DMT

Ammonia as Hydrogen Carrier

How to increase efficiency of hydrogen reconversion?

Hydrogen Tech World Conference 2023

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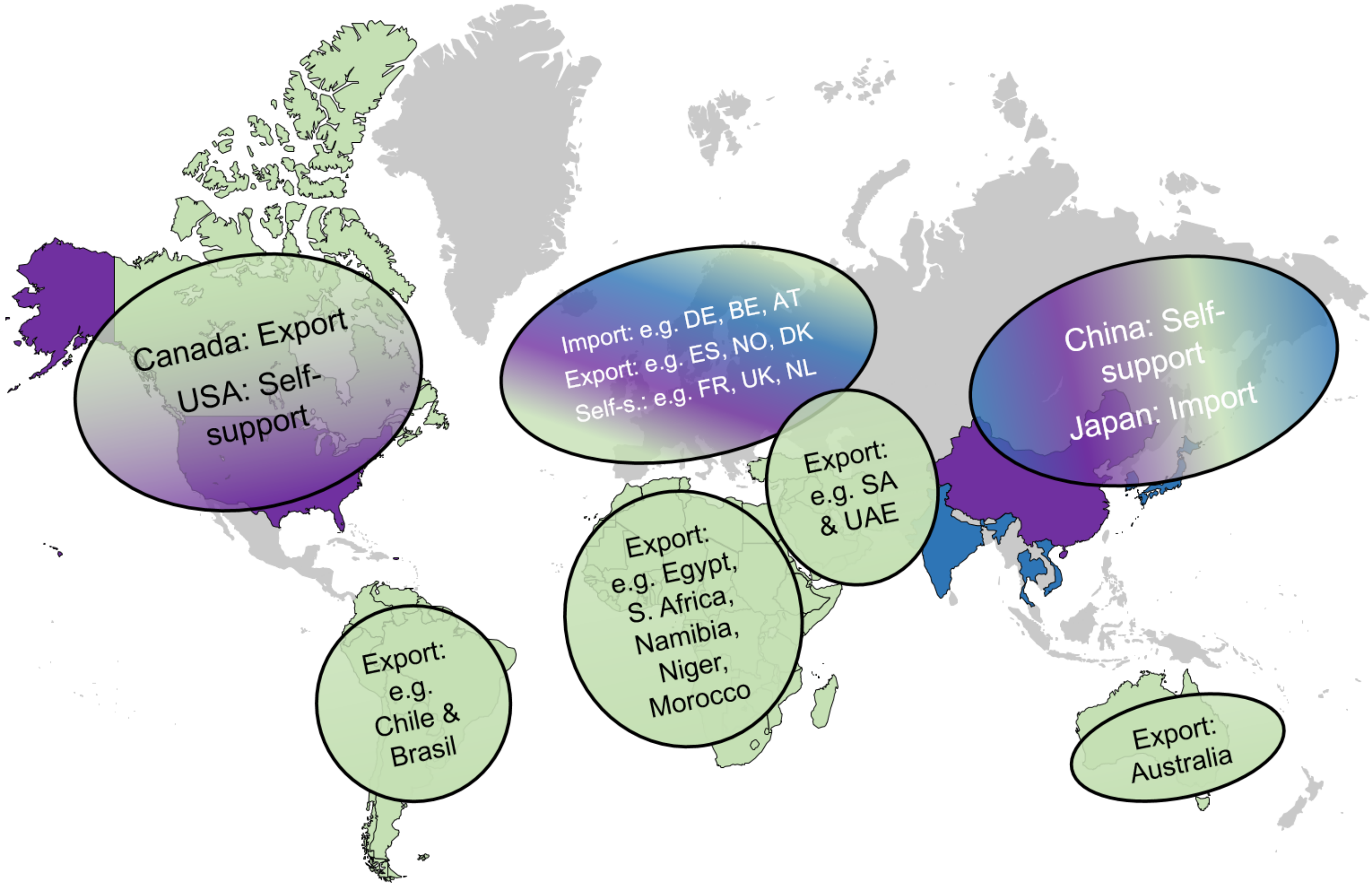
Engineering Performance

H_2 Import/Export: Typical trade routes



Legend:

- Net import country /-region
- Net export country /-region
- Self-supporter

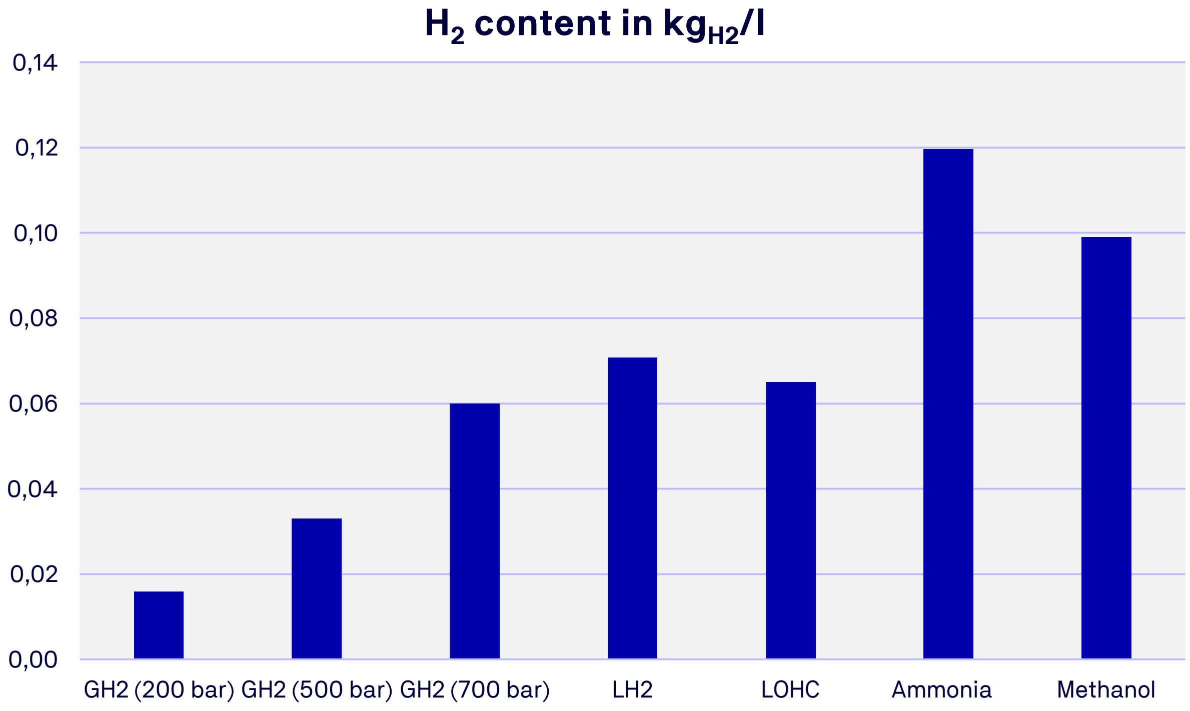
Country Codes:

AT: Austria
BE: Belgium
DE: Germany
DK: Denmark
ES: Spain
FR: France
NL: Netherlands
NO: Norway
SA: Saudi-Arabia
UK: United Kingdom
UAE: United Arab Emirates

Source: TÜV NORD GROUP HydroHub

Hydrogen carriers

"H_2 Storage" Capacities



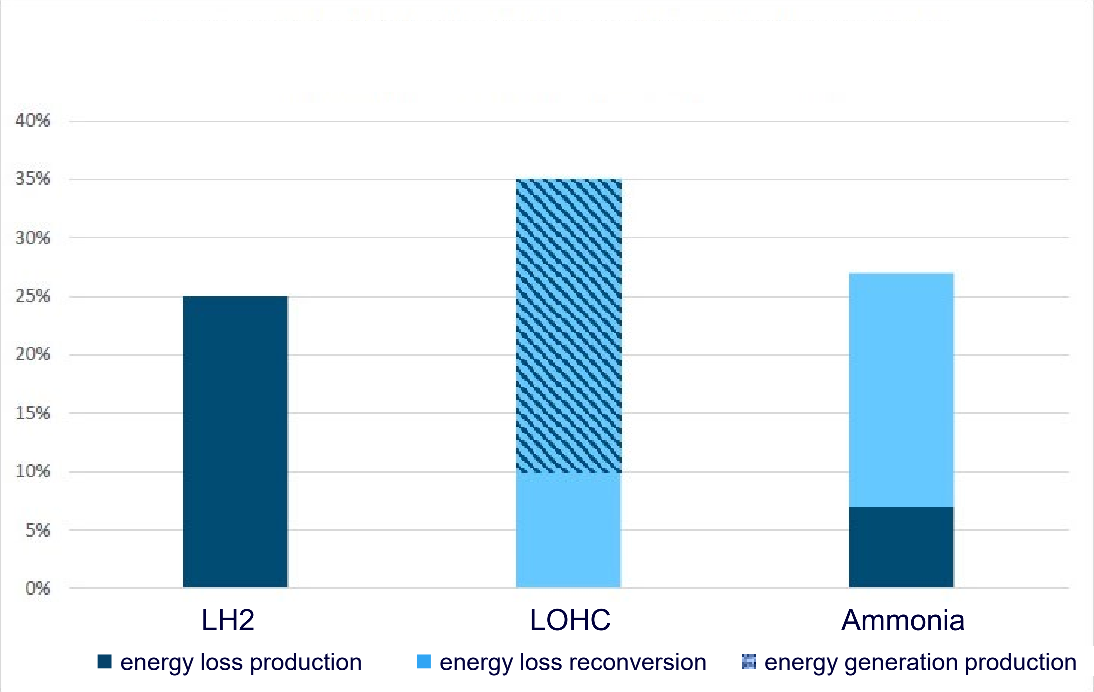
Source: EE ENERGY ENGINEERS GmbH & Co. KG (TÜV NORD GROUP)

- **Increase of transported H_2** per unit through compression, liquefaction or bonding in "carrier liquid".
- Lowest energy density with **GH_2** (gaseous H_2) even under high pressure.
- **LOHC** (liquid organic hydrogen carrier) reveals lower energy density compared to **LH2** (liquefied H_2), but on same level as GH_2 at 700 bar.
- **Ammonia** (NH_3) has highest H_2-storage capacity followed by **methanol.**
- LOHC and methanol have easy **storage technologies** at ambient temperature and pressure (like mineral oil).
- Ammonia, methanol and LOHC need energy intense **reconversion processes** to recover H_2**.**

**Highest „storage" capacities can be achieved with methanol and ammonia.
The storage and handling technologies for these "H_2-carriers" are well known and proven.**

Hydrogen carriers

Energy losses for conditioning, production and reconversion relative to their energy content of „stored“ H_2



Source: EE ENERGY ENGINEERS GmbH & Co. KG (TÜV NORD GROUP)

- **LH_2** (liquefied H_2) needs electrical energy for conditioning (liquefaction at -253 °C).
- **LOHC** needs thermal energy for reconversion of H_2, but produces heat during uptake of H_2.
- **NH_3** needs thermal energy for production as well as for reconversion of H_2.
  - Production and handling of ammonia (NH_3) is proven and shows relatively low energy losses.
  - However, reconversion of ammonia to H_2 consumes a lot of energy due to the high catalytic cracking temperature (400-700 °C) and endothermic reaction.

The crack catalyst is a key element to reduce the cracking temperature and increase the energy efficiency of the NH_3 reconversion process!


DMT test facility for catalytic NH_3 cracking

Reconversion of NH_3

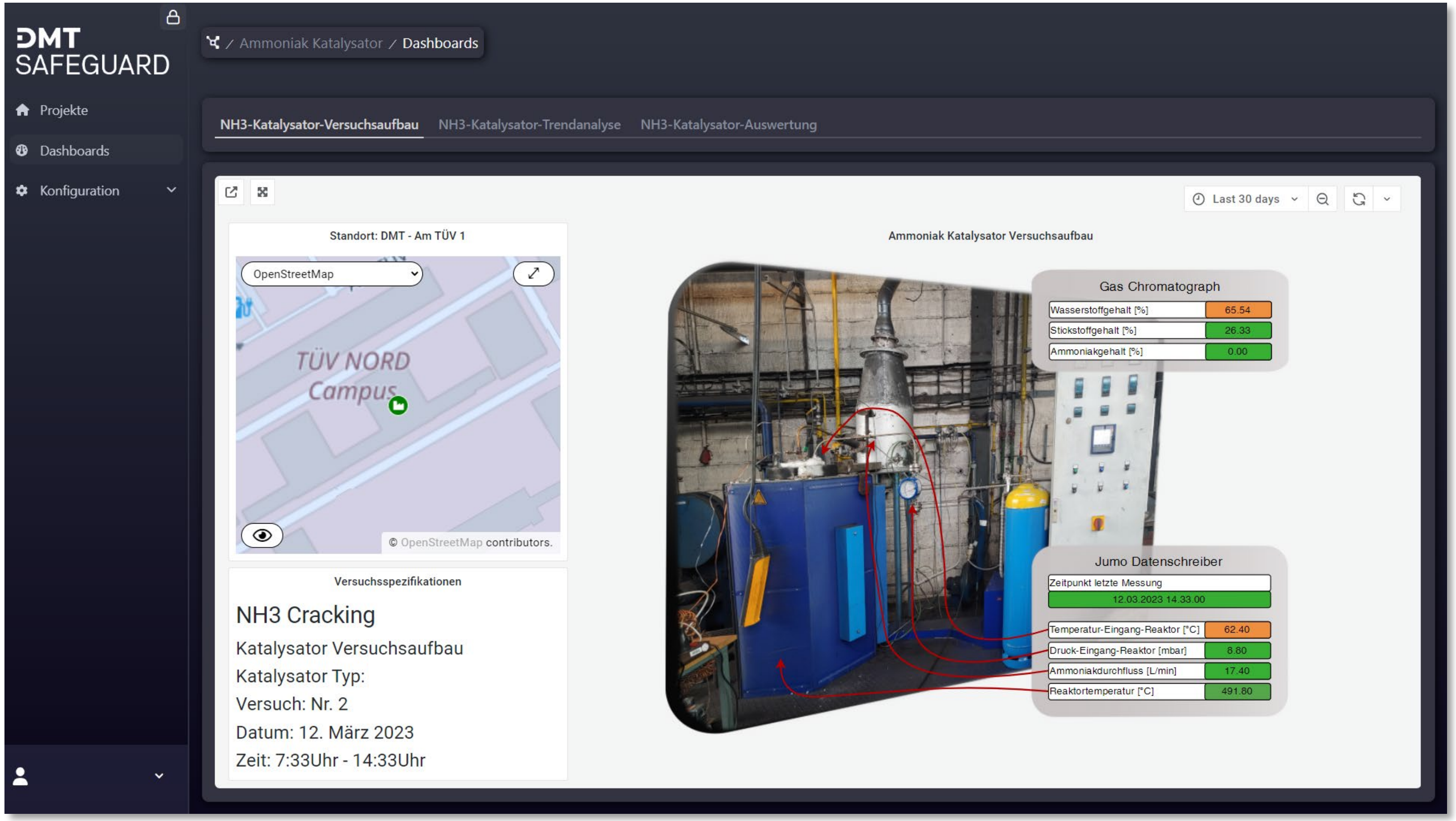
Testing of catalytic ammonia cracking at DMT

- Test parameters
  - T = 300 °C to 900 °C
  - P = atmospheric pressure
  - Ammonia Flow up to 60 l/min (99,9% NH_3)
  - GHSV (Gas hourly space velocity) 2.000, 4.000 and 6.000 h^{-1}
  - NH_3-conversion (per gas chromatography)
  - Catalyst volume max. 570 cm^3
    (85 mm diameter x 100 mm height (cylinder))
- Actually 4 catalysts of different composition in test phase
  - Variation in composition of catalysts (content)
  - Variation in doted metal

DMT

Ammonia cracking tests in own laboratory

Data logging and visualization in DMT SAFEGUARD system



Haber-Bosch Process
T: 450-550 °C, P: 250-350 bar, catalyst

ΔH = +46 kJ / mol
exothermic reaction

←

$$2\,NH_3 \Leftrightarrow N_2 + 3\,H_2$$

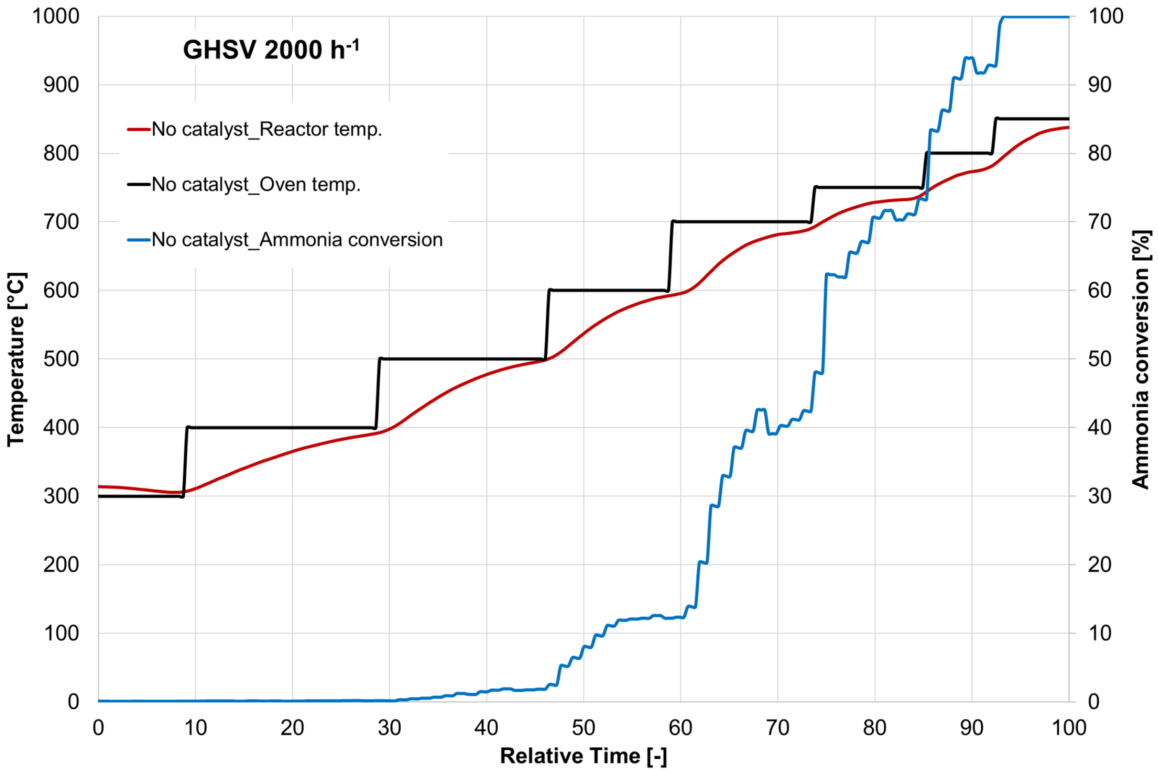
→

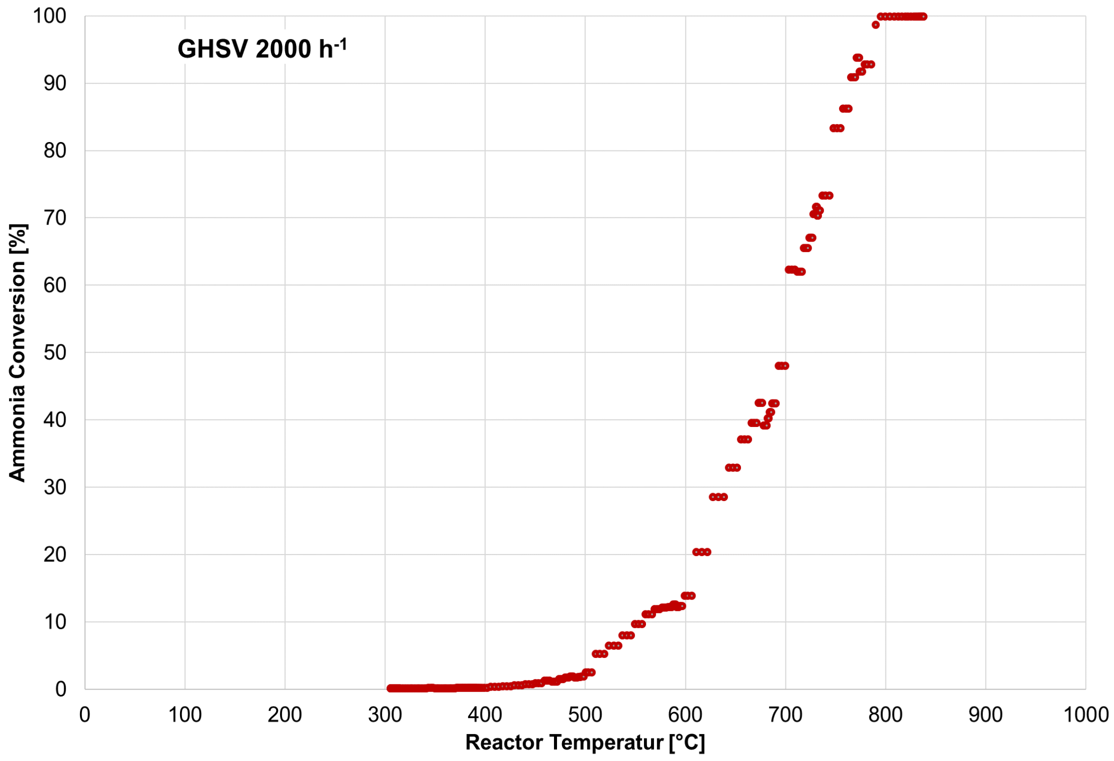
ΔH = -46 kJ / mol
endothermic reaction

Ammonia Cracking
T: 400-700°C, P: <10 bar, catalyst

Test results of ammonia cracking

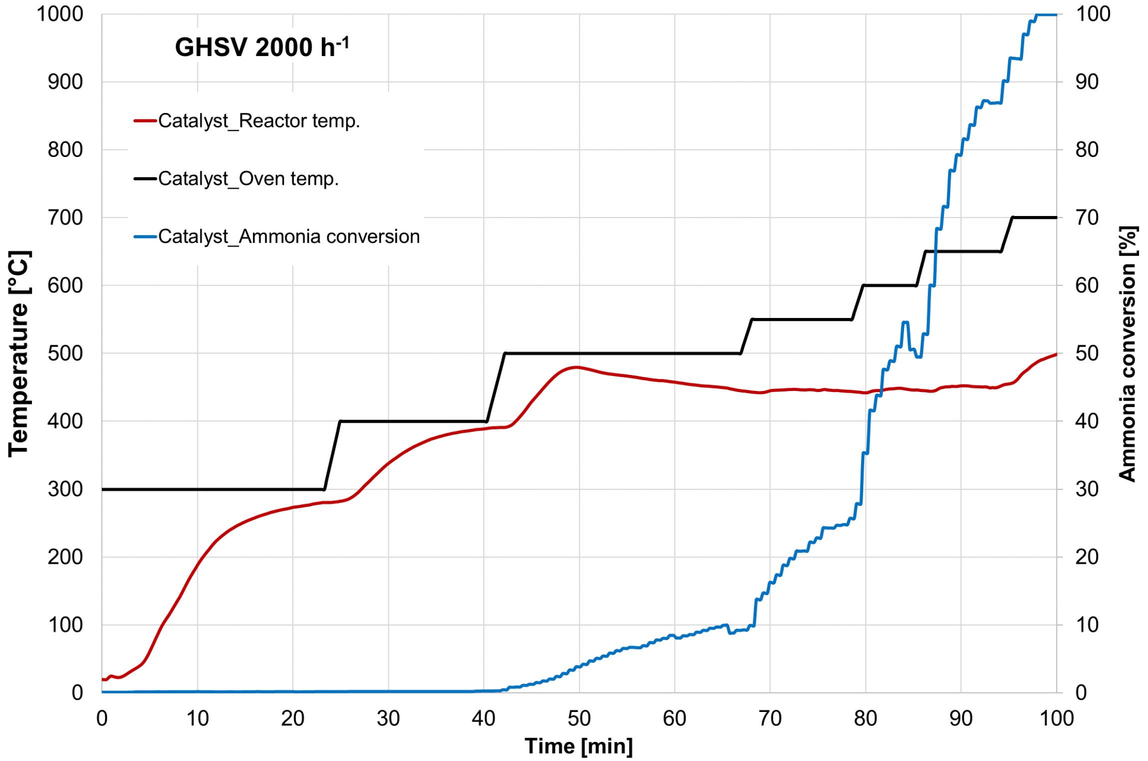
Thermal cracking of NH_3

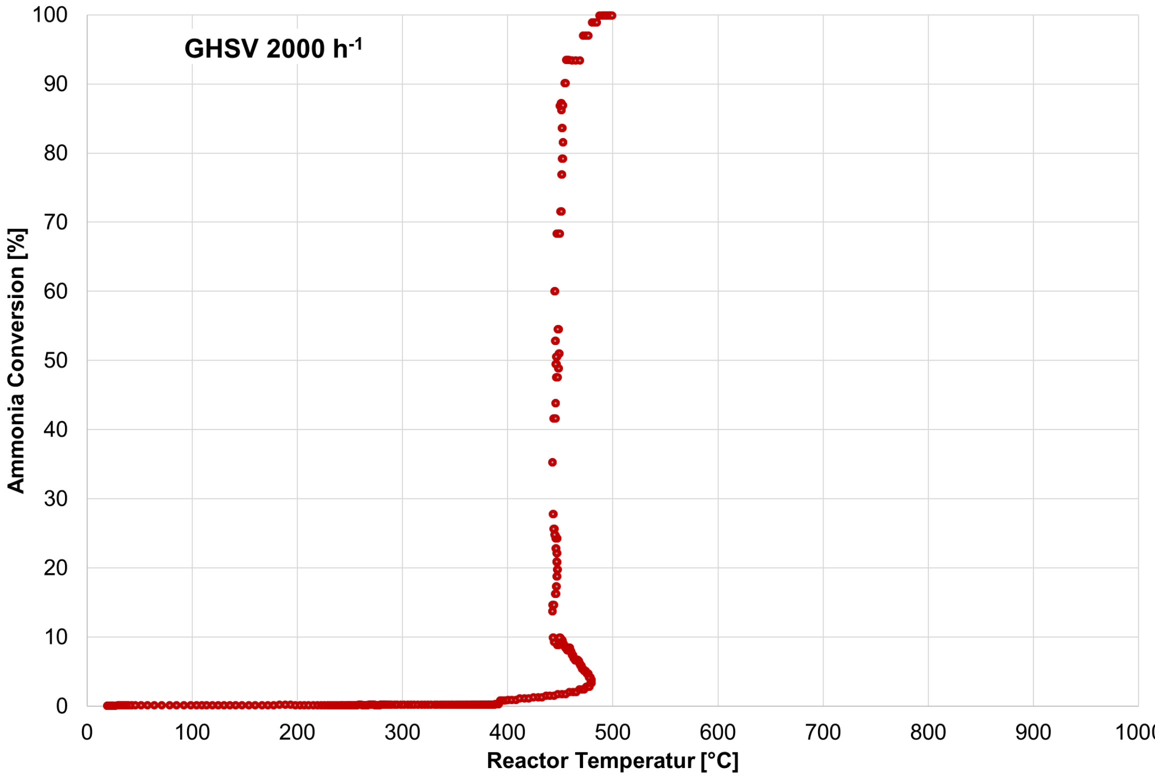




Test results of ammonia cracking

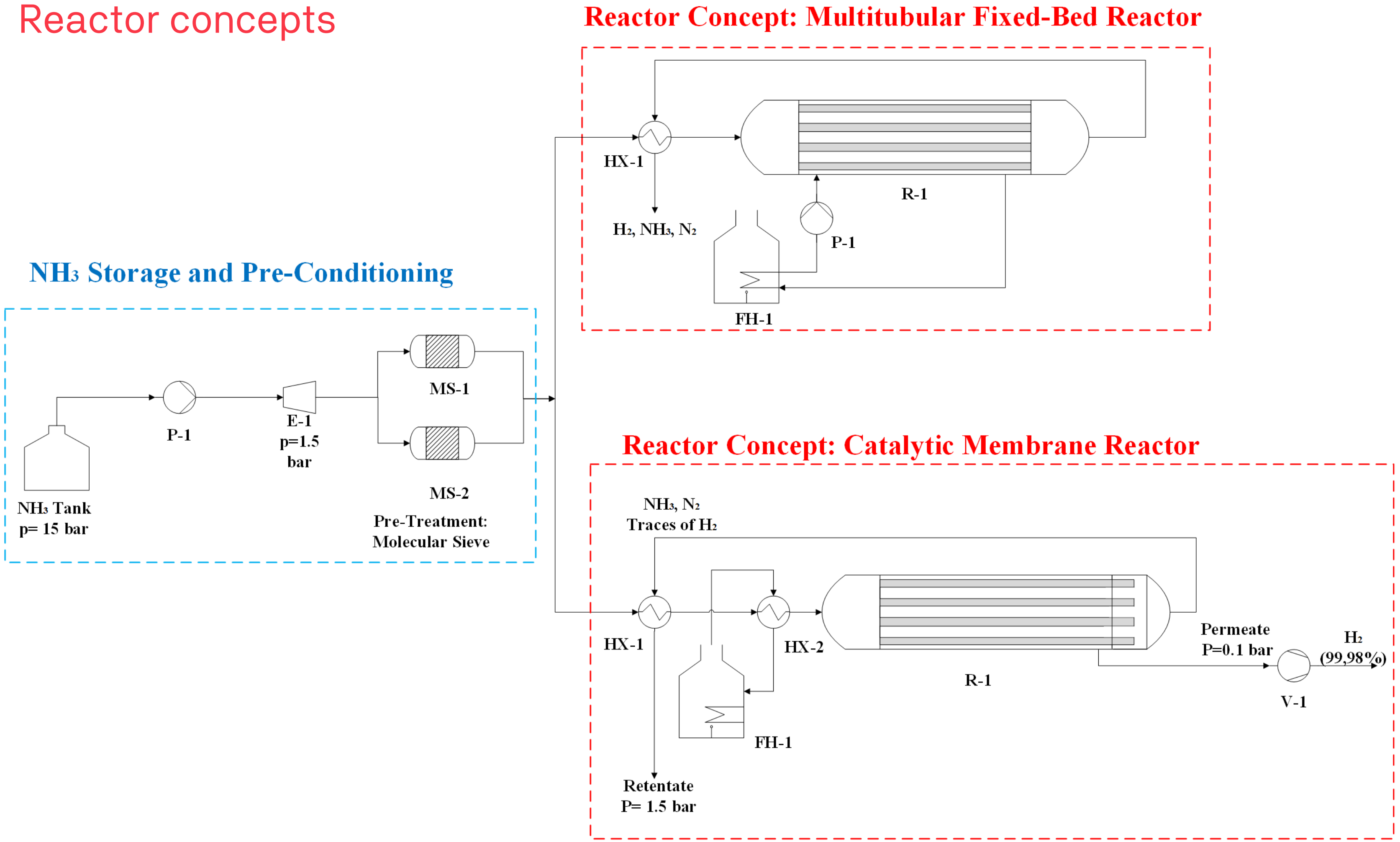
Catalytic cracking of NH_3





Concepts for ammonia cracking

Reactor concepts



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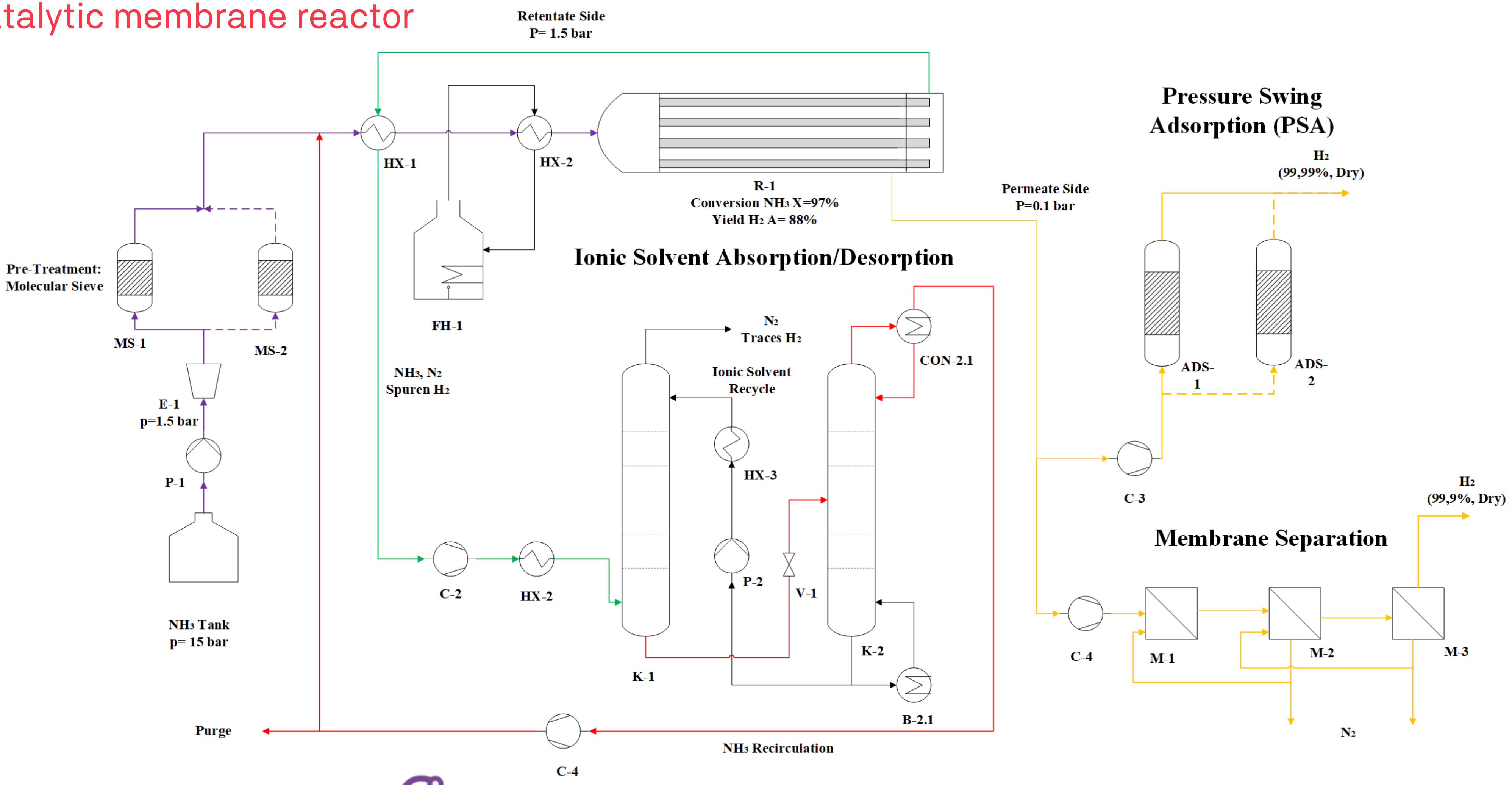
Concepts for ammonia cracking

Concept catalytic membrane reactor



Conclusions

How to increase efficiency of hydrogen conversion?

- Highest **„H_2-storage“ capacities** can be achieved with methanol and ammonia (NH_3).
  - ➢ The storage and handling technologies for these carriers are well known.
  - ➢ Supply of NH_3 as hydrogen carrier seems to become favourite option.
- The **cracking catalyst is a key element** to reduce the cracking temperature and increase the energy efficiency of the NH_3 reconversion process.
  - ➢ Optimum between catalyst costs and efficiency has to be identified.

Conclusions

How to increase efficiency of hydrogen conversion?

- The **cracking reactor concept can be decisive** for the energy efficiency of the cracking plant.
  - ➢ A **catalytic membrane reactor** offers a process **efficiency increase.**
    - Clean H_2 is directly available as permeate (but can be upgraded further).
    - Removal of H_2 as permeate from process enhances NH_3 reconversion (principle of Le Chatelier).
    - Smaller plant dimensions for retentate upgrading and NH_3 recirculation.
    - Catalytic membrane reactor needs constant process operation (sensitive to start-up / shutdown operations / temperature changes).

Thank you for your attention!

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