EMPOWERING EXPERTISE.

OST
Eastern Switzerland
University of Applied Sciences

Power-to-Ammonia

Seasonal energy carrier – Power-to-X technology

About 70% of global ammonia production is used in agriculture, primarily as a base for fertilizers like urea and ammonium nitrate [5]. In industry, ammonia is used in the production of textiles, plastics, and various chemicals.

Traditionally, ammonia production has relied heavily on fossil fuel-based processes. Conventional ammonia production methods include steam methane reforming (SMR) of natural gas, 70% of ammonia production [1], and coal gasification, 30% of the global production [1]. These carbon-intensive methods contribute significantly to global CO_2 emissions – approximately 1.2% of total global emissions [3].

China is the largest producer, accounting for 30% of the total production, followed by the United States and the EU [5]. The transition to sustainable ammonia production represents a crucial shift in the energy landscape. Power-to-X (PtX) technologies offer an alternative pathway through electrolytic hydrogen production. In this process (described in Figure 1), nitrogen is obtained via Air Separation Unit (ASU) or Pressure Swing Adsorption (PSA), while hydrogen is produced through electrolysis. Both molecules then react in the Haber-Bosch process following this equation:

$$N_2 + 3\,H_2 \rightarrow NH_3$$

When both hydrogen and nitrogen are produced using renewable energy and sustainable methods, the resulting product is known as green ammonia or e-ammonia. Unlike methane or methanol, $PtNH_3$ is a carbon-free energy carrier, offering a significant advantage when used in gas turbines, fuel cells, and other energy systems. It also benefits from a high energy density, offering significant advantages for energy storage and transport. In this context, $PtNH_3$ also offers a promising solution for seasonal energy management.

During summer, when renewable electricity supply often exceeds demand, surplus electricity can be used to synthesize ammonia, which is then stored and reconverted to electricity in winter using gas turbines or fuel cells. This seasonal arbitrage not only optimizes the use of renewable energy but also allows for integration with thermal systems in Power-to-Heat or Power-to-Cool applications. By reducing dependence on fossil fuel imports and allowing strategic energy reserves to be built up, it strengthens energy resilience and independence.

While there are currently no Power-to-Ammonia installations in Switzerland, ammonia is imported and used in a variety of applications, particularly in agriculture for fertilizer production and spreading, in industrial processes such as chemical manufacturing and refrigeration. Although the global deployment of Power-to-Ammonia remains limited – only ten plants are currently operational worldwide according to the IEA hydrogen database – numerous projects are in development, indicating increasing momentum for this technology.

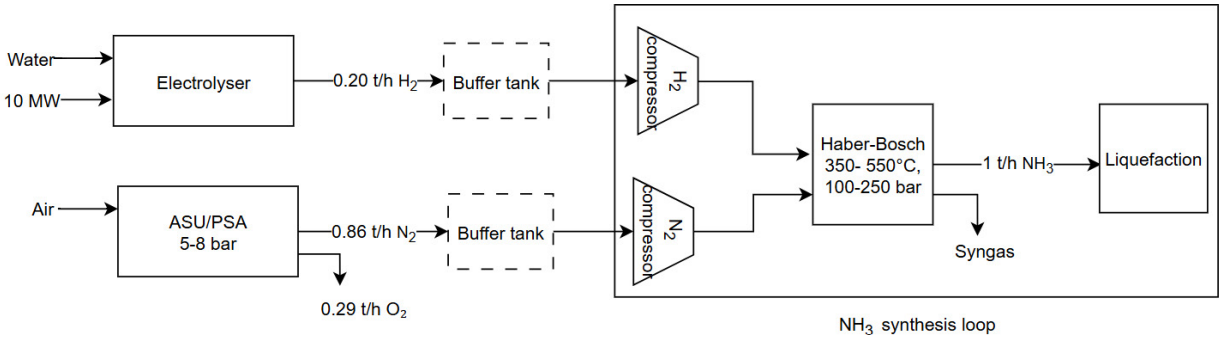


Figure 1: $PtNH_3$ synthesis process flow diagram for a 10 MW electrolyser. Dashed units are the ones that can be installed but are not necessary. ASU: Cryogenic air separation unit. PSA: Pressure swing adsorption.

Pre-commercial state

The Haber-Bosch process for ammonia synthesis is fully mature, having been developed for more than a century. Electrolysis technologies are less mature, and their integration with Haber-Bosch is still under development.

Efficiency (LHV basis)

Overall $PtH_2$to-NH_3 efficiencies are in the range of 52–62 % [6]. Electrolysis efficiencies are 50–70% for PEM and 56–61% for alkaline [2]. Additional energy requirements include ASU/PSA consumption below 0.9 GJ per tonne NH_3 [6,8] and an ammonia synthesis loop demand of about 2 GJ per tonne NH_3 [6].

Storage and transport

In its state at atmospheric conditions, ammonia exists as a gas. It can be stored as compressed gas in pressure vessels, as liquid in semi-refrigerated tanks (~0 °C) or at low temperatures (–33 °C), and less commonly in solid-state storage. Transport options include pipelines, maritime shipping, rail, and trucks.

$PtNH_3$ is compatible with existing infrastructure, and handling expertise further supports its potential role in decarbonized energy systems. However, challenges remain, including the high energy consumption of the production process, safety concerns due to its toxicity and corrosiveness, current cost disadvantages compared to conventional ammonia, and the lack of a fully developed regulatory framework for large-scale deployment.

Despite these limitations, the broad applicability and energy security benefits of $PtNH_3$ make it a key element in the transition to a more sustainable and resilient energy system.

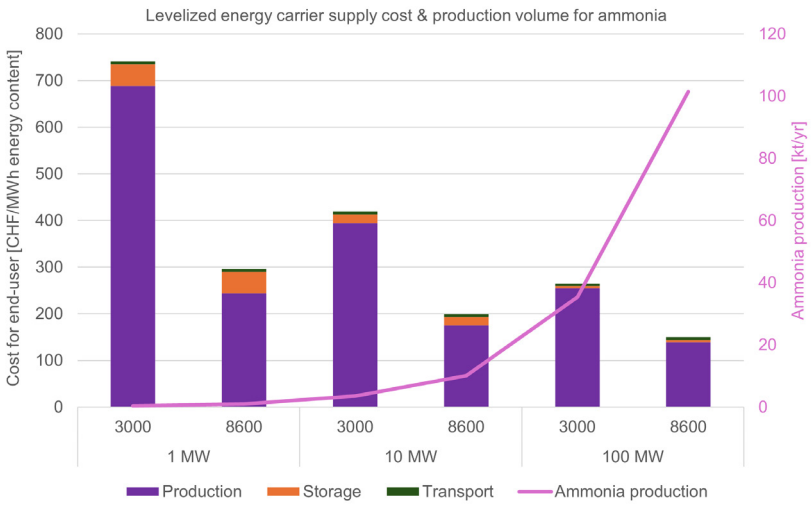
Availability

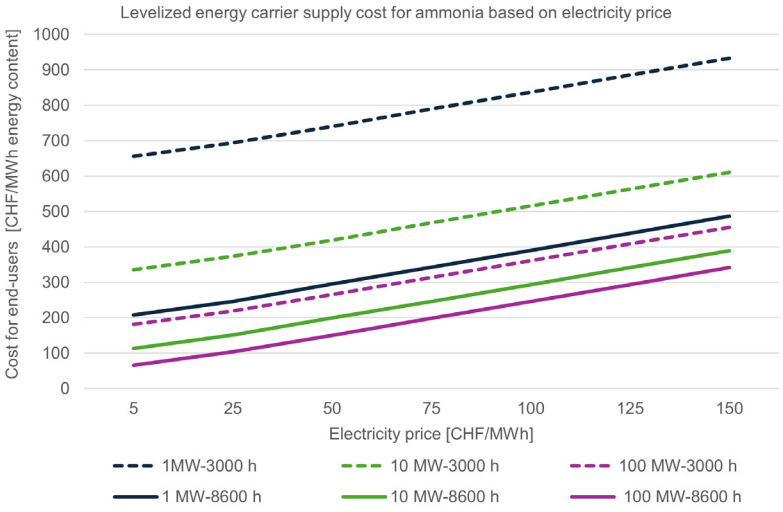
Global production of ammonia in 2023	240 Mio. tonne [3]
Swiss production capacity of $PtNH_3$ in 2024	-

Chemical properties & Safety

Volumetric energy density (LHV): Net calorific value	8.56 kWh/m³ @standard conditions: 273.15 K, 1.013 bar 3596 kWh/m³ @ (-33°C, 1 bar), (20°C, 8.6 bar) Durch die Vorfertigung der Fassadenmodule wird die Bauzeit minimiert.
Gravimetric energy density:Net calorific value	6.25 kWh/kg
Melting point / boiling point	-78 / -33 °C
Flash point / Auto ignition	11 / 651 °C
Ammonia is a colorless gas with a pungent odor. It is toxic and corrosive at high concentrations. Exposure to concentrations above 300 ppm can pose an immediate danger to life and health. It causes severe irritation to the eyes, respiratory system, and skin. Proper handling, storage, and ventilation are essential in all applications.	
Safety (hazard based on EU Regulation)	H221, H280, H314, H331, H400, H410 / H411
Safety (precaution based on EU Regulation)	P210, P260, P271, P303 + P361 + P353, P304 + P340, P305 + P351 + P338, P310, P377, P403 + P233, P405
Explosive / flammability in air	15-28% (slightly flammable)
Corrosion	Causes severe skin burns and eye damage
Toxicity	Toxic if inhaled and very toxic to aquatic life
Air purity regulation	30 mg/m³

Cost analysis





The production costs take into account the hydrogen production encompassing the electrolyser and all external costs, the air separation unit for N_2 extraction, and the NH_3 synthesis. For both N_2 and NH_3 synthesis, the cost functions have been derived from two studies [8], [7]. The bigger the size of the ammonia production, the higher the impact of the electricity cost. The same is observed with the number of operation hours. For the 100 MW scenario with full-year operation, the total cost is multiplied by five between the lowest and highest electricity cost. The levelized cost of ammonia ranges from 120-250 CHF/t under full operation and 180-700 CHF/t under half-year operation, compared to 260-4410 CHF/t for fossil-based fuels [4].

Sources / additional information

[1] ACS Publications, «The Colors of Ammonia,» June 2025. https://pubs.acs.org/doi/10.1021/acsenergylett.4c01391

[2] van Leeuwen, «D8.3: Report on the costs involved with PtG technologies and their potentials across the EU,» STORE&GO, University of Groningen, 2018. https://www.storeandgo.info/fileadmin/downloads/publications/delivera-bles_2019/STOREandGO_D8.3.pdf

[3] Kriegsmann et al., «Power-to-Ammonia,» 2025.

[4] Eliseev, «The Ammonia Market Today and a Bridge to the Future,» S&P Global, 2024.

[5] International Energy Agency (IEA), «Ammonia Technology Roadmap.» https://www.iea.org/reports/ammonia-technol-ogy-roadmap

[6] Innovation Outlook, «Renewable Ammonia,» June 2025. https://www.researchgate.net/publication/360688024_Innova-tion_Outlook_Renewable_Ammonia

[7] Fasihi et al., «Global potential of green ammonia based on hybrid PV-wind power plants,» Applied Energy, 2021. https://www.sciencedirect.com/science/article/pii/S0306261920315750

[8] Rivarolo et al., «Clean Hydrogen and Ammonia Synthesis in Paraguay from the Itaipu 14 GW Hydroelectric Plant,» ChemEngineering, 2018. https://doi.org/10.3390/chemengineering2030045

SPF INSTITUTE FOR SOLAR TECHNOLOGY

Contact
Yvonne Bäuerle, Projektleiterin SPF
OST – Ostschweizer Fachhochschule,
Campus Rapperswil-Jona
Oberseestrasse 10, 8640 Rapperswil
T +41 58 257 42 04
yvonne.baeuerle@ost.ch | ost.ch/spf

Prepared as part of the ReWAX research project, funded by the Swiss Federal Office of Energy (SFOE), Buildings and Cities Program – Version 1.0, November 2025.