15°
ΠΑΝΕΛΛΗΝΙΟ
ΕΠΙΣΤΗΜΟΝΙΚΟ
ΣΥΝΕΔΡΙΟ
ΧΗΜΙΚΗΣ
ΜΗΧΑΝΙΚΗΣ
ΧΑΝΙΑ | 3-5 Ιουνίου 2026

15ο Πανελλήνιο Επιστημονικό Συνέδριο Χημικής Μηχανικής
3 –5 Ιουνίου 2026, Χανιά

# Ammonia as an Efficient Hydrogen Vector: Catalytic Pathways, Reactor Concepts and System Integration

Christos K. Mytafides[1,2]*, Andrianna Gouziou[1,2], Catherine Drosou[1,2], Nikolaos Kostoglou[2], Anastasios Labropoulos[2], Emmanuel Stamatakis[3], Athanasios Stubos[3], Dimitrios Gournis[1,2], Ioannis V. Yentekakis[1,2]**

[1]Institute of GeoEnergy, Foundation for Research and Technology-Hellas (FORTH)
[2]Laboratory of Physical Chemistry & Chemical Processes, School of Environmental Engineering, Technical University of Crete, 73100, Chania, Greece
[3]Institute of Nuclear & Radiological Sciences and Technology, Energy & Safety (INRASTES), National Center for Scientific Research “DEMOKRITOS” (NCSRD), Athens, Greece
**Corresponding author email: cmytafides@gmail.com (Christos K. Mytafides)*
*** Corresponding author email: igentekakis@tuc.gr (Ioannis V. Yentekakis)*

***keywords:*** *Ammonia carrier; Hydrogen production; Ammonia decomposition; Catalysts; Reactor design; Hydrogen purification*

## Introduction

The transition toward low-carbon energy systems requires hydrogen delivery pathways that are not only clean at the point of use but also practical for storage, transport, and large-scale deployment. In this context, ammonia ($NH_3$) emerges as a particularly attractive hydrogen vector because it combines a high hydrogen content, established industrial logistics, and comparatively mild liquefaction conditions [1-3]. Its role is especially compelling for distributed energy systems, maritime applications, and sectors where direct hydrogen handling remains technically burdensome [2-4]. This study examines ammonia not simply as a chemical commodity, but as an enabling intermediary for future hydrogen infrastructure.

## Materials and methods

The study is based on a critical survey of recent peer-reviewed literature addressing the full ammonia-to-hydrogen value chain. The analysis covers ammonia synthesis and logistics, catalyst and reactor engineering for $NH_3$ cracking, $H_2$ separation and purification, as well as techno-economic and environmental assessments. Particular attention is given to catalyst design, reaction pathways, operating temperature windows, reactor intensification strategies, and the compatibility of the resulting hydrogen with fuel-cell-grade specifications.

## Results and discussion

The literature shows that ammonia cracking is a favorable route for hydrogen generation [5, 6], yet its practical implementation is constrained by kinetic limitations, heat-transfer demands, catalyst stability, and product purification requirements. Ruthenium-based systems remain highly active [7, 8], but their cost motivates the development of earth-abundant alternatives based on nickel, cobalt, and iron [6-9], together with bimetallic formulations, tailored supports, and nanostructured architectures. In parallel, reactor concepts such as membrane reactors, microreactors, fluidized beds, and plasma-assisted systems [10-12], can improve conversion efficiency and reduce downstream separation burden. The integration of hydrogen-selective membranes is particularly promising because it enables in situ separation of $H_2$, shifts equilibrium toward higher conversion, and supports continuous operation at lower effective temperatures [10, 11]. From a systems perspective, the overall attractiveness of ammonia increases when the upstream production route is decarbonized and when the cracking unit is coupled with renewable electricity, compact purification trains, and robust thermal management. Figure 1 illustrates $NH_3$ as a sustainable and carbon-free energy vector in the energy revolution. Techno-economic studies further indicate that the feasibility of ammonia-based hydrogen supply depends strongly on catalyst lifetime, scale, energy input, and infrastructure reuse [3]. Table 1 shows a comparative performance of catalysts for ammonia decomposition toward hydrogen production [6-9].

## Conclusions

Ammonia can serve as a credible bridge between hydrogen production and end use, provided that catalytic activity, durability, reactor integration, and purification efficiency continue to improve. The most viable near-term route is likely to combine optimized catalysts with membrane-assisted cracking and flexible heat supply, thereby enabling fuel-cell-grade hydrogen from a transportable carbon-free carrier. Future progress will depend on coordinated advances in materials design, process intensification, and system-level integration.

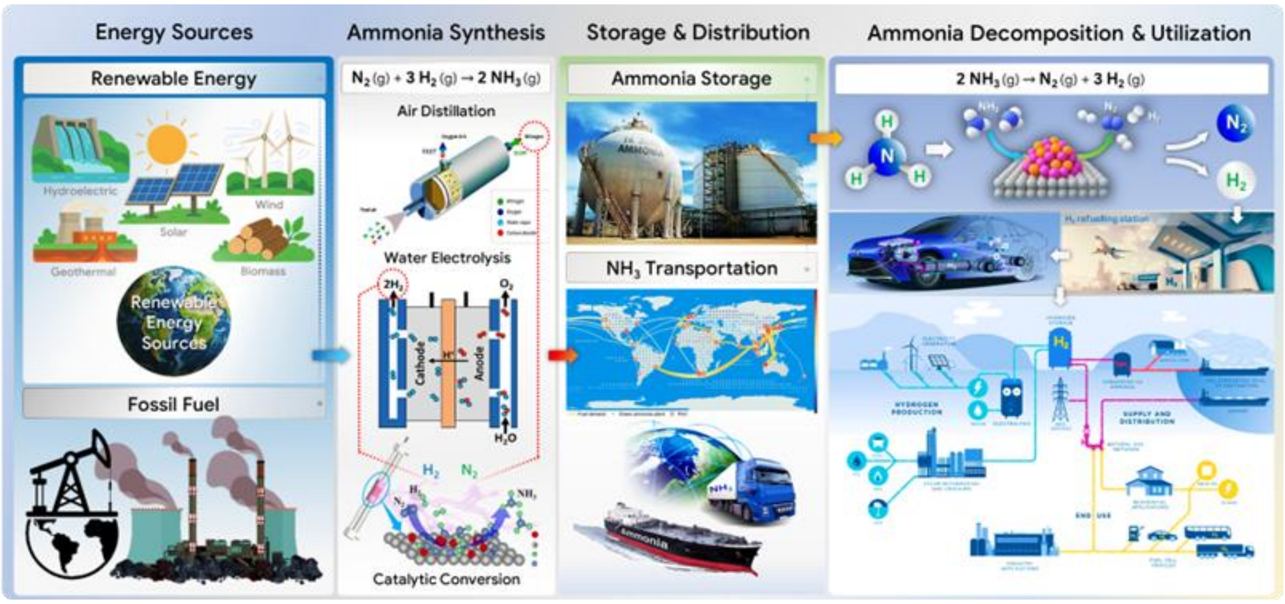

***Figure 1.*** *Ammonia as a sustainable and carbon-free energy vector in the energy revolution.*

***Table 1.*** *Comparative performance of catalysts for ammonia decomposition toward hydrogen production [6-9].*

| Catalyst System | Active Phase | Temperature (°C) | Conversion (%) | Key Advantages | Limitations |
|---|---|---|---|---|---|
| Ru-based | $Ru/Al_2O_3$, Ru/CNT | 400–600 | ~100 | Highest activity, low temperature operation | High cost, scarcity |
| Ni-based | $Ni/Al_2O_3$, Ni-MgO | 500–800 | 80–95 | Low cost, scalable | Higher temperature required |
| Co-based | $Co/SiO_2$, Co spinels | 550–750 | 70–90 | Moderate cost, good stability | Lower activity than Ni |
| Fe-based | Fe catalysts | 600–800 | 60–85 | Abundant, inexpensive | Kinetic limitations |
| Bimetallic | Ni-Ru, Co-Ni | 450–700 | 85–98 | Synergistic effects, improved stability | Synthesis complexity |

***Acknowledgements:*** This study is implemented in the framework of H.F.R.I call “4th Call for H.F.R.I.’s Research Projects to Support Postdoctoral Researchers” (H.F.R.I. Project Number: 29172).

## References

[1] D.R. MacFarlane, P.V. Cherepanov, J. Choi, B.H.R. Suryanto, R.Y. Hodgetts, J.M. Bakker, F.M. Ferrero Vallana, A.N. Simonov, (2020) Joule 4(6) 1186.
[2] I. Lucentini, X. Garcia, X. Vendrell, J. Llorca, (2021) Industrial & Engineering Chemistry Research 60(51) 18560-18611.
[3] H. Asgharian, L. Baxter, F. Iov, X. Cui, S.S. Araya, M.P. Nielsen, V. Liso, (2024) Int. J. Hydrog. Energy 69 608-618.
[4] S. Sun, Q. Jiang, D. Zhao, T. Cao, H. Sha, C. Zhang, H. Song, Z. Da, (2022) Renewable and Sustainable Energy Reviews 169 112918.
[5] Z. Yanxing, G. Maoqiong, Z. Yuan, D. Xueqiang, S. Jun, (2019) Int. J. Hydrogen Energy 44(31) 16833.
[6] S. Mukherjee, S.V. Devaguptapu, A. Sviripa, C.R.F. Lund, G. Wu, (2018) Applied Catalysis B: Environmental 226 162-181.
[7] S.F. Yin, B.Q. Xu, W.X. Zhu, C.F. Ng, X.P. Zhou, C.T. Au, (2004) Catalysis Today 93-95 27-38.
[8] G. Li, M. Kanezashi, T. Yoshioka, T. Tsuru, (2013) AIChE J. 59(1) 168.
[9] I. Dincer, C. Acar, (2015) International Journal of Hydrogen Energy 40(34) 11094-11111.
[10] H. Maleki, M. Fulton, V. Bertola, (2021) Chemical Engineering Journal 411.
[11] V. Cechetto, L. Di Felice, F. Gallucci, (2023) Energy & Fuels 37(15) 10775-10798.
[12] Y. Gorbanev, I. Fedirchyk, A. Bogaerts, (2024) Current Opinion in Green and Sustainable Chemistry 47 100916.