

HYDROGEN PRODUCTION FROM AMMONIA: CATALYTIC PATHWAYS AND REACTOR TECHNOLOGIES

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Abstract

Ammonia (NH₃) is increasingly recognized as a practical hydrogen carrier for the low-carbon energy transition, combining a high volumetric hydrogen density with mature production, storage and transport infrastructure. Converting stored ammonia back into usable hydrogen, however, requires catalytic decomposition (cracking) steps that remain limited by reaction kinetics, energy demand and downstream purification needs. This work reviews the catalytic and reactor engineering strategies currently shaping the ammonia-to-hydrogen conversion route, with emphasis on technologies capable of delivering fuel-cell-grade hydrogen. A critical survey of recent peer-reviewed literature was conducted, focusing on catalyst formulations for NH₃ decomposition, reactor architectures for process intensification and hydrogen separation/purification approaches. Comparative catalytic performance data (activity, operating temperature, stability) and reactor design parameters were compiled to identify the most promising near-term technology combinations. Ruthenium-based catalysts continue to show the highest intrinsic activity for ammonia decomposition, but their cost has driven substantial research into earth-abundant alternatives based on nickel, cobalt and iron, often enhanced through bimetallic compositions, engineered supports and nanostructuring to approach Ru-like performance at lower cost. On the reactor side, membrane reactors, microreactors, fluidized-bed systems and plasma-assisted configurations offer routes to overcome the equilibrium and heat-transfer limitations of conventional fixed-bed crackers. Among these, hydrogen-selective membrane integration stands out: by continuously removing H₂ from the reaction zone, it shifts equilibrium toward higher NH₃ conversion and allows operation at lower effective temperatures, reducing both energy input and downstream

Biography

Christos K Mytafides, is a Sustainability and Materials Engineer (MSc, PhD) currently working as a postdoctoral researcher at the Laboratory of Physical Chemistry & Chemical Processes (PCCP/Lab), School of Chemical & Environmental Engineering, Technical University of Crete (TUC) and the Institute of GeoEnergy, Foundation for Research and Technology-Hellas (FORTH). He completed his PhD in Materials Engineering on integrated architectures of printed electronics with energy-harvesting capabilities, specializing in the design, fabrication and characterization of multifunctional materials embedding photovoltaic and thermoelectric energy-harvesting functions, including fully printed carbon-nanotube-based thermoelectric generators, hybrid photothermal devices and additively manufactured flexible thermoelectric devices. His broader engineering background also includes sustainability-oriented building design, with work on energy performance assessment and zero-energy consumption structures using building information modeling. Since joining the TUC, as well as the Institute of GeoEnergy/FORTH, his research has shifted toward nanocatalytic materials and processes for clean energy conversion, including CO₂ methanation catalysis and, most recently, ammonia decomposition and catalytic pathways for hydrogen production, in collaboration with Prof. Ioannis V. Yentekakis, Prof. Dimitrios P. Gournis and colleagues at the Technical University of Crete and the National Center for Scientific Research “DEMOKRITOS” (NCSR). His work has been published in journals including the Chemical Engineering Journal, Journal of Power Sources, Applied Materials & Interfaces and is currently supported by the Hellenic Foundation for Research and Innovation (H.F.R.I.) under its post-doctoral researcher funding scheme. He combines an experimental and computational materials-engineering background

purification burden. The comparative catalyst performance data compiled in this study indicate that catalyst lifetime, active-metal loading and support architecture are decisive factors for scale-up, while techno-economic considerations show that overall system viability depends strongly on coupling the cracking unit with efficient thermal management and, where possible, renewable electricity input. Catalyst design and reactor engineering are converging toward integrated solutions in which membrane-assisted cracking, paired with durable, cost-effective catalysts, offers the most realistic near-term pathway to fuel-cell-grade hydrogen from ammonia. Continued progress will depend on coordinated advances in catalyst stability, process intensification and system-level integration of production, cracking and purification stages.

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with a growing focus on nanomaterials, sustainable energy technologies, catalyst and reactor technologies for ammonia-based hydrogen carriers, bridging materials synthesis with applied energy-system integration.