

First Workshop ARENHA project: "Introduction to novel technologies related to ammonia-based energy storage"

Advanced Ammonia Synthesis Technologies Overview

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I.About Proton Ventures

- 35 years experience in ammonia business
- Globally active in ammonia (storage) market, energy (storage) market
- Focusing on de-centralised ammonia production
- Working towards the energy transition from the chemical (ammonia) perspective

Ammonia business segments







Bread from the air Haber-Bosh Process







(1874-1940)

Nobel Prize in Chemistry 1918 and 1932



- 85% of Ammonia used as fertilizer and fertilizer feedstock.
- \circ 15% for chemical production

Reference: TU Delft, Fossil-free fuel lecture, Haber-Bosch Process, Prof. Earl Goetheer, 2018. https://es.okchem.com/news/wGkHZIJi4/OCP-Group-expects-ammonia-plant-in-Nigeria-to-begin-production-in-late-2023.html





Bread from the air Haber-Bosh Process

 $N_2 + 3H_2 \leftrightarrow 2NH_3 \Delta H^o = -92 \, kJ/mol$



Reference: TU Delft, Fossil-free fuel lecture, Haber-Bosch Process, Prof. Earl Goetheer, 2018







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Abh. 1 Haber-Le Rossignol-Apparatur zur Ammoniaksynthese

- A closed circulation system for ammonia synthesis that was built by Haber and his team.
 Operating pressure: 175 bar, temperature 550°C with 98 g of osmium catalyst.
- Ammonia production capacity from the loop was 80 g/hr.

Reference: Catalytic Ammonia Synthesis, J.R.Jennings, Springer Science and Business Media, New York, 1991.





Production Capacity of Ammonia Worldwide from 2018 to 2021, with a forecase for 2026 and 2030



Reference: https://www.statista.com/statistics/1065865/ammonia-production-capacity-globally/

 The forecast capacity growth is attributable to approx. 107 planned and announced ammonia plants, primarily located in Asia and Middle East, that are expected to go online by 2030.



Ammonia Plant (1850 metric tons per day)

Reference: https://www.energy.gov/sites/default/files/2021-05/052721-h2iqhour_0.pdf

- Hydrogen from Steam Methane Reforming
- Nitrogen from Cryogenic Air Separation





4. Ammonia Synthesis Loop Process Concept



Single pass conversion: 18-20% Ο







Green Ammonia Production (TRL 7) (<u>Proton Ventures</u>)





Green Ammonia Production (TRL 7) (Proton Ventures)





Modular Haber-Bosch (Proton Ventures NFuel Unit)

	CAPACITY	CAPACITY	POWER CONSUMPTION
UNIT	metric ton/year	metric ton/day	Megawatt
NFUEL 1	1000	3	1,5
NFUEL 4	4000	10	5-6
NFUEL20	20000	60	25-30





One-step Reactions using Water as a Hydrogen Source (TRL I-2) (Davide Ripepi, 2022)



- Atmospheric Pressure and Room Temperature
- Nitrogen Adsorption on a polycrystalline Ni-surface
- Hydrogen Permeation via a Thick Ni-Electrode
- \circ Nitrogen Hydrogenation to Ammonia



Reference: Ammonia synthesis at ambient conditions via electrochemical atomic hydrogen permeation, Davide Ripepi et., ACS, Energy Letters, 2022





Single-Vessel Ammonia Synthesis and Separation for Green Ammonia Production (TRL 1-2) (Collin Smith, 2021)

- Low temperature Ru catalyst
- High temperature stable absorbent
- An integration system that exceeds reaction equilibrium
- Reactors with single and double layer configurations





Reference: Single-vessel ammonia synthesis and separation for green ammonia production – redefining Haber-Bosch process, Collin Smith, University of Cambridge, NH3 Event 2021





Plasma-Catalytic Ammonia Synthesis (Kevin Rouwenhorst, etc., 2019)

- Plasma is an ionized gas (free electrons)
- Electrons can pre-activate strong triple N≡N bond (931 kJ mol-1)
- Decreases barrier for N2 dissociation on catalyst (lower T operation), from ~100 kJ mol-1 without plasma to ~30 kJ mol-1 with plasma (Ru catalyst)
- Ambient pressure operation in non-thermal plasma



Reference: <u>Vibrationally Excited Activation of N2 in Plasma-Enhanced Catalytic Ammonia Synthesis: A Kinetic Analysis, Kevin H.</u>. Rouwenhost etc., ACS Sustainable Chem. Eng, 2019. Overcoming ammonia synthesis scaling relations with plasma-enabled catalysis, Prateek Methta etc., Nature Catalysis, 2018.





Green Hydrogen and Ammonia Plant: ACME Group in India (2022)

- Location: Bikaner, Rajasthan, India
- Demonstration size facility powered by 5 MW of solar panels (with an expansion to 10 MW panned.)







Advanced Ammonia Synthesis Loop ARENHA Concept (TRL 3-5) (Proton Ventures & DTU)

- Conventional Haber-Bosch process with new catalytic material which allows a mild operation conditions.
- Selectively ammonia separation by developed absorbent material. (DTU)
- Prototype in 2023 with nominal ammonia production capacity of 10 kg/day.











PROTON VENTURES

- June 2&3 Rotterdam, The Netherlands
- Discount for AFA amd AEA Members
- More information and registration: <u>www.nh3event.com</u>





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Thank you for your attention

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