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## Green Ammonia: The Future of Nitrogen Fertilizers

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Modern agriculture depends heavily on ammonia-based nitrogen fertilizers, but conventional ammonia production is highly energy-intensive and contributes significantly to greenhouse gas emissions. Rising global energy instability and disruptions in fuel supply chains have further highlighted the need for sustainable alternatives. In this context, green ammonia produced using renewable energy sources such as solar and wind power is emerging as a promising solution for cleaner fertilizer production and future energy security. This article discusses the concept of green ammonia, its environmental importance, role in sustainable agriculture and its growing relevance for India under the current global energy crisis.

**Key Words:** Green ammonia, Fertilizers, Renewable energy, Sustainable agriculture.

### Introduction

Nitrogen is the most yield-limiting nutrient in agriculture and plays a central role in determining crop productivity and soil fertility. Modern farming depends heavily on nitrogen fertilizers such as urea, ammonium sulphate, ammonium nitrate and ammonium phosphates, which are all produced from ammonia. Globally, more than 80% of total ammonia production is consumed by the fertilizer industry, mainly for manufacturing urea and ammonium nitrate, emphasizing the dominant role of ammonia in feeding the world (IEA, 2020). However, the conventional production of ammonia is highly energy-intensive and carbon-emitting, raising serious sustainability concerns for modern agriculture, where heavy dependence on synthetic fertilizers are becoming major environmental challenges. In this context, green ammonia produced using renewable energy instead of fossil fuels has emerged as a promising solution for providing a clean and sustainable nitrogen fertilizer supply for future food security.

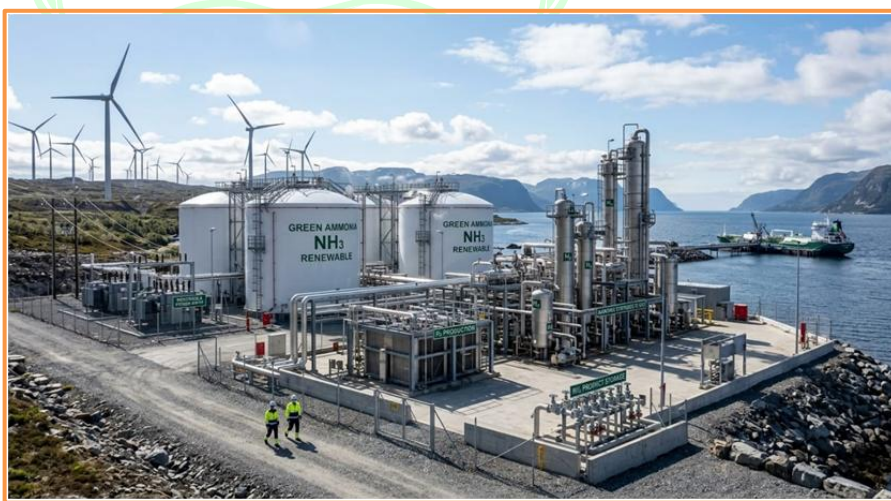
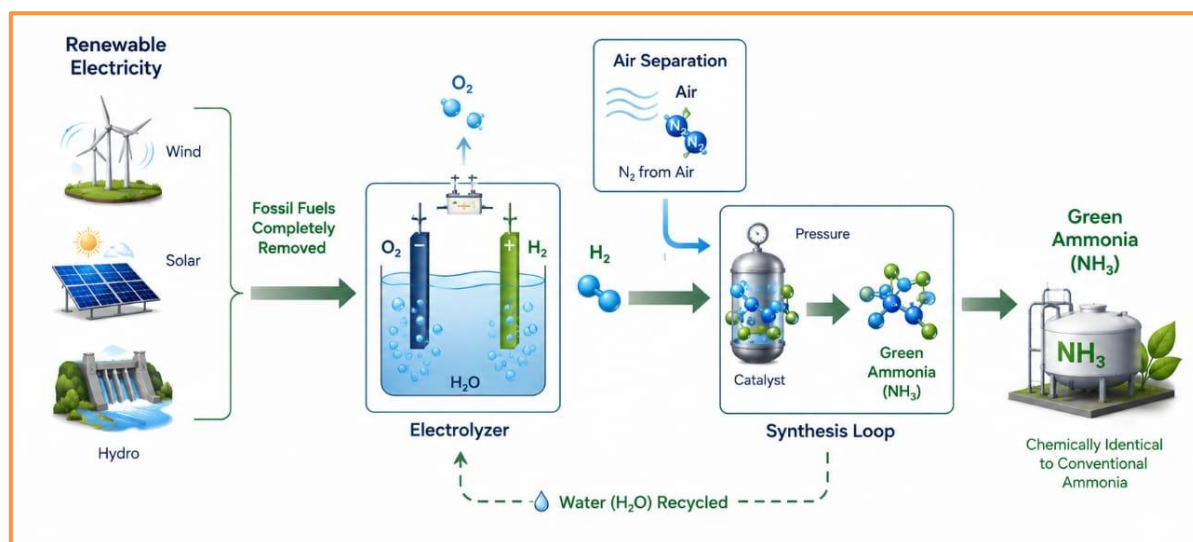


Figure 1: Green ammonia production facility powered by renewable energy sources

## What is green ammonia?



**Figure 2: Green ammonia production pathway using renewable electricity.**

Green ammonia is ammonia produced using 100 % renewable and carbon-free sources. It is produced by using hydrogen from water electrolysis and nitrogen separated from air. This are then fed into Haber process (Also known as Haber-Bosch), **all powered by sustainable electricity**. In the Haber process, hydrogen and nitrogen are reacted together at high temperatures and pressures to produce ammonia. Green ammonia production makes use of renewable energy sources such as hydro-electric, solar power or wind turbines instead of fossil fuels (Klaas *et al.*, 2021) Since fossil fuels are not involved, greenhouse gas emissions during production are significantly reduced, making green ammonia an environmentally cleaner alternative to conventional ammonia.

### The problem with conventional ammonia

Traditionally, ammonia is produced using the **Haber-Bosch process**, which relies mainly on natural gas as a hydrogen source. This process operates at very high temperature and pressure and consumes nearly **1–2% of the world's total energy demand** (IEA, 2020). It also contributes about **2% of global anthropogenic carbon dioxide emissions**. For every tonne of ammonia produced, roughly **2.15 tonnes of CO<sub>2</sub>** are released into the atmosphere. Such a high carbon footprint makes fertilizer production one of the major contributors to climate change.

Although nitrogen fertilizers increase crop yields and improve food availability, their production pathway raises sustainability concerns. Urea alone contributes nearly **9% of total CO<sub>2</sub> emissions from the chemical sector**, even though some CO<sub>2</sub> is reused during urea synthesis. If fertilizer demand continues to grow using fossil-fuel pathways, the environmental burden will further intensify.

### Why Green Ammonia?

Green ammonia is gaining global attention as a practical pathway to decarbonize nitrogen fertilizer production without compromising agronomic performance. Life Cycle Assessment studies comparing conventional and green ammonia routes demonstrate that green pathways significantly reduce environmental impacts when renewable power sources are used (Galusnyak *et al.*, 2023). In fertilizer manufacturing systems, green ammonia coupled with urea and ammonium nitrate production can lower global warming potential by nearly 4 to 5 times when wind or hydro energy is applied, confirming its strong environmental advantage over fossil-based ammonia. Among renewable options, hydropower-based systems show the best overall environmental performance across multiple indicators such as global warming, fossil fuel depletion and eutrophication, whereas photovoltaic-based systems may sometimes exhibit weaker performance due to emissions associated with solar panel manufacturing.

These findings highlight that the sustainability of green ammonia strongly depends on the choice of electricity source.

From a soil fertility perspective, green ammonia does not alter the chemical behavior of nitrogen in soils, and fertilizers derived from it undergo the same processes of mineralization, nitrification, volatilization, leaching and plant uptake as conventional products. Crop response and nutrient availability therefore remain unchanged at the field level. The key benefit lies in producing nitrogen fertilizers through cleaner production pathways, which reduces indirect carbon emissions associated with nutrient management, supports climate-smart agriculture, stabilizes fertilizer supply chains and indirectly contributes to long-term soil sustainability

### **Importance for India and future agriculture**

India is among the world's leading producers and consumers of nitrogen fertilizers and relies heavily on imported natural gas for ammonia production. With abundant solar and wind resources, the country has strong potential to shift toward green ammonia technologies. This transition is already visible through India's largest green ammonia project being developed at Kakinada in Andhra Pradesh, which targets a production capacity of 1.5 million tonnes per year by 2030. Such large-scale investments demonstrate India's commitment to building a domestic, low-carbon fertilizer supply chain. Adoption of green ammonia at this scale can significantly reduce import dependency, enhance energy security, support national climate goals and ensure long-term availability of nitrogen fertilizers for Indian agriculture.

The recent Iran–Israel conflict has once again exposed the vulnerability of the global energy and fertilizer supply system. A major portion of the India's crude oil, liquefied natural gas (LNG), ammonia and urea trade passes through the Strait of Hormuz, one of the world's most important energy transport routes. Disruptions in this region have caused sharp increases in fuel, natural gas and fertilizer prices across international markets. Reports indicate that nearly one-third of global fertilizer trade and a substantial portion of ammonia and urea exports are affected by instability in the Gulf region.

For countries like India, which depend heavily on imported LNG and fertilizer raw materials, such global crises create serious economic and agricultural challenges. Since conventional ammonia production relies mainly on natural gas, fluctuations in global gas prices directly increase the cost of nitrogen fertilizer manufacturing. This not only raises the fertilizer subsidy burden on the government but also creates uncertainty regarding fertilizer availability and affordability for farmers.

The present situation has highlighted the urgent need for alternative and sustainable fertilizer production systems. In this context, green ammonia is emerging as a promising solution because it can be produced using renewable energy resources such as solar and wind power instead of fossil fuels (Kurien, and Mittal, 2022). India possesses enormous renewable energy potential, particularly in western states like Gujarat and Rajasthan, which can support large-scale green hydrogen and green ammonia production in the future.

### **Conclusion**

Green ammonia represents a promising pathway toward cleaner nitrogen fertilizer production. Although it does not directly alter soil nutrient dynamics, it significantly reduces the environmental footprint of fertilizer manufacturing and supports sustainable agriculture. With appropriate renewable energy integration, green ammonia can strengthen fertilizer security, protect environmental quality and contribute to climate-resilient food systems. As agriculture moves toward sustainability, green ammonia is likely to become a cornerstone of future nitrogen fertilizer production.

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