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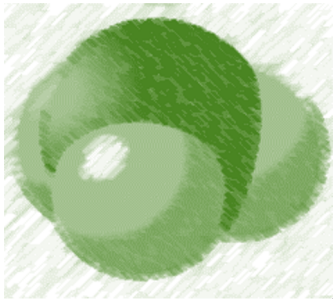
Hydrogen or ammonia: why not both?



Th. Belmonte

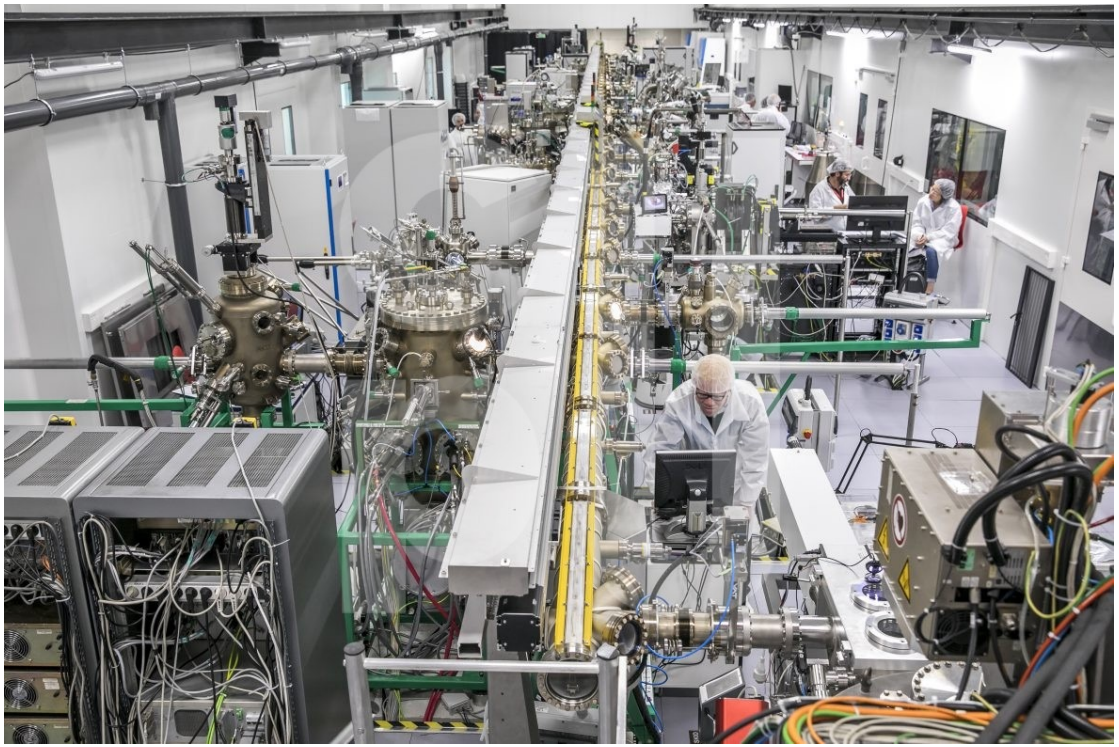
Institut Jean Lamour - CNRS - Université de Lorraine - Nancy, France

June 17-19, 2021 - Nancy

WORLD MATERIALS FORUM

IJL

24 research groups in 4 departments
509 people
Research staff: 410
Research support: 99
Keywords: Materials, Plasmas, Surfaces, Electronics, Metallurgy, Nanomaterials



The « TUBE »
70 m-long
UHV
35 equipments for synthesis and characterization at atomic level

AMMONIA

1 Hydrogen or ammonia: why not both?

2 An easier and available way to transport energy

3 Challenges to tackle

1 – Hydrogen or ammonia: why not both?

favoured by catalysis

Δn = -2 mol

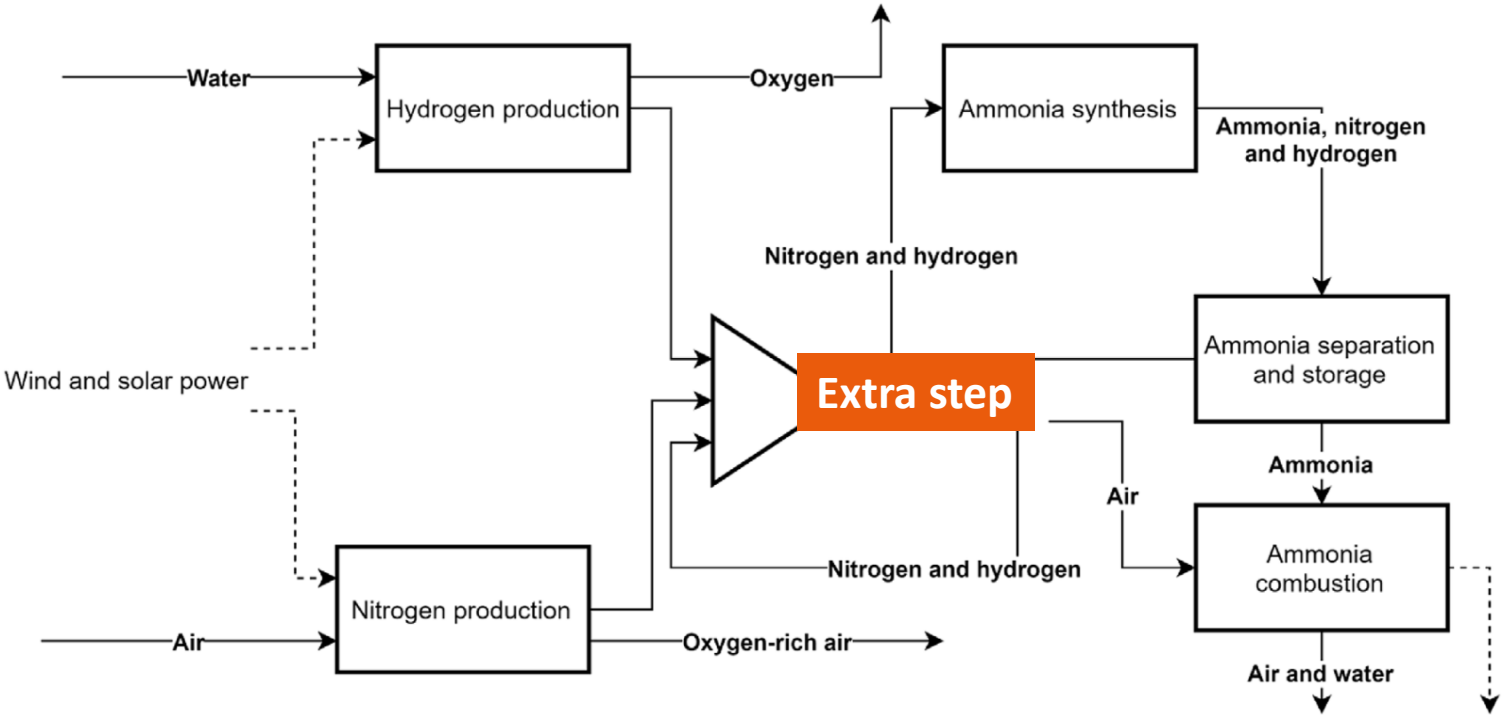
$N_2 + 3H_2 \rightarrow 2NH_3$

ΔH = −91.8 kJ/mol

favoured by high pressure

favoured by low temperature

(not too low as the kinetics is too slow)



K.H.R. Rouwenhorst, Renewable and Sustainable Energy Reviews 114 (2019) 109339

1 – Hydrogen or ammonia: why not both?

(150 - 350 bar and 450 - 550 ° C)

N_2 production
0,175 – 0,28 kWh kg^{-1} of N_2

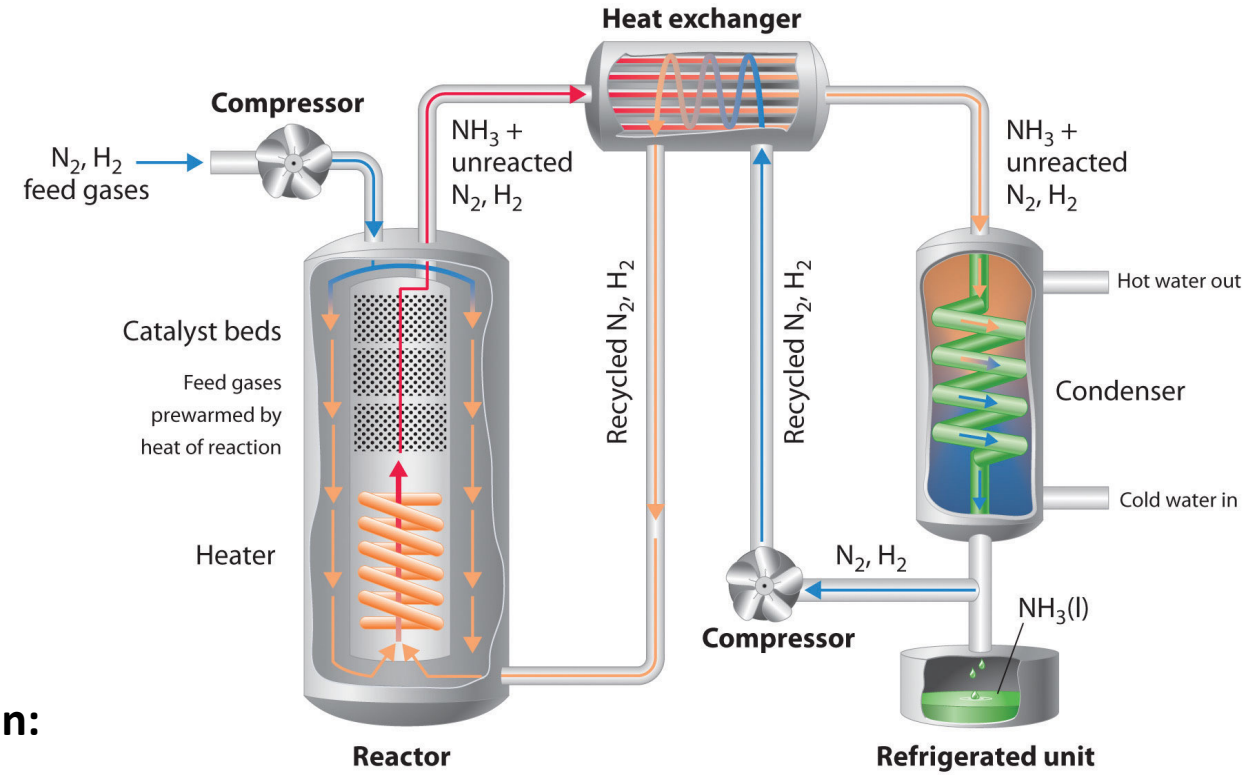
H_2 production (by electrolysis)
50 – 56 kWh kg^{-1} of H_2

For 1 kg de NH_3 (824 g N_2 + 176 g H_2)
~9,5 kWh kg^{-1} of NH_3

Liquefaction of H_2 vs NH_3
11-15 kWh kg^{-1} vs 0.2 kWh kg^{-1} of NH_3

kWh needed for synthesis per available kWh in:

Liq. H_2: 2.04 **liq. NH_3: 3.94**



The Haber-Bosch process

~100% of extra energy needed !

8,5-13 kWh kg^{-1} of NH_3

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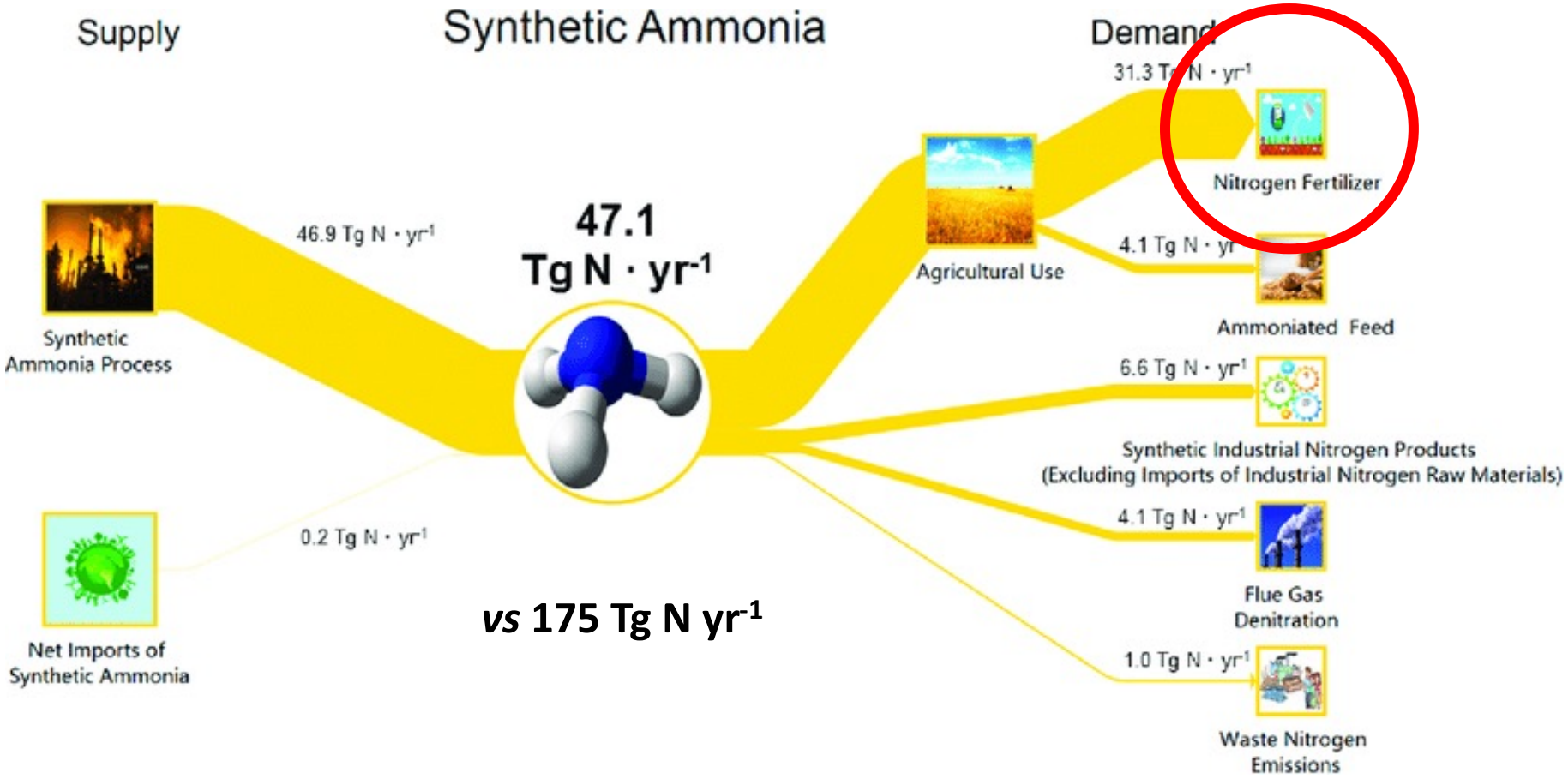
2 – An easier and available way to transport energy

A technology already available all over the world: The chinese example

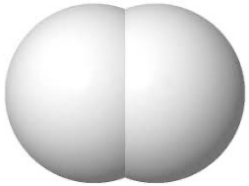


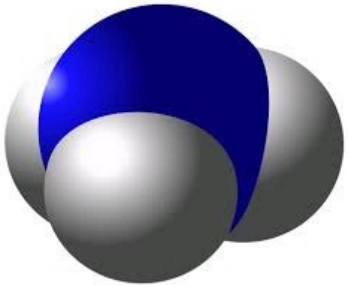
***vs* 175 Tg N yr^{-1}**

Z. Luo, S. Hu, D. Chen, B. Zhu, Environ. Sci. Technol. (2018) 52, 2025

Units: Tg N yr^{-1} (1 Tg = 10^6 t)

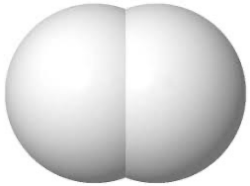
2 – An easier and available way to transport energy

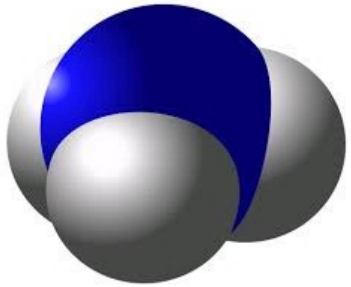




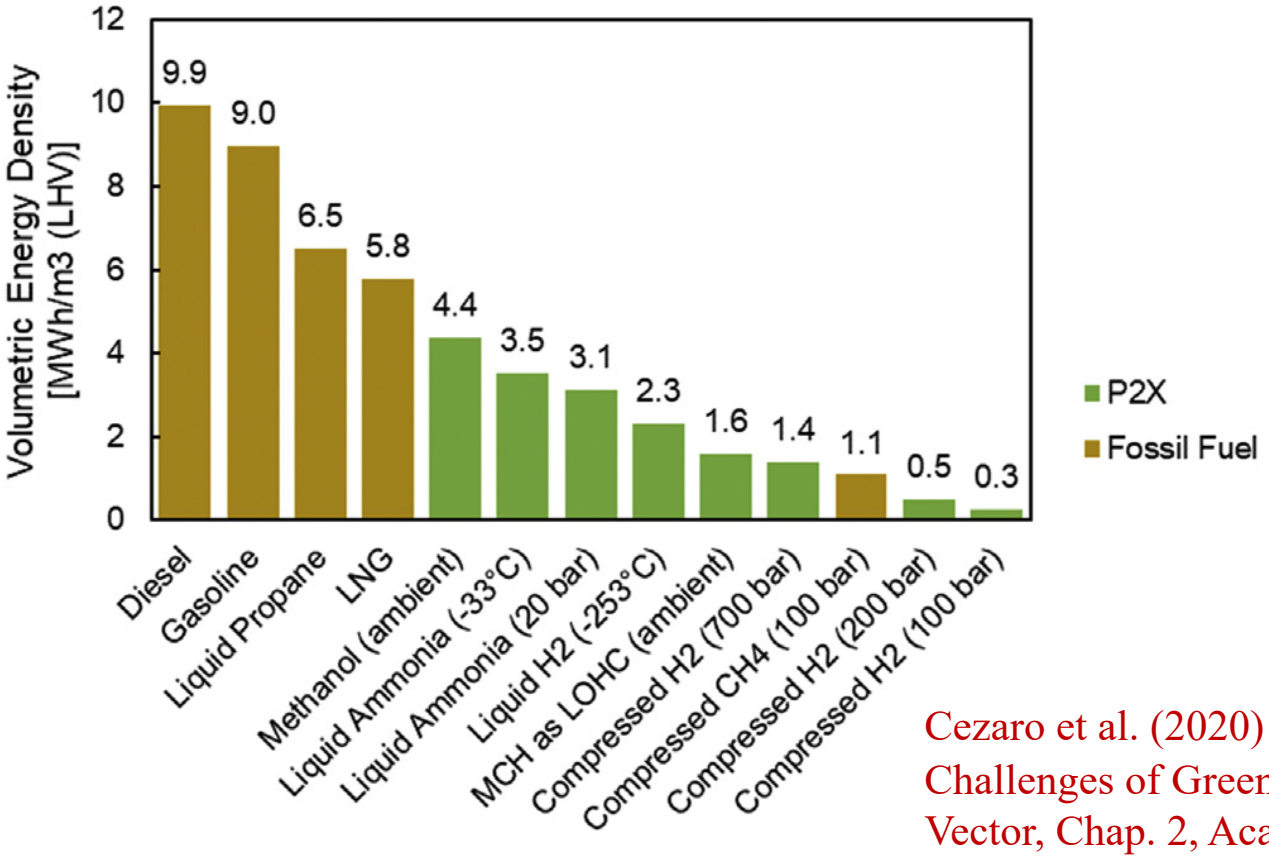
Difficult	Transport	**Easy**
Lower OPEX	OPEX/CAPEX	**Lower CAPEX**
0.071 kg/L	Liquid density	**0.6819 kg/L**
−252.76 °C	Boiling point	**−33.35 °C**
Easy	Combustion	**Difficult**
moderate	(Green) energy cost	**Expensive**

2 – An easier and available way to transport energy



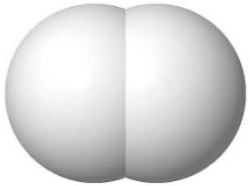


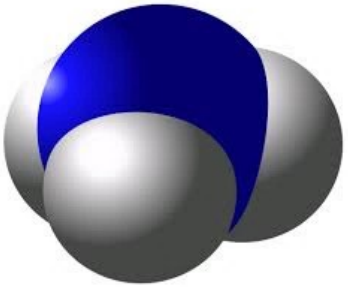
Volumetric energy density of various chemicals under commonly used conditions



Cezaro et al. (2020) Techno-Economic Challenges of Green Ammonia as an Energy Vector, Chap. 2, Academic Press.

3 – Challenges to tackle





SAFETY

Both have drawbacks

Risk of explosion

Death beyond 1,700 ppm

Detectable by most people beyond 50 ppm

3 – Challenges to tackle

Successful health and safety protocols and regulations already exist for every feature of the ammonia industrial application, from its synthesis to its combustion.

(17.5 million tons ammonia safely traded and transported yearly by ship, truck, train & pipelines)

Public acceptance through community engagement plans will be necessary for the implementation and widespread use of ammonia in our society.

3 – Challenges to tackle

Direct ammonia fuel cells (DAFC)

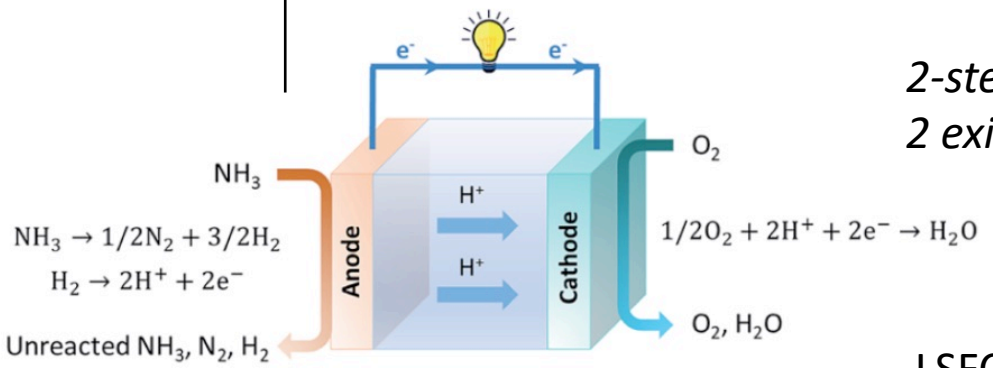
- SOEC (TRL 4-9) | Proton conducting

  O^{2-} conducting

Higher mobility of H^+ vs O^{2-}
Lower temperatures

For Ni–YSZ and Ni–GDC anodes, 750°C required for complete decomposition of ammonia.
For Ni–BCZY, 600°C (less sensitive to H poisoning

NH_3 and H_2O are separated
No NO_x production
Main advantage of SOFC-H



2-step process
2 exits

LSFC cathode

Gd, Zr and Nd-doped BCO ($BaCeO_3$)

~200 mW cm^{-2}
1.0-1.2 V

Conclusion

Major actors are willing to use Ammonia in their energy mix, due to:

- the difficulty to transport hydrogen over long distances
- The availability of infrastructures for NH_3 use in fertilizers industry

It is likely a mid-term solution before:

- Hydrogen storage is improved
- NH_3 is synthesized directly from water with high yields

The transition duration is country-dependent.

Hydrogen will not be replaced by ammonia but its economy might rely on ammonia for easier transportation and storage, at least for a transition period of a few tens of years.

Thank you for your attention