

White paper

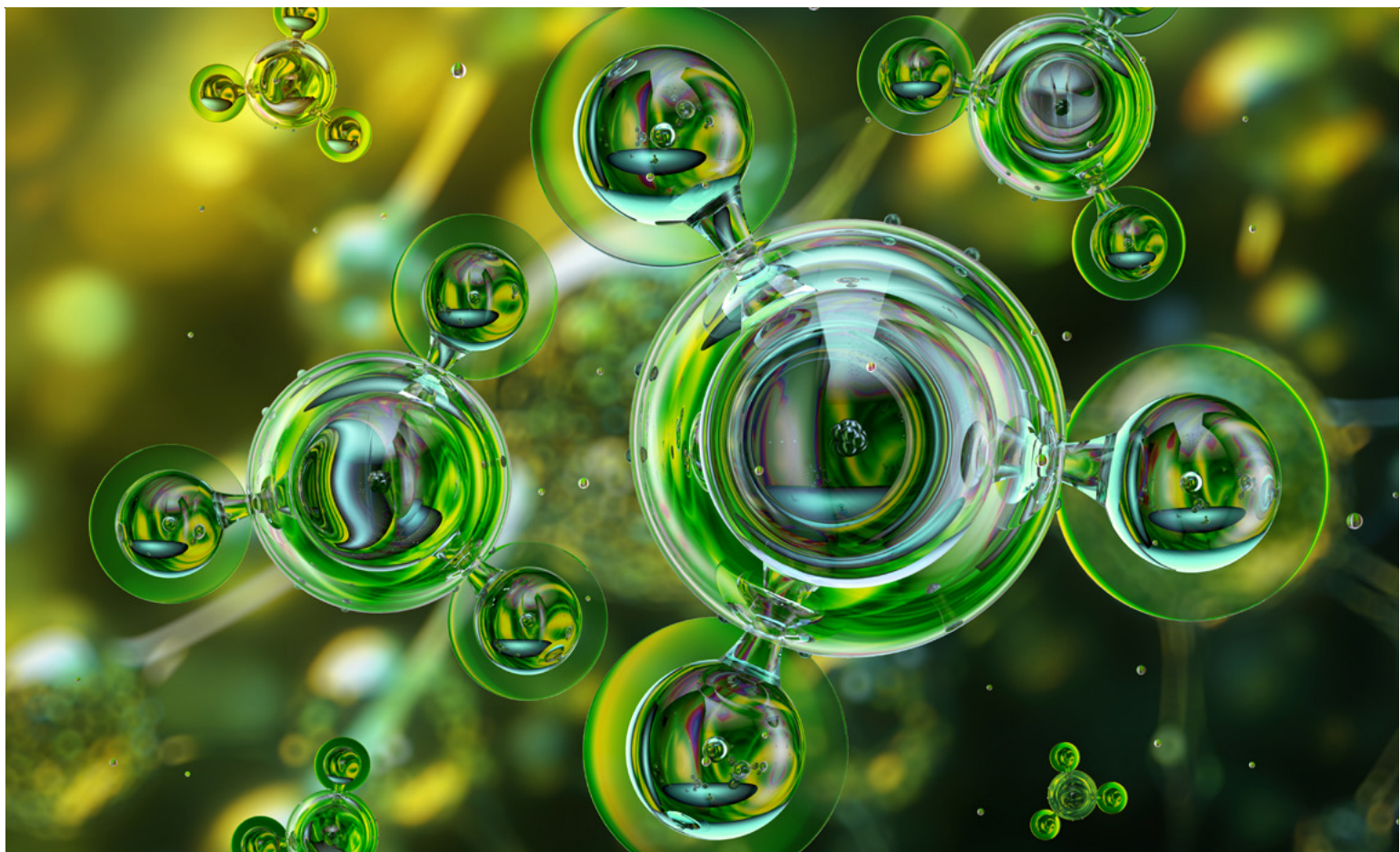
Optimizing green ammonia production with Raman spectroscopy

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In the quest for sustainable and environmentally friendly industrial processes, the production of green ammonia has emerged as a critical innovation. It offers a promising alternative to traditional ammonia production methods that rely heavily on fossil fuels. The application of Raman spectroscopy in green ammonia production ensures quality control and process efficiency.

What is green ammonia?

Green ammonia refers to ammonia produced using renewable energy sources such as wind, solar, or hydropower. Unlike conventional methods that rely on natural gas or coal, green ammonia production focuses on minimizing carbon emissions and reducing environmental impact. The Haber-Bosch process is a well-established industrial method to produce ammonia (NH_3). The primary raw materials for the process are nitrogen (N_2) and hydrogen (H_2). The N_2 from the air separation unit is combined with the H_2 and reacted via the Haber-Bosch process in an ammonia conversion reactor.

Traditionally used for ammonia synthesis, this process is adapted to utilize hydrogen derived from water electrolysis powered by renewable energy. Some recent technologies utilize solid oxide electrolysis cell to produce hydrogen and nitrogen coming from water and air powered by renewable electricity and feeding existing plants.

In today's energy landscape, green ammonia is emerging as a fast response largely driven by the high cost of hydrogen (H_2). The production of green ammonia becomes especially advantageous during periods when solar and wind energy generation results in negative electricity prices. During these times, both ammonia (NH_3) and methanol can be produced at highly competitive rates.

These “cheap” periods are characterized by their rapid onset and short duration, requiring the development of fast or dynamic green ammonia installations. These systems are designed to quickly ramp up production in response to favorable electricity pricing, utilizing advanced control systems and real-time data analytics to optimize performance.

The synthesis loop in green ammonia production involves several critical steps, including the Haber-Bosch process, where nitrogen (N_2) and hydrogen (H_2) are combined under high pressure and temperature, with a catalyst, to produce ammonia (NH_3). To maximize efficiency in this process, the measurements within the synthesis loop must be extremely fast and accurate. This includes monitoring parameters such as temperature, pressure and gas composition in real-time.

Producing green ammonia faces several challenges. One of the primary obstacles is the high cost associated with renewable energy sources compared to fossil fuels. The process also requires significant amounts of electricity, which can be a limiting factor in regions with less access to renewable energy. Additionally, the efficiency of electrolysis and the durability of the materials used in the process are critical factors that need continuous improvement.

However, while the shift to green ammonia supports the decarbonization of the chemical industry, it also advances the broader goal of achieving net-zero emissions. As a result, its global market is experiencing rapid growth.

In 2021, the ammonia market volume reached approximately 5.8 thousand metric tons, rising from 3.7 thousand metric tons in the previous year. This figure is expected to grow at a compound annual growth rate (CAGR) of 90%, reaching around 1.6 million metric tons by 2030. Additionally, the market size was valued at \$151.57 million (USD) in 2022 and is projected to grow at a CAGR of 116.5% from 2023 to 2030.¹

Challenges in controlling the quality of ammonia

Ensuring the quality of ammonia is crucial for its various applications, including fertilizers, pharmaceuticals and industrial chemicals. The primary challenges in maintaining ammonia quality during the green production process include:

Impurities: The presence of impurities such as oxygen, nitrogen oxides and other contaminants can compromise ammonia's purity and performance.

Process variability: Fluctuations in renewable energy sources can cause inconsistencies in the production process, affecting the quality and stability of the final product.

Real-time monitoring: Traditional quality control methods often rely on offline sampling and laboratory analysis, which can be time-consuming and may not provide real-time insights into the production process.

The need for advanced measurement tools

To address these challenges, advanced measurement tools are required to ensure continuous monitoring and control of the ammonia production process. Key requirements for these tools include:

- **Accuracy:** Precise measurement of chemical composition and detection of impurities.
- **Real-time analysis:** Capability to provide immediate feedback on process conditions and product quality.
- **Non-intrusive monitoring:** Methods that do not interfere with the production process or require extensive sample preparation.

¹ [Green Ammonia Market Size](#), Share & Growth Report, 2030



Innovative process monitoring with Raman technology

To enhance the efficiency of ammonia production, Raman spectroscopy can be employed. This advanced solution continuously monitors production and compensates for inherent process fluctuations, minimizing maintenance needs. The Raman spectroscopic system from Endress+Hauser provides accurate measurements and faster response times compared to traditional gas chromatographs (GCs).

Raman spectroscopy is based on the inelastic scattering of light, known as Raman scattering. When light interacts with a molecule, it can scatter with a shift in energy corresponding to the vibrational modes of the molecule. This shift provides a molecular fingerprint that can be used to identify and quantify chemical species.

Raman spectroscopy can be employed to monitor the concentration of reactants and products in the production of green ammonia. The most critical measurement is the hydrogen-to-nitrogen ratio between the synthesis reactor and the compressor in the recycle stream. Raman spectroscopy is highly sensitive to homonuclear diatomic gases like hydrogen (H₂) and nitrogen (N₂), which are key components in ammonia production.

The technology provides real-time, in-situ monitoring of the chemical composition of gas streams, allowing for immediate adjustments to optimize production. It can be installed at the reactor feed to control the H₂/N₂ ratio, in the synthesis loop recycle gas to verify the composition and impurities and in the synthesis loop purge gas.

Raman spectroscopy is a non-invasive technique that does not require sample extraction or preparation, lowering the risk of contamination and ensuring highly accurate measurements. As a result, minimal maintenance is required, as it provides continuous monitoring and early detection of process fluctuations, reducing downtime.

In addition, by eliminating the need for consumables and sample transport, Raman technology can lead to significant cost savings compared to traditional analytical methods.

Summary

The integration of Raman spectroscopy into green ammonia production represents a significant advancement in ensuring product quality and process efficiency. By providing real-time, accurate and non-intrusive monitoring of H₂ and N₂ ratios, Raman spectroscopy addresses the key challenges in ammonia production and supports the transition to sustainable industrial practices. As the demand for green ammonia continues to grow, the adoption of advanced analytical tools like Raman spectroscopic systems will be crucial in achieving the goals of sustainability and environmental responsibility.

Raman spectroscopy is set to play a crucial role in the future of green ammonia production, helping to drive the industry towards greater efficiency, sustainability and environmental responsibility.