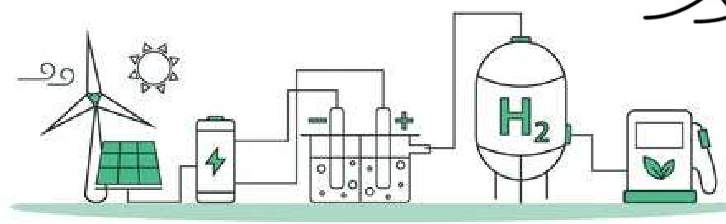
# Ammonia as a hydrogen carrier

*Renewable energy*

Challenges:
- Intermittency
- Availability far from end-use point

*Energy storage in the form of dispatchable energy carriers*

*Green Hydrogen Production*


Challenges:
- Storage
- Transportation

*$H_2$ storage in liquid carrier compounds*

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

$NH_3$

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

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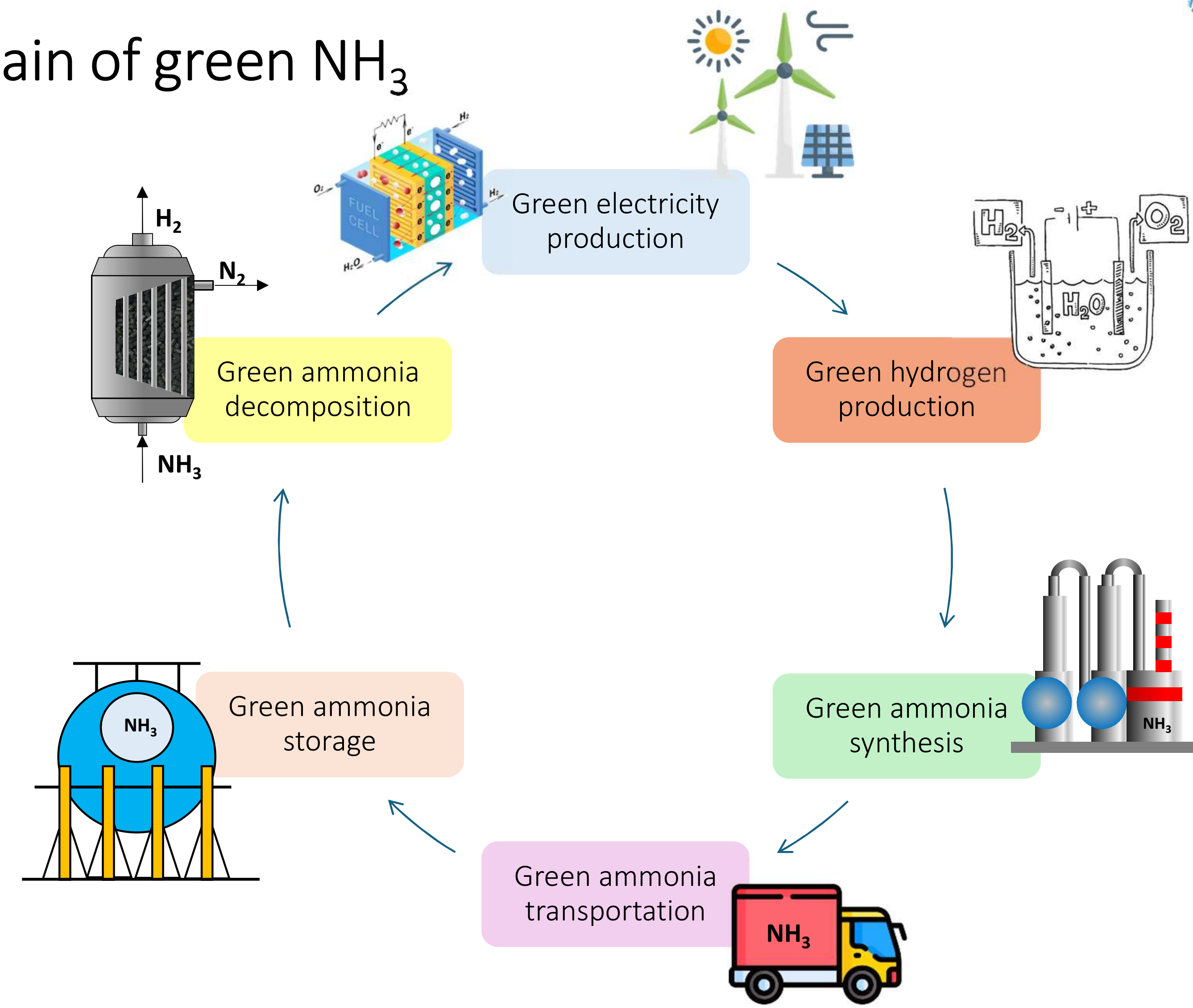
# Value chain of green $NH_3$

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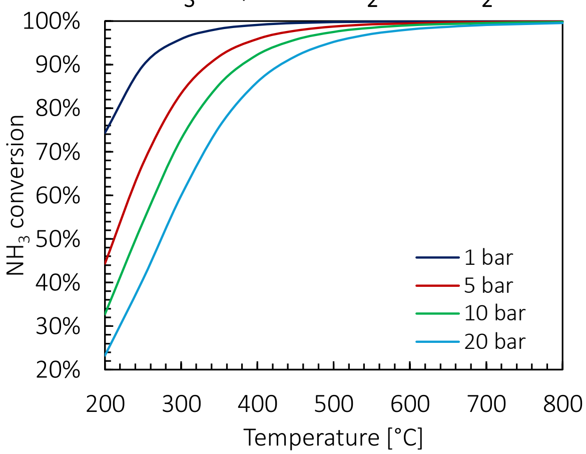
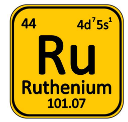
# Ammonia decomposition

$NH_3 \rightleftarrows 0.5\ N_2 + 1.5\ H_2$




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

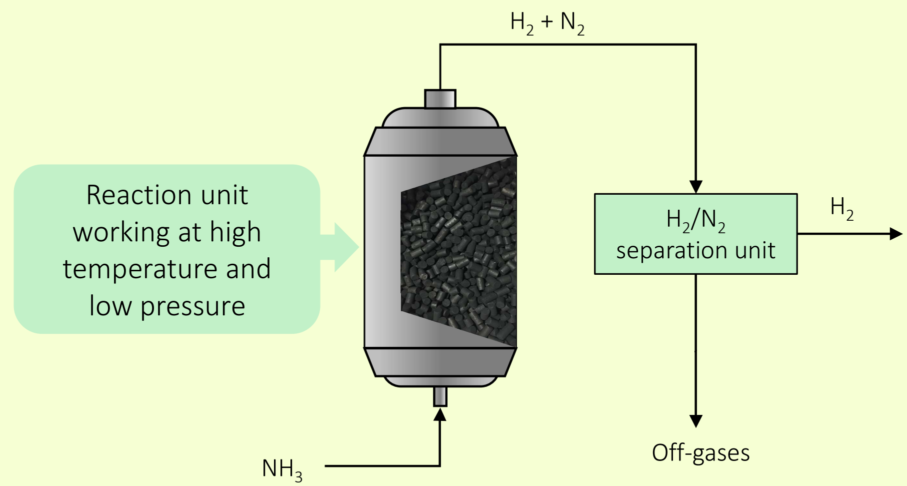
$NH_3$ decomposition is usually performed catalytically on Ni- or Ru-based catalysts.




- Not abundant in nature
- Expensive
- Operating T > 400 ˚C


- Abundant in nature
- Relatively inexpensive
- Operating T > 600 ˚C

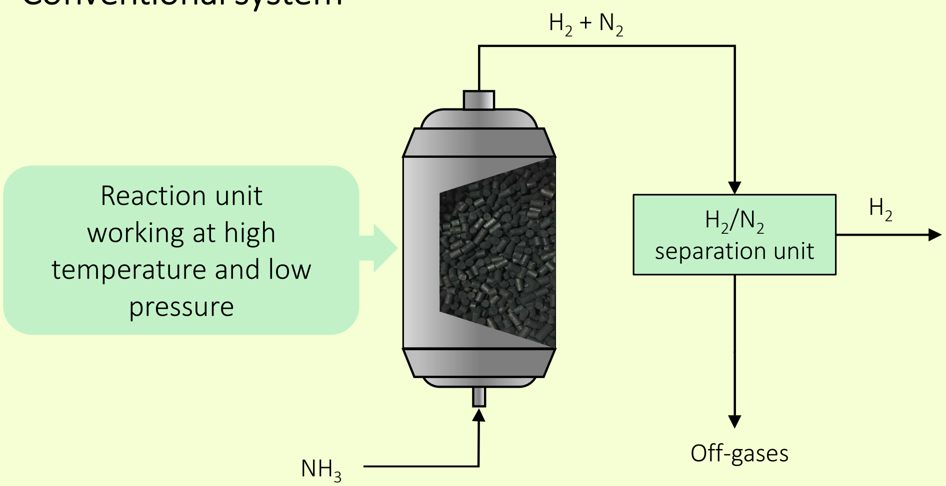
*Conventional process for $H_2$ recovery from $NH_3$*



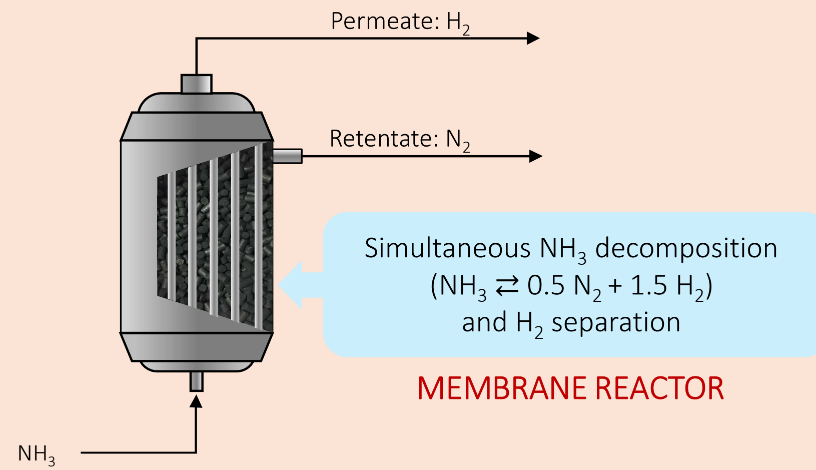

Efficient catalytic decomposition of ammonia challenging due to:
- thermodynamic limitations
- the strongly endothermic nature of the reaction
- the need for high hydrogen throughput with minimal reactor volume

# Ammonia decomposition

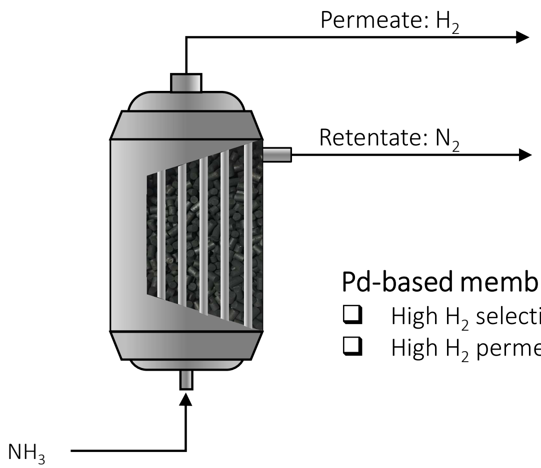
## Conventional system




## Novel system

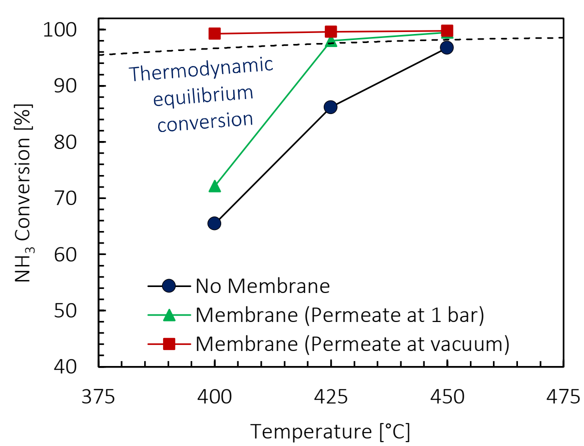


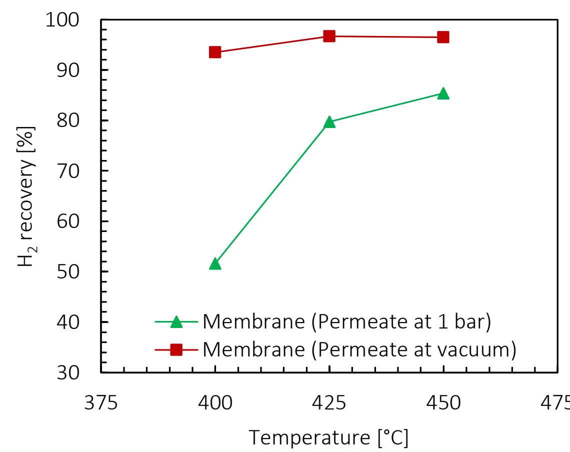
# Membrane reactors for ammonia decomposition




**Pd-based membranes**
- High $H_2$ selectivity
- High $H_2$ permeability

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



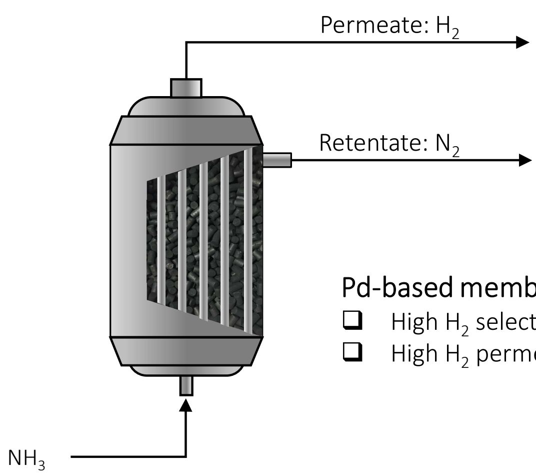




Compared to conventional systems, a MR allows comparable or higher $NH_3$ conversion at lower temperature
**Higher efficiency**

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

**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 ammonia decomposition

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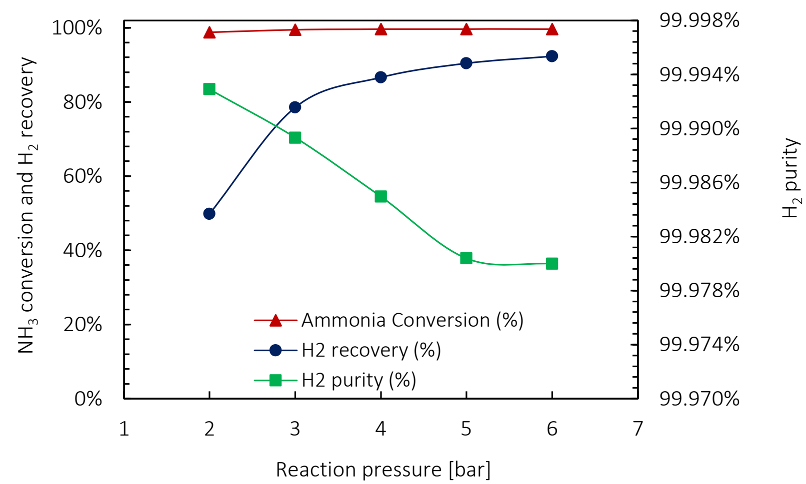


Compared to conventional systems, a MR allows higher $NH_3$ conversion at comparable pressures
**Higher compactness**

| 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 |

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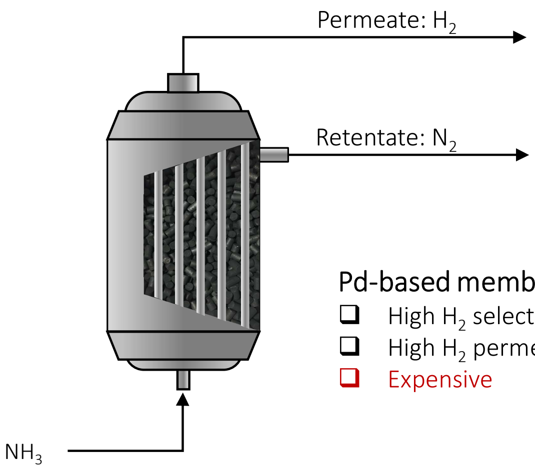
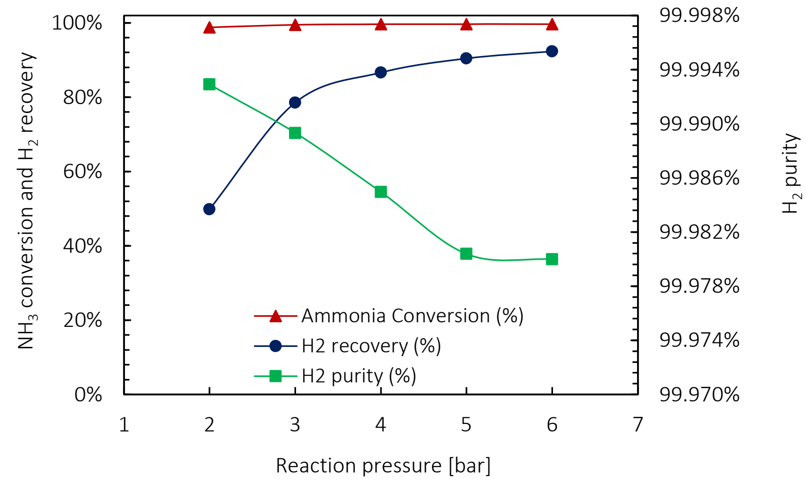



**Pd-based membranes**

- ❑ High $H_2$ selectivity
- ❑ High $H_2$ permeability
- ❑ Expensive

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

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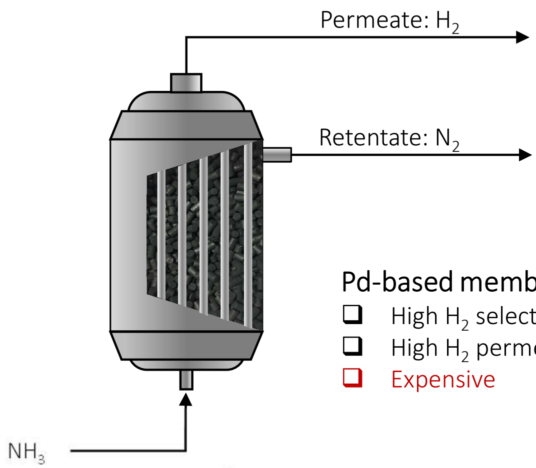


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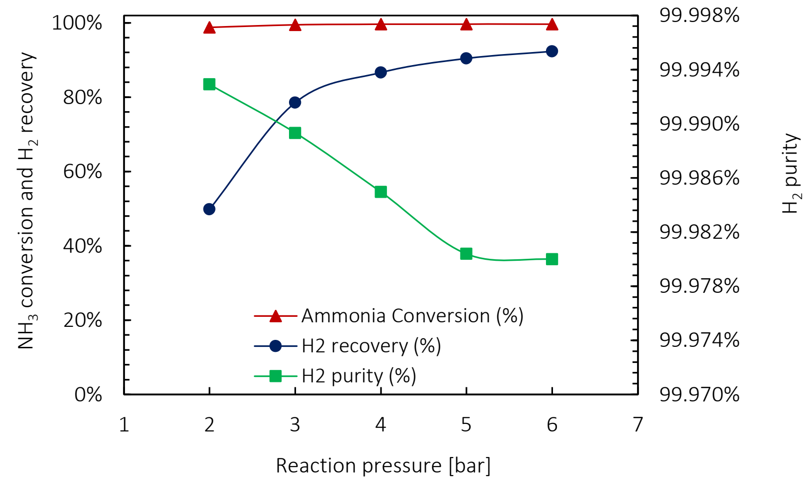
AndreaH

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

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

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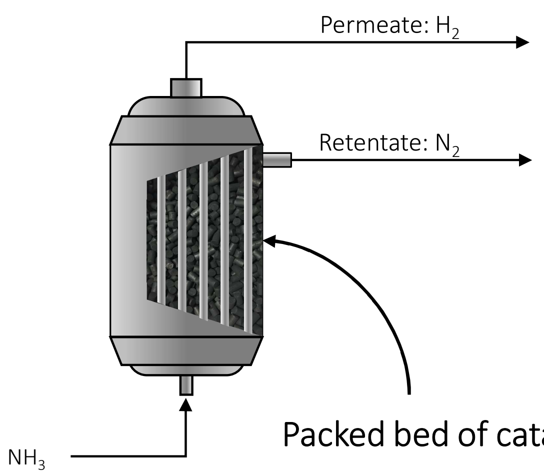
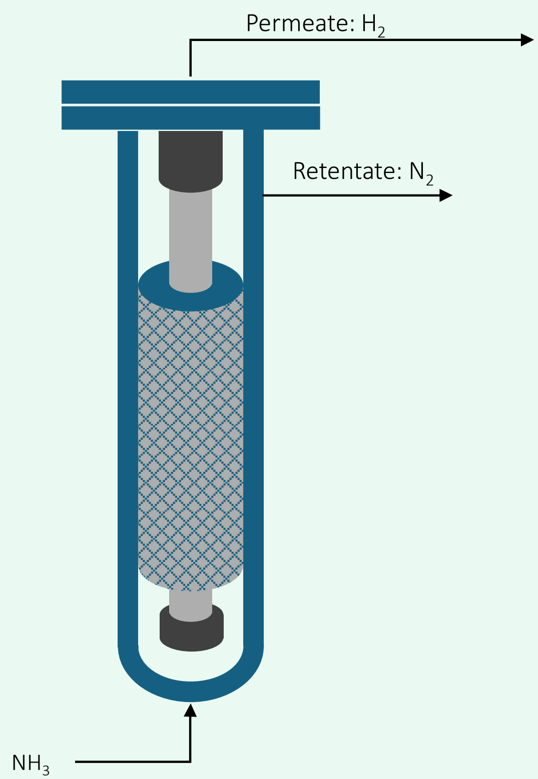
# Reactors for ammonia decomposition




Packed bed of catalyst pellets

- mass-transfer resistance
- poor heat transport
- channelling
- pressure drops

## Innovative technology




Periodic Open Cellular Structures (POCS)

- uniform flow distribution
- enhanced heat and mass transfer
- mechanical robustness
- low pressure drop
- high surface area

crucial to maintain high conversion and efficient $H_2$ extraction in membranes-assisted processes

# POCS for ammonia decomposition

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

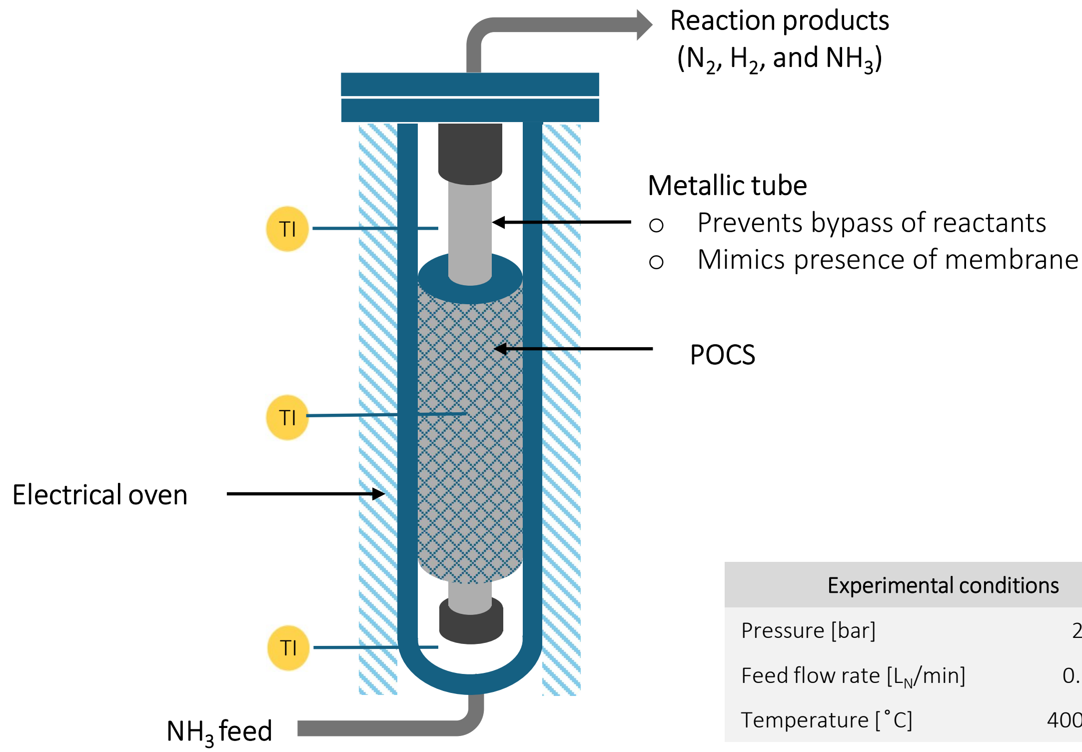
<u>POCS fabrication</u>


$1 wt.\%$ Ru $3 wt.\%$ $K/Al_2O_3$
catalyst deposition through
**wash coating** procedure


$L = 0.10\ m$
$D_{external} = 0.027\ m$
$D_{central\ internal\ channel} = 0.017\ m$

| POCS | Catalyst weight [g] | Catalyst loading [$g/cm^3$] |
|---|---|---|
| 1 | 4.738 | 0.15 |
| 2 | 5.059 | 0.15 |

# Experimental methods

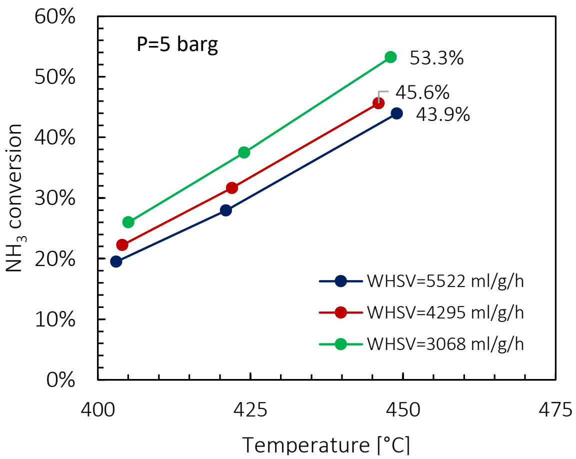


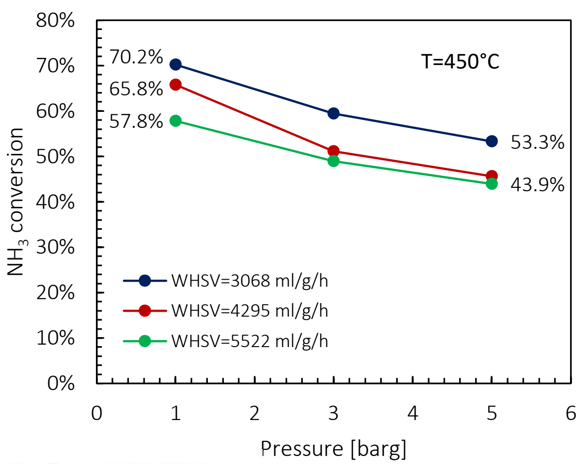

| Experimental conditions | |
|---|---|
| Pressure [bar] | 2 – 6 |
| Feed flow rate [$L_N$/min] | 0.5 – 1 |
| Temperature [˚C] | 400 – 450 |

**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*

**Comparison with literature**

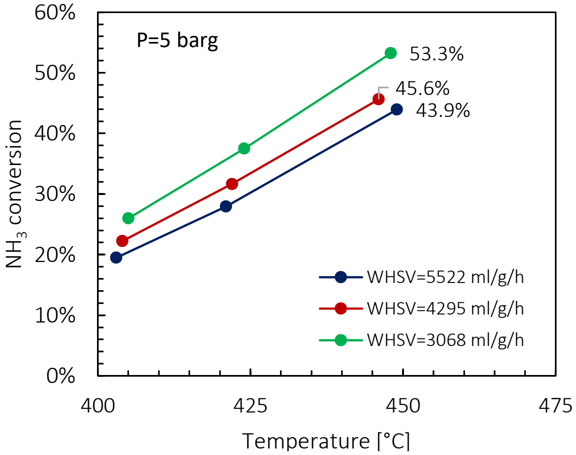
*2 wt.% $Ru/Al_2O_3$*

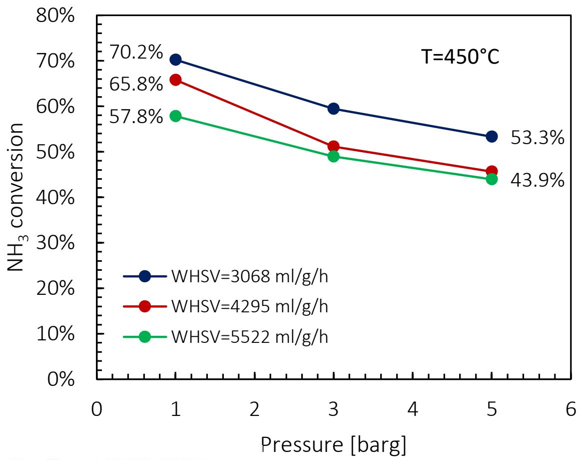
- $NH_3$ conversion = 70% at 425 ˚C and 1 bar with WHSV = 21600 ml/g/h*
- $NH_3$ conversion = 90% at 450 ˚C and 1 bar with WHSV = 21600 ml/g/h*

Although not overcoming the performance of commercially available catalysts, the performance of the POCS is promising.

*V. Cechetto, "Ultra-pure hydrogen production via ammonia decomposition in packed bed membrane reactors," PhD thesis, May 2024

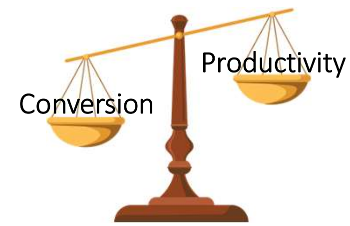
# Towards the integration of POCS and $H_2$-selective membranes



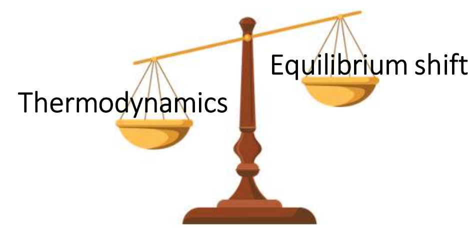




When integrating the POCS with $H_2$-selective membrane:

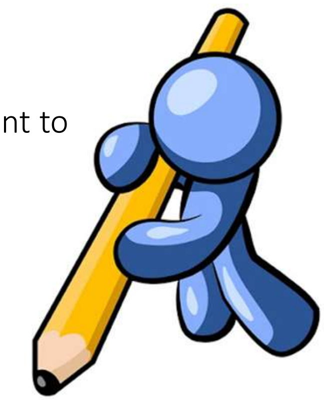
- high WHSV corresponds to larger throughput per catalyst mass




- High pressure corresponds to larger driving force for $H_2$ separation



# Conclusions and Outlook



- Assessment of the **performance of a Ru-K/$Al_2O_3$-coated POCS** for $NH_3$ decomposition under conditions relevant to intensified $H_2$-production systems.

- The experimental results demonstrate that **the POCS deliver predictable and thermodynamically consistent behaviour.**

- **Promising results** although not better than results available in literature for commercial catalysts.

- These standalone results establish the essential baseline required for evaluating the impact of $H_2$-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

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