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Review

Green ammonia: the sustainable strategy to limit global carbon footprint

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Abstract

Ammonia is a cornerstone of modern society, essential for fertilizer production and increasingly recognized as a potential carbon-free energy carrier. However, conventional ammonia synthesis via the fossil-fuel-based Haber–Bosch process is highly energy intensive and responsible for nearly 400 million tons of CO_2 emissions annually, posing a major challenge to global climate mitigation efforts. Green ammonia offers a sustainable alternative by replacing fossil-derived hydrogen with hydrogen produced through renewable energy-powered water electrolysis and combining it with atmospheric nitrogen to synthesize ammonia with near-zero carbon emissions. The core process involves renewable electricity generation (solar, wind, or hydro), electrolytic hydrogen production, nitrogen separation from air, and ammonia synthesis using modified Haber–Bosch or emerging low-temperature pathways such as electrochemical, plasma-assisted, and protonic ceramic technologies. Beyond decarbonizing fertilizer production, green ammonia serves as an efficient hydrogen carrier and long-term energy storage medium, enabling integration of intermittent renewable energy into energy systems and supporting decarbonization of hard-to-electrify sectors such as shipping and power generation. Life-cycle assessments indicate that green ammonia can reduce greenhouse gas emissions by more than 99% compared to conventional ammonia. Although current production costs remain higher due to electricity prices and capital costs, rapid declines in renewable energy costs, advances in electrolyzer and catalyst technologies, and supportive policy frameworks are expected to make green ammonia economically competitive within the next decade. Overall, green ammonia represents a critical and versatile pathway for reducing the global carbon footprint while supporting both food security and the clean energy transition.

Keywords: Green ammonia, Renewable hydrogen, Haber–Bosch decarbonization, Energy storage, Carbon footprint reduction

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Introduction

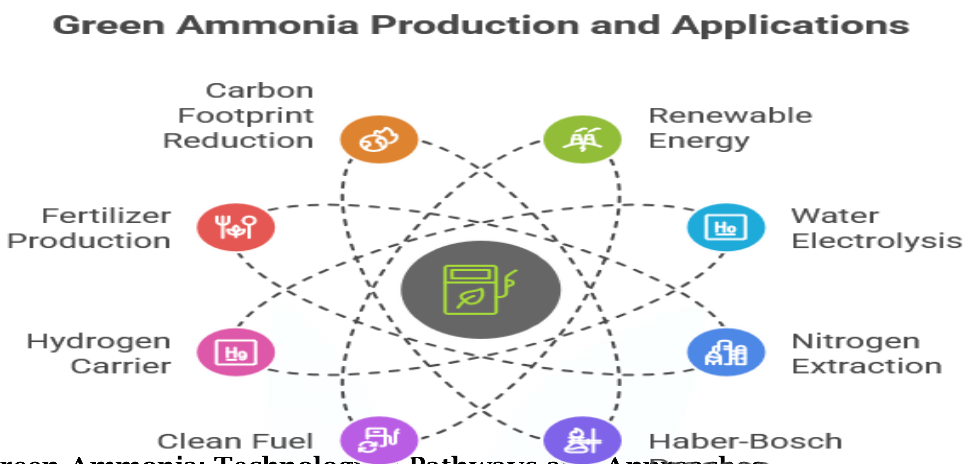
Ammonia (NH_3) stands as one of the most critical chemicals in modern industry, with global production reaching approximately 170 million tons annually. [16]. The conventional Haber-Bosch process, which has dominated ammonia synthesis for over a century, consumes approximately 2% of the world's total energy supply and generates emissions equivalent to 1.6-2.0 tons of CO_2 for every ton of ammonia produced [39]. This energy-intensive process operates under harsh conditions temperatures exceeding 400˚C and pressures of 150-300 bar fundamentally dependent on hydrogen derived from fossil fuels, primarily natural gas through steam methane reforming [4]. The environmental cost of this dominant production route is staggering: the ammonia industry collectively emits nearly 400 million tons of CO_2 annually, representing a significant portion of global greenhouse gas emissions and contributing substantially to planetary warming [9]. However, ammonia's importance extends far beyond fertilizer production. As global energy systems transition toward decarbonization, ammonia has emerged as a promising carbon-free energy carrier and hydrogen storage vector with exceptional advantages over molecular hydrogen itself [16]. Its high hydrogen content (approximately 17.8% by weight), ease of liquefaction at moderate pressures, established global infrastructure for transportation and distribution, and potential for direct utilization in fuel cells and combustion engines position ammonia as a critical enabler of the global energy transition [29]. The fundamental paradox facing the chemical and energy industries is clear: while ammonia is essential for feeding a global population dependent on synthetic nitrogen fertilizers, its current production methodology undermines climate mitigation efforts. Green ammonia produced through electrochemical synthesis powered by renewable energy sources represents a transformative solution to this paradox, offering a pathway toward simultaneous decarbonization of both the chemical industry and energy systems.

The Haber-Bosch Process and Its Environmental Limitations

The Haber-Bosch process, developed in the early twentieth century, revolutionized agricultural production by enabling large-scale synthetic nitrogen fixation [13]. The reaction proceeds according to the fundamental equation: $N_2 + 3H_2 \rightleftharpoons 2NH_3$. Despite its remarkable achievement in sustaining modern civilization approximately 40% of global food production depends on synthetic ammonia-derived fertilizers the process carries enormous environmental costs that have become increasingly untenable in the context of climate change [26]. The conventional Haber-Bosch methodology requires extreme operational conditions, with typical industrial reactors operating at temperatures between 400-500°C and pressures of 150-300 atmospheres to achieve reasonable conversion rates and reaction kinetics [32].

The thermodynamic character of ammonia synthesis creates a fundamental constraint: the reaction is highly exothermic and equilibrium-favoring at lower temperatures but kinetically limited at low temperature ranges. Consequently, industrial practitioners must accept a critical tradeoff between thermodynamic equilibrium (favoring ammonia formation at lower temperatures) and reaction rate (requiring higher temperatures for practical production volumes). This technological compromise necessitates substantial energy inputs, which historically derived predominantly from coal and natural gas combustion [13]. Modern gray ammonia production relies heavily on steam methane reforming, where natural gas undergoes catalytic conversion with steam at approximately 800-900°Cover nickel catalysts to produce hydrogen, carbon monoxide, and carbon dioxide. The resulting syngas is subsequently converted to ammonia using iron-based catalysts under the harsh pressure and temperature conditions described above [33].

The environmental burden associated with this pathway extends substantially beyond direct CO_2 emissions from hydrogen production. Process-related emissions stem from multiple sources: fuel consumption for heating reactors and separation systems, the thermodynamic requirement for continuous hydrogen recycling due to equilibrium limitations, energy demands of air separation units for nitrogen provision, and emissions associated with compression and purification steps [32]. When accounting for the complete lifecycle, including feedstock extraction, processing, transportation, and distribution, the carbon footprint of conventional ammonia frequently exceeds 2.0 kg CO_2-equivalent per kilogram of ammonia, though some analysis suggests values near 2.16 kg CO_2-eq/kg NH_3 when including comprehensive system boundaries [13]. Global ammonia production thus represents a significant contributor to anthropogenic greenhouse gas emissions, with particular significance given the projected demand increases associated with expanding agricultural needs in developing regions.



Green Ammonia: Technological Pathways and Approaches

Green ammonia production encompasses multiple technological approaches; all fundamentally centered on replacing fossil fuel-derived hydrogen with hydrogen produced through renewable energy-powered electrolysis and utilizing atmospheric nitrogen as the feedstock [39]. The electrochemical synthesis pathway represents the most extensively researched and promising route, wherein water electrolysis-powered by wind, solar, or other renewable electricity sources-generates hydrogen gas and oxygen. This green hydrogen is subsequently combined with atmospheric nitrogen through catalytic ammonia synthesis under milder conditions compared to conventional Haber-Bosch processes [4]. The system achieves complete decarbonization when electricity originates entirely from renewable sources, eliminating fossil fuel combustion and creating a fundamentally sustainable production framework.

Electrolytic Hydrogen Production

Proton exchange membrane (PEM) electrolyzers and alkaline water electrolyzers represent the two dominant technologies for renewable hydrogen production [38]. PEM electrolyzers demonstrate superior operational flexibility, enabling rapid response to variable renewable energy inputs characteristic of wind and solar systems. These systems utilize a solid polymer electrolyte membrane separating anode and cathode compartments, enabling hydrogen production at the cathode through water reduction while oxygen evolution occurs at the anode. The ability of PEM electrolyzers to tolerate significant pressure fluctuations and dynamic load variations makes them particularly suitable for integration with intermittent renewable energy sources [4]. Alkaline water electrolyzers, conversely, utilize liquid alkaline solutions (typically potassium hydroxide) as electrolytes and demonstrate maturity as established technology, though with somewhat lower dynamic response capabilities than PEM systems. Recent research indicates that synergistic hydrogen generation utilizing both AWE and PEMEC technologies can optimize thermodynamic and economic performance by capitalizing on the distinct advantages of each electrolyzer type [38].

The efficiency of electrolytic hydrogen production constitutes a critical parameter determining overall green ammonia system viability. Modern PEM electrolyzers achieve electrical efficiencies approaching 70-80% (higher heating value), while alkaline systems reach comparable or slightly higher efficiency values depending on operating conditions and system design [9]. The energy requirement for hydrogen production through electrolysis substantially exceeds that of steam methane reforming on a per-unit-hydrogen basis; however, when assessed comprehensively including avoided fossil fuel combustion, lifecycle emissions, and integration with renewable electricity sources providing minimal marginal cost, the sustainability advantages become overwhelmingly apparent [13].

Ammonia Synthesis from Green Hydrogen

Once green hydrogen has been generated through electrolysis, conversion to ammonia follows established catalytic pathways similar to conventional Haber-Bosch technology, yet operating under substantially modified conditions optimized for renewable energy integration [9]. Small-scale flexible ammonia production plants represent an emerging paradigm, contrasting sharply with the centralized, massive-scale infrastructure characterizing conventional ammonia production. These distributed systems can operate under conditions specifically tailored to integrate renewable energy intermittency, utilizing energy storage mechanisms including battery systems and hydrogen storage to buffer mismatches between renewable generation and ammonia synthesis demands [10]. Research on nonthermal plasma-assisted ammonia synthesis has demonstrated remarkable potential for producing ammonia under mild conditions—temperatures below 200°C, atmospheric or near-atmospheric pressures—coupled with direct utilization of renewable electricity [39]. Plasma-catalytic systems generate energetic electrons and reactive species capable of activating the thermodynamically inert N_2 triple bond, circumventing the kinetic limitations that necessitate extreme conditions in conventional processes [37]. The synergistic combination of plasma technology with catalytic systems represents a frontier area in green ammonia research, potentially enabling substantially more efficient and flexible production pathways.

Environmental and Climate Benefits of Green Ammonia

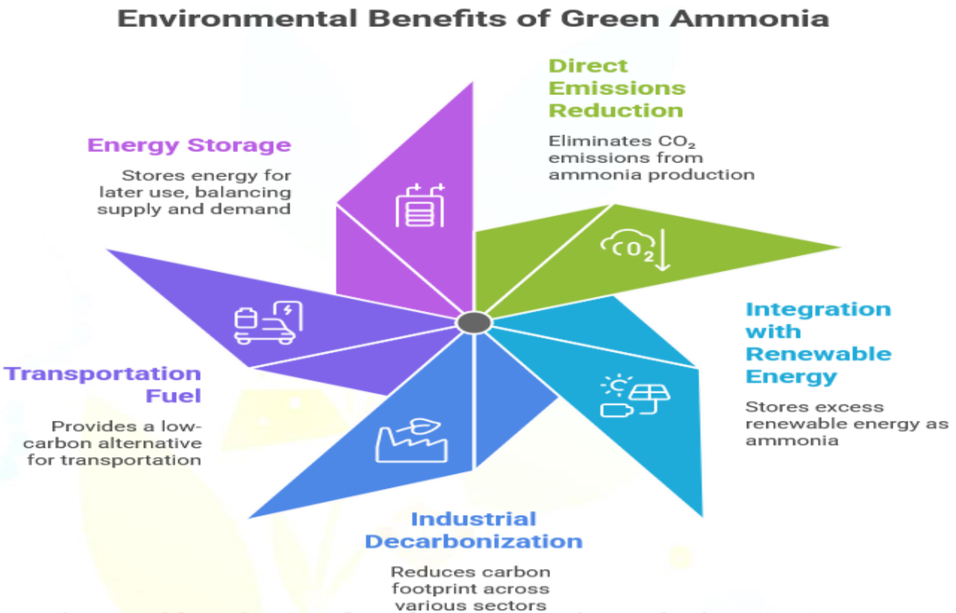
The environmental advantages of green ammonia production span multiple dimensions, fundamentally addressing the carbon footprint of conventional ammonia while creating opportunities for industrial decarbonization beyond the chemical sector itself. When ammonia is synthesized entirely from renewable electricity and atmospheric nitrogen, carbon dioxide emissions approach zero representing a reduction exceeding 99% compared to gray ammonia [32]. Lifecycle assessment studies comparing various ammonia production methodologies demonstrate that green ammonia produced through PV-powered electrolysis achieves carbon footprints near 0.0197 kg CO_2-eq/kg ammonia, while wind-powered green ammonia reaches approximately 0.01039 kg CO_2-eq/kg ammonia, compared with gray ammonia at 0.148 kg CO_2-eq/kg and conventional diesel at 0.0851 kg CO_2-eq/kg when considering stoichiometric combustion [27].

Direct Emissions Reduction

The direct emissions reduction potential proves substantial when deployed at scale. Global ammonia production currently generates approximately 400 million tons of CO_2 annually; transitioning to green ammonia production could eliminate the vast majority of these emissions [9]. For agricultural applications consuming 70-90% of global ammonia supply, this transition alone would provide major climate mitigation benefits comparable to significant renewable energy deployments in other sectors [33]. Furthermore, the geographic decentralization inherent to green ammonia systems through small-scale distributed production eliminates substantial transportation-related emissions associated with conventional centralized ammonia plants, particularly in regions distant from major ammonia production centers [9].

Integration with Renewable Energy Systems

Green ammonia production simultaneously addresses critical challenges associated with renewable energy integration into energy systems [10]. Solar and wind resources, while abundant and increasingly cost-competitive, exhibit substantial temporal and spatial variability. Excess renewable electricity during high-generation periods, currently economically problematic and frequently curtailed, can be converted into ammonia-a liquid or pressurized gas amenable to long-term storage and long-distance transportation. This process effectively converts intermittent renewable electricity into a chemically stored, dispatchable energy carrier [28]. Ammonia subsequently serves multiple roles: as a direct industrial feedstock, as a transportation fuel, as a chemical energy storage mechanism, and as a hydrogen carrier for end-use applications. This multifunctional capability positions green ammonia as particularly valuable for achieving deep decarbonization across multiple sectors simultaneously [29].



Economic Considerations and Techno-Economic Analysis

The economic viability of green ammonia production remains the critical barrier to widespread deployment, despite remarkable technological progress and demonstrated feasibility [12]. The levelized cost of ammonia (LCOA) from green processes currently ranges from $300-600 per ton depending on electricity prices, electrolyzer capital costs, ammonia synthesis conditions, and system integration efficiency-substantially exceeding conventional gray ammonia at approximately $200-300 per ton under typical natural gas pricing [29]. However, this economic comparison fundamentally shifts when environmental externalities, carbon pricing mechanisms, and dynamic electricity market considerations are incorporated into comprehensive analyses.

Electricity Cost as the Dominant Economic Factor

The electricity cost overwhelmingly dominates the economic profile of green ammonia systems, with energy input accounting for 60-70% of total production costs in systems powered by renewable electricity [38]. Consequently, as renewable electricity costs continue their dramatic decline with onshore wind electricity achieving costs below $30/MWh in optimal locations and solar photovoltaic electricity approaching $20/MWh in excellent resources—the competitiveness of green ammonia improves substantially [8]. Analysis indicates that achieving ammonia production cost parity with conventional Haber-Bosch methodology requires electricity prices near $30-50/MWh sustained over extended time periods, representing realistic targets in many global locations characterized by excellent renewable resources [12]. Furthermore, the recent trajectory of renewable electricity costs suggests that widespread achievement of cost-competitive green ammonia production globally is foreseeable within the next decade.

Policy and Market Factors

Beyond technical and energy cost parameters, carbon pricing mechanisms and policy frameworks dramatically alter green ammonia economic competitiveness [32]. When carbon prices reach levels reflecting the true social cost of greenhouse gas emissions estimated at $50-100+ per ton CO_2-equivalent by many economists conventional ammonia becomes economically uncompetitive relative to green ammonia. European Union climate policies, including both carbon pricing through the Emissions Trading System and regulatory requirements for decarbonization of fertilizers, have begun shifting market economics substantially toward green ammonia adoption [32]. Conversely, regions lacking carbon pricing mechanisms or with continued subsidization of fossil fuels maintain economic advantages for conventional ammonia production, though long-term unsustainability of such policies appears evident.

Catalytic Advances and Reaction Engineering

Substantial catalytic innovations have emerged to enhance green ammonia production efficiency and enable operation under milder conditions compared to conventional Haber-Bosch technology. Ruthenium-based catalysts, particularly when supported on polar materials including magnesium oxide and modified with promoters such as cesium compounds, demonstrate remarkably superior performance for low-temperature, low-pressure ammonia synthesis [35]. Oxygen vacancy-engineered metal oxides show promise for electrochemical nitrogen reduction reactions, achieving Faradaic efficiencies near 100% in certain configurations [24]. Computational screening and machine learning approaches have accelerated discovery of novel catalyst materials for nitrogen reduction reactions, enabling rational design of catalytic systems optimized for specific operating conditions [23].

Intermediate-Temperature Protonic Ceramic Electrolysis

Protonic ceramic electrolysis cells (PCECs) represent an emerging technology enabling ammonia synthesis through electrolytic pathways at intermediate temperatures (typically 400-700°C) [25]. These systems directly electrolyze steam to generate protons at the oxygen electrode, with these protons subsequently driving ammonia synthesis directly at the fuel electrode through N_2 reduction in the presence of hydrogen. This integrated approach circumvents the need for separate hydrogen production and ammonia synthesis steps, potentially enhancing system efficiency substantially compared to sequential processes [40]. While still primarily within research and development phases, PCEC technology offers significant promise for future green ammonia systems, particularly when coupled with concentrated solar thermal or waste heat sources.

Plasma-Catalytic Synthesis

Nonthermal plasma combined with catalytic systems represents a sophisticated approach enabling ammonia production under mild conditions while directly utilizing renewable electricity [37]. Plasma discharge generates energetic electrons capable of exciting nitrogen molecules and creating reactive species (nitrogen atoms, ions, excited states) that subsequently undergo rapid reactions with hydrogen on catalytic surfaces at temperatures substantially below conventional Haber-Bosch requirements [18]. Mechanistic understanding of plasma-catalytic synergies has advanced substantially, revealing how plasma discharge creates favorable conditions for activation of the normally unreactive

N_2 molecule while catalytic surfaces direct subsequent hydrogenation steps efficiently (Bingyu, 2025).

Hydrogen Storage and System Integration Challenges

Effective integration of green ammonia production systems with variable renewable energy sources necessitates addressing multiple challenges related to hydrogen storage, buffer capacity, and system stability [10]. Hydrogen, produced continuously through electrolysis when electrical generation fluctuates substantially, requires intermediate storage to balance production and ammonia synthesis demands. Hydrogen storage methodologies include compression in high-pressure vessels (typical industrial practice), liquefaction (requiring substantial refrigeration), chemical storage in compounds including ammonia or organic hydrogen carriers, or combination approaches utilizing multiple storage mechanisms simultaneously [21].

The variable nature of renewable energy sources particularly wind and solar creates mismatches between hydrogen production and ammonia synthesis capacity requirements. Battery energy storage, hydrogen storage, or integrated multi-stage systems including heat storage can mitigate these challenges [5]. Achieving stable, efficient operation under variable supply conditions demands sophisticated control systems utilizing model predictive control, optimization algorithms, and real-time demand management [20]. Recent research demonstrates feasibility of maintaining stable ammonia production under realistic variable renewable power inputs through properly designed storage and control configurations, though optimal system sizing requires careful analysis of site-specific renewable resource characteristics [38].

Regional Case Studies and Deployment Potential

Offshore Green Ammonia Systems

Offshore renewable energy resources, particularly tidal stream and offshore wind, offer exceptional potential for green ammonia production in coastal regions [11]. Tidal stream-energy provides superior predictability compared to wind and solar, enabling more stable hydrogen and ammonia production with reduced storage requirements. Analysis of the Pentland Firth, a globally excellent tidal stream location, demonstrates that incorporating tidal capacity alongside wind capacity can reduce hydrogen storage requirements by 96% and decrease levelized ammonia costs by 12% compared to wind-only systems [11]. Offshore green ammonia platforms could export ammonia via established shipping infrastructure, providing significant advantages for island nations and coastal regions with limited land availability.

Solar-Powered Systems in Arid Regions

Solar photovoltaic resources in arid and semi-arid regions globally including North Africa, the Middle East, Australia, and southwestern North America offer exceptional potential for green ammonia production [8]. Decentralized, small-scale systems could be deployed regionally, dramatically reducing transportation-related emissions compared to centralized production. Environmental and economic analysis of solar-powered electrocatalytic ammonia synthesis in sunny regions indicates competitive feasibility when accounting for lifecycle environmental impacts and moderate CO_2 pricing scenarios [8]. Such systems offer particular advantages for agricultural regions in developing nations, enabling local fertilizer production and reducing dependence on global ammonia supply chains.

Grid-Connected Systems in High-Wind Regions

Regions with exceptional wind resources—including northern Europe, North America, and parts of South America could support large-scale grid-connected green ammonia production integrated with electrical power systems [34]. These systems would function as flexible loads, consuming excess renewable electricity when generation exceeds demand and contributing to grid stability through demand-response participation. Economic analysis indicates such systems could achieve competitive LCOA values in optimal high-wind locations, particularly when integrated with existing industrial infrastructure and transportation networks [38].

Policy, Regulatory and Market Frameworks

Widespread deployment of green ammonia production necessitates supportive policy environments addressing multiple dimensions: carbon pricing sufficient to reflect greenhouse gas externalities, investment support or subsidies for emerging technologies, research funding for technological advancement, regulatory frameworks mandating decarbonization of ammonia production, and international coordination on trade and standards [33]. The European Union has begun implementing policies supporting green ammonia through carbon pricing mechanisms, renewable hydrogen production mandates, and fertilizer decarbonization requirements [32]. Similar policy frameworks are emerging in other regions, including China's ambitious hydrogen strategy and the United States' clean hydrogen production tax credits.

Standardization of green ammonia definitions, lifecycle assessment methodologies, and quality specifications constitutes an ongoing challenge requiring international cooperation [33]. Emerging certifications for low-carbon-intensity ammonia (LCIA) establish market differentiation enabling price premiums for decarbonized production, though verification and certification systems remain under development [33]. International cooperation through forums including the International Energy Agency Hydrogen Technology Collaboration Programme, United Nations Environment Programme, and various regional initiatives has accelerated knowledge sharing and technology development.

Techno-Economic Projections for 2030-2050

Projections indicate that green ammonia production will achieve substantial cost-competitiveness with conventional ammonia by 2030-2035, driven by continued renewable electricity cost reductions, electrolyzer cost decreases, and catalytic efficiency improvements [8]. By mid-century, green ammonia could represent the dominant ammonia production pathway globally, with lifecycle carbon emissions near zero when produced using renewable electricity coupled with atmospheric nitrogen as feedstock [29]. Modeling studies incorporating ambitious but realistic technology improvement rates suggest that green ammonia production costs could decline to $200-250 per ton by 2050, approaching or matching conventional ammonia at realistic carbon prices [8].

Global green ammonia production capacity is projected to reach 10-20 million tons annually by 2030 if aggressive policy support and investment materialize, expanding to 100+ million tons by 2050 as the technology matures and achieves widespread deployment [33]. Such scaling could meet a substantial portion of global ammonia demand, particularly in regions with excellent renewable resources and supportive policy environments. However, achievement of these ambitious deployment scenarios requires sustained investment, policy support, and technological advancement, alongside addressing infrastructure and supply chain development challenges.

Integration with Other Decarbonization Pathways

Green ammonia serves multiple roles within comprehensive decarbonization strategies extending beyond its traditional use as a fertilizer feedstock [29]. As an energy carrier and hydrogen storage mechanism, green ammonia facilitates renewable energy integration into energy systems while enabling long-distance energy transport via existing infrastructure [15]. Ammonia can substitute for fossil fuels in power generation, directly through ammonia combustion in gas turbines or indirectly through ammonia-based fuel cells, enabling decarbonization of electricity generation where electrification proves technically or economically challenging [14]. In transportation sectors, ammonia serves potential roles as a fuel for maritime vessels and potentially certain hard-to-electrify applications.

Integration of green ammonia production with other industrial processes including steel production, chemical synthesis, and waste treatment offers synergies enhancing overall system efficiency [3]. Coupling ammonia synthesis with CO_2 capture and utilization could produce urea and other chemicals directly, addressing both decarbonization and resource efficiency objectives [7]. Biological approaches utilizing engineered microorganisms or synthetic biology methodologies represent frontier research areas potentially offering complementary production pathways under specific conditions [1].

Challenges and Research Frontiers

Despite remarkable progress, substantial challenges remain restricting near-term deployment of green ammonia production at scale. Catalyst development for electrochemical nitrogen reduction remains an active research frontier, with faradaic efficiencies and ammonia production rates still limiting commercialization of direct electrochemical N_2 reduction for large-scale application [19]. System integration challenges, including buffering intermittent renewable energy, maintaining stable operation across load variations, and optimizing thermodynamic cycles for maximum efficiency, require continued innovation [36]. Infrastructure development-encompassing electrolysis capacity expansion, ammonia synthesis reactor manufacturing, hydrogen storage systems, and distribution networks—constitutes a substantial undertaking requiring substantial capital investment and supply chain development.

Policy uncertainty in many regions inhibits private investment in green ammonia facilities, as technology costs remain uncertain and long-term carbon pricing policies have not been established reliably in many jurisdictions. International trade frameworks and carbon border adjustment mechanisms remain under development, potentially affecting competitiveness of green ammonia in global markets [33]. Water availability represents a constraint in certain regions where renewable resources are excellent but freshwater availability proves limited, as ammonia synthesis via electrolysis demands substantial water inputs [13].

Conclusion and Path Forward

Green ammonia production through renewable energy-powered electrolysis represents a transformative technology essential for achieving deep decarbonization across multiple industrial and energy sectors simultaneously. The convergence of multiple enabling factors-declining renewable electricity costs, advancing electrolyzer and catalyst technologies, growing policy support for decarbonization, and increasing recognition of ammonia's multifunctional role in sustainable energy systems creates unprecedented opportunities for rapid deployment of green ammonia production at scale [29]. From a purely technical perspective, producing zero-carbon ammonia has been conclusively demonstrated at multiple scales and in various configurations; primary barriers to widespread deployment have become predominantly economic and policy-related rather than fundamental technical constraints. The agricultural sector, currently consuming 70-90% of global ammonia production, offers immediate deployment opportunities for green ammonia with substantial climate benefits [33]. This fertilizer market constitutes a foundation for technology commercialization and cost reduction through learning-by-doing dynamics typical of emerging technologies. Simultaneously, emerging applications as an energy carrier, hydrogen storage mechanism, and industrial feedstock create additional revenue streams and demand pathways supporting green ammonia deployment beyond traditional fertilizer uses [29].

Achieving the transition to green ammonia production at the scale required for meaningful global climate mitigation requires coordinated efforts spanning technology development, policy establishment, infrastructure investment, and international cooperation. The estimated cost of necessary infrastructure development and deployment pales in comparison to the avoided climate damages from continued reliance on carbon-intensive ammonia production. Green ammonia thus merits prioritization among industrial decarbonization strategies, combining practical near-term deployment potential with exceptional long-term climate mitigation benefits and integration potential with renewable energy systems. The sustainability imperative facing humanity, coupled with the exceptional environmental and energetic advantages of green ammonia, establishes this technology as a cornerstone of the transition to a sustainable, decarbonized future.

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