Climate Action Programme for the Chemical Industry

International PtX Hub

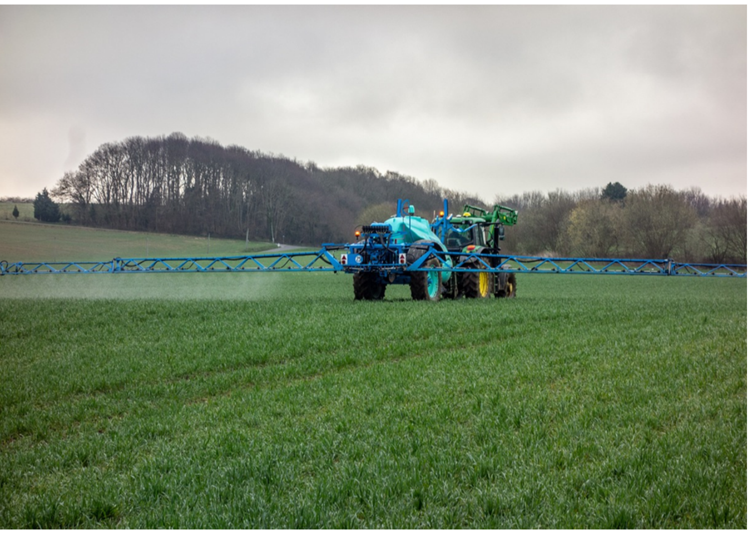
Implemented by giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

GREEN AMMONIA

Factsheet

Introduction

According to the Sixth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC 2022), the chemical and petrochemical industry is responsible for 7.4 % of global greenhouse gas (GHG) emissions [1] and 10 % of the global final energy demand. The sector shows distinct growth, and its emissions also continue to rise. In addition to energy-intensive production, the entire life cycle of the chemical products leads to further GHG emissions. The production of basic chemicals such as ammonia is particularly energy- and GHG-intensive; and it usually requires natural gas, oil and coal as a feedstock. There are already several approaches to reduce GHG in the production and use of chemicals. One is the production of green ammonia.



Background

Around 70% of world-wide ammonia production is used for fertiliser manufacturing. It can also be used in the production of explosives, refrigeration technologies, the textile industry and pharmaceuticals. Additionally, it is used in direct ammonia fuel cells and hydrogen energy storage. Ammonia enables long-term, location-independent storage of chemical energy. [2] The production of ammonia accounts for around 1.8% of CO_2eq emissions globally with a production volume of around 170 million tonnes per year. [3] The most used production route of ammonia is through the Haber-Bosch process. In this process, nitrogen (obtained from the air) and hydrogen (obtained from fossil feedstocks) are mixed at a ratio of 3:1 at temperatures from 450-600°C at a pressure of 100-250 bar. These conditions demand a substantial amount of energy, that is primarily still generated from fossil feedstocks and thereby contributing significantly to CO_2emissions. [4]

The synthesis of ammonia is described with the following chemical equation:

$$N_2(g) + 3\,H_2(g) \leftrightarrow 2\,NH_3(g) + Q$$

g gaseous

Q thermal energy

Green Ammonia

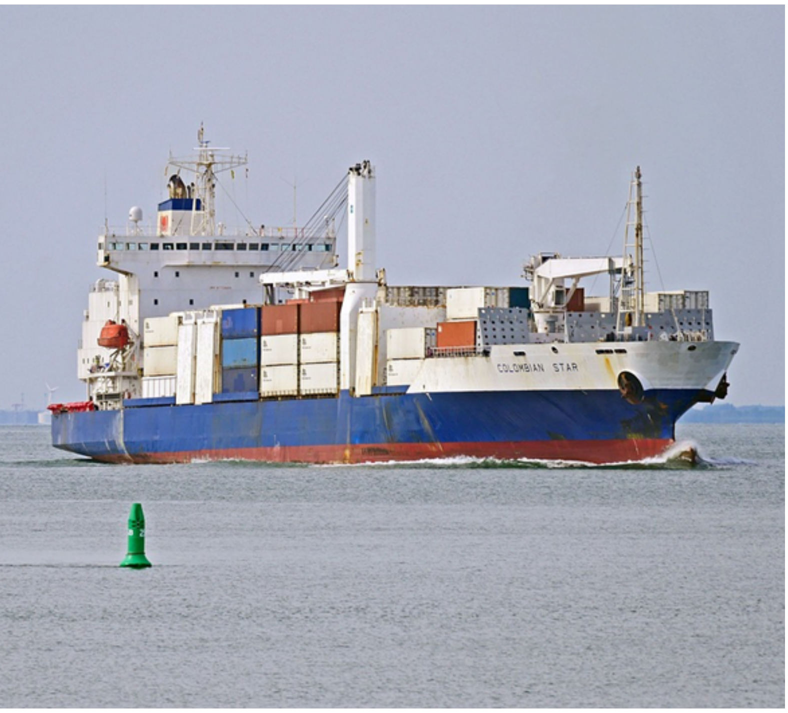
Instead of conventionally produced hydrogen, green ammonia production uses hydrogen obtained by electrolysis of water. This green hydrogen production process is powered by renewable resources, while the nitrogen would be extracted from the air also with renewable energy. If fully commercialised, green ammonia produced with renewable energy could replace ammonia production from fossil resources. Ammonia could potentially be used as a fuel or converted back into hydrogen and burned to generate electricity. When ammonia is burnt, only water and nitrogen are produced as by-products. In addition, ammonia also serves as a hydrogen carrier, and it is being considered to transport ammonia instead of hydrogen in transatlantic transport. [5]

Green Haber-Bosch process [3]

- Renewable energy source: The green process uses renewable energy sources such as solar, wind, geothermal or hydroelectric power as its primary energy input.
- Electrolysis: Renewable electricity powers an electrolyser, which splits water (H_2O) into green hydrogen (H_2) and oxygen gas (O_2) through electrolysis.
- Hydrogen use: The generated green hydrogen (H_2) is used as the feedstock for ammonia production, replacing the hydrogen derived from natural gas, oil and coal in conventional processes.
- Ammonia synthesis: Green hydrogen is combined with nitrogen (N_2) obtained from the air in a high-pressure reactor using the same Haber-Bosch chemical reaction as in the conventional process. However, the key difference is that the hydrogen used is produced without emitting carbon dioxide.
- Carbon neutrality: Because the hydrogen used in the process is produced without emitting CO_2, the overall carbon footprint of ammonia production and other negative impacts of fossil fuel use are significantly reduced, making it an environment-friendly option for carbon neutrality.

Green ammonia applications

Green ammonia has the potential to become a sustainable and environmentally friendly alternative to conventionally produced ammonia. It is gaining prominence as a key component in the transition to clean agriculture and clean energy. Green ammonia has a wide range of applications and the potential to serve as a critical element in reducing GHG emissions and achieving a net-zero economy. As a more sustainably produced precursor to widely used nitrogen fertilisers, green ammonia can reduce the overall environmental impact of agriculture while ensuring high crop yields. It has applications in industries such as chemicals, pharmaceuticals, explosives and refrigeration. In general, ammonia is easy to transport and store. Due to its transformative potential, green ammonia can also serve as an energy carrier, an e-fuel and a hydrogen carrier, because ammonia is easier, safer and cheaper to transport than hydrogen (see two examples below).



Energy storage

Looking at common routes for energy storage, methane is usually utilised, due to its great hydrogen-density. To generate energy from ammonia (NH_3), the molecular bonds between the nitrogen and the hydrogen need to be broken, whilst ammonia decomposes into nitrogen and water. Applying renewable energy for the ammonia production, the only substances needed are nitrogen and water. Another aspect of the energy storage capacity of ammonia is that liquefied ammonia contains 50 % more hydrogen per volume than liquid hydrogen. Based on these aspects, ammonia can be considered for the storage and delivery of hydrogen for hydrogen fuel cell vehicles. Green ammonia can serve as an energy carrier, storing excess renewable energy and providing grid stability. [5]

E-fuel

Green Ammonia has the potential to replace fossil-based fuel as a sustainable alternative. There are two ways to utilise green ammonia as a fuel. There are two ways to utilise green ammonia as a fuel: Firstly by direct combustion in an engine or secondly in a fuel cell, where ammonia reacts with oxygen in the air to generate electricity for an engine. [5] Ammonia has an advantage over pure hydrogen as a fuel, as it has higher volumetric energy density and liquefaction temperature. Compared to Heavy Fuel Oil (HFO) or Liquefied Petroleum Gas (LPG), the space requirement of ammonia will be significantly higher. [6] The use of ammonia as a fuel presents a significant challenge due to its inherent combustion instability. However, this issue can be addressed by incorporating a hydrogen-ammonia mixture in the combustion process. This approach can achieve both emission-free combustion and improved flame combustion. [7] Green ammonia can be used as a clean fuel for ships and even as a hydrogen carrier for long-distance transport. [3]

Challenges

The Haber-Bosch process must be adapted to intermittent renewable energy sources, as the ammonia synthesis reactor requires stable operating conditions. One of the key challenges for green ammonia production is to invest in good electrolysers that use renewable energy and water to produce green hydrogen under ambient conditions. Attention is also being paid to critical raw materials, such as platinum, iridium and yttrium, which will have a significant impact on the production costs of electrolysers. In addition, environmental and social criteria need to be taken into account in mining, and dependencies could arise if recycling infrastructure is not established. [8] Another investment might be the treatment of wastewater or desalination of seawater to produce freshwater which is suitable for the production of green hydrogen. Green hydrogen production requires fresh water, which could put additional pressure on freshwater resources, especially in areas where drinking water is hard to come by. [6] Scaling up green ammonia production to meet global demand also presents a significant challenge that necessitates substantial infrastructure investments. Exploring the feasibility of ammonia synthesis at lower pressures and identifying appropriate catalysts that match the reaction conditions needs further investigation.

Another alternative is the absorbent/ adsorbent-enhanced Haber-Bosch process, which is still in pilot plant scale. Establishing a green ammonia supply chain and distribution network is essential for enabling widespread adoption. [7]

Outlook

A big advantage, regarding the further establishment of green ammonia, is the already existing infrastructure for transportation and storage. This allows for a scenario of ammonia being a competitive option to deliver a zero-carbon energy source via road, rail, ship, or pipeline. [5] The success of affordable green ammonia production in different regions will promote the use of ammonia as a versatile, renewable energy carrier, green fertiliser feedstock, and e-fuel. Green ammonia has significant potential across various sectors and is receiving attention for its potential of reducing GHG emissions in broad range of economically important applications. For instance, it is being considered as an option for sustainable maritime fuel, which has the potential to defossilise an entire sector. With a rising global demand for ammonia, the production with net-zero emissions is an important approach to climate-friendly solutions, particularly in industry and transport. [3]

Literature

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