GREEN AMMONIA: GATHERING MOMENTUM

Karan Bagga and Bernd Mielke, thyssenkrupp Uhde, consider the increasingly crucial role of green ammonia as a renewable energy vector and low emissions feedstock for the fertilizer and chemicals industry, and the developing technologies that can be used to help harness its potential.

This article introduces the green ammonia production process and technology as a method based on the use of renewable energy, which results in the avoidance of CO_2 emissions that are otherwise associated with the production of ammonia from fossil fuels. There are some key challenges involved in the production of green ammonia, which will be discussed along with the mitigation measures.

Ammonia's use case as an energy and hydrogen vector is gaining more and more attention in addition to its traditional use as a precursor for nitrogenous fertilizers. This new use case is prompting the development of new technology features and plant set-ups for harnessing renewable energy in resource-rich (but often geographically remote) locations. Customised design tools are required to develop optimum concepts early in the project to ensure the best techno-economic feasibility.

21st century industrial and energy ecosystems are dependent on the large-scale use and transport of fossil fuels to satisfy the primary energy demand. As many regions transition towards net zero carbon emissions by 2050, it becomes increasingly important to replace the fossil-based energy and industrial chemicals systems with renewable energy. Emissions reduction via electrification, where affordable, will remain a priority. However, in the regions where this cannot be achieved at the required pace, there will be a need for using molecular energy carriers to enable space and temporal shift of renewable energy.

Hydrogen can be produced by using renewable energy via water electrolysis, completely free of carbon dioxide emissions, thus providing a means of storing and transporting renewable energy. Being a key precursor for many chemicals, green hydrogen also offers the potential to enable deep decarbonisation in industry sectors that are hard to abate with direct electrification, such as industrial chemicals, fertilizers and steel manufacturing.

However, the molecular and thermodynamic properties of hydrogen make it economically challenging to store and transport globally. This is where ammonia offers a much more promising substitute. It can be produced from green hydrogen and nitrogen from the air without any CO_2 emissions. It has a higher volumetric energy density than hydrogen, which makes it an attractive medium for transporting renewable energy. At the point of destination, it can be used to recover hydrogen via cracking or can be used directly for a variety of first merit order applications, such as low carbon fertilizer production (Figure 1). Additional use cases are also emerging, such as fuel for stationary power generation (co-firing with coal and gas), and bunker fuel for marine transport. Lastly, ammonia is already traded worldwide in large quantities (around 19 million tpy), therefore safe handling is an established global standard, and the infrastructure is already in place.

Today, 80% of the annual global production of ammonia goes into fertilizer production, but it has been shown that its use as a renewable energy vector will potentially dwarf this figure in a conceivable future low-emission society. Therefore, it becomes increasingly important to focus on the developing methods for the safe and economical production of green ammonia at a large scale.

Green ammonia production

A green ammonia production facility at its core produces hydrogen via the electrolysis of water using renewable energy. Green hydrogen then serves as feedstock for ammonia synthesis, together with nitrogen, which is cryogenically separated from the air in an air separation unit (ASU).

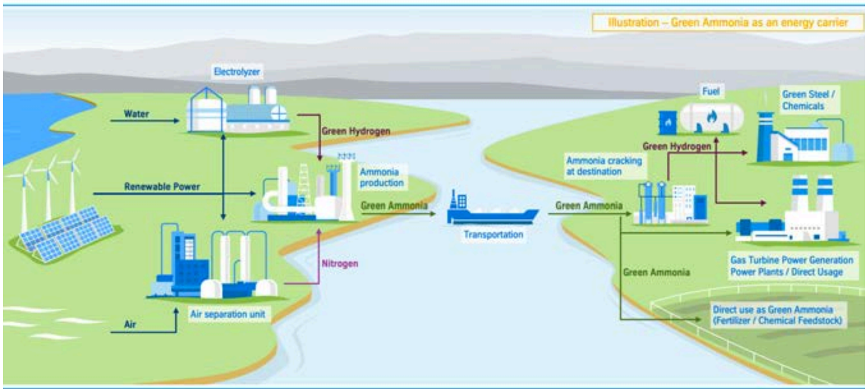

Figure 1. Ammonia value chain (source: thyssenkrupp Uhde).

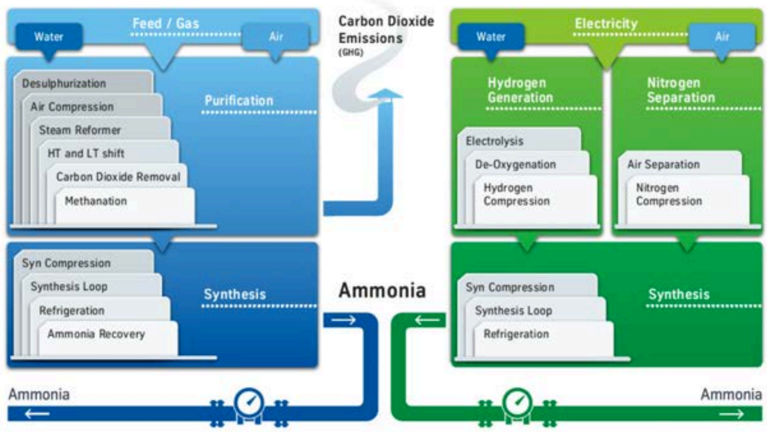

Figure 2. Conventional vs green ammonia production (source: thyssenkrupp Uhde).

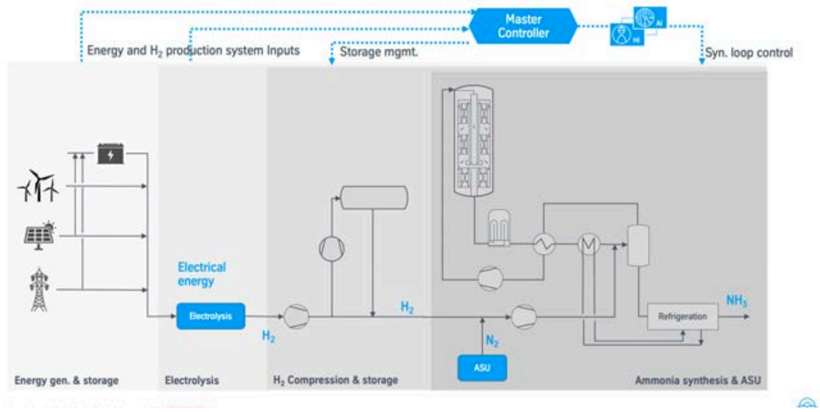

Figure 3. Illustration of integrated green ammonia solution (source: thyssenkrupp Uhde).

Ammonia synthesis as such is carried out according to the well-known Haber Bosch process. Further derivatives of ammonia, such as fertilizers, can be produced further downstream.

Figure 2 shows a comparison of a green ammonia production process with the conventional fossil fuel-based route.

Challenges of production

The key characteristic of the green ammonia production process is the fluctuations in the energy supplied from the renewable power plant (e.g. wind or solar), which must be accounted for by the downstream electrolysis and ammonia synthesis process. Whilst the electrolysis unit can quickly follow the changing availability of electric power in its production rate, this is a challenge for conventional ammonia synthesis. To compensate for this operational inflexibility, large intermediate hydrogen storage may be required.

The intermittent operation, if not adequately addressed via core design, can also lead to undesirable and unsafe events, such as reaction shut-off in the ammonia converter, catalyst damage due to uncontrolled thermal cycling, and potential loss of containment due to pressure cycling fatigue. These issues impose a CAPEX and OPEX penalty, which can adversely affect the viability of the project business case.

Summarising it all, several unique factors apply in the context of the green ammonia production process:

- Energy intermittency (natural or deliberate) – this depends on the location and type of renewable energy.
- Energy supply uncertainty (energy pattern, price variability).
- Plant flexibility (turn down, ramp rates, mechanical integrity).
- Energy storage (size, form, cost, technology readiness level).
- Green certification constraints (e.g. allowable carbon intensity of the product ammonia).

These points must be taken into account during the concept development in order to ensure a techno-economically robust process flowsheet.

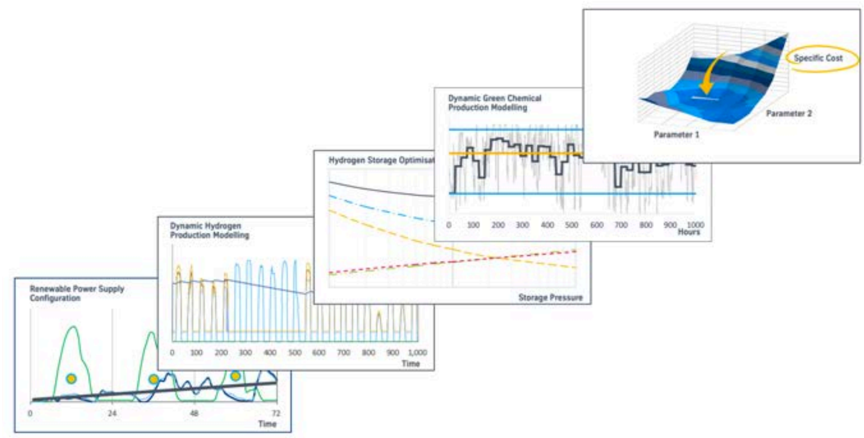

Figure 4. RHAMFS end to end-techno-economic modelling – illustration (source: thyssenkrupp Uhde).

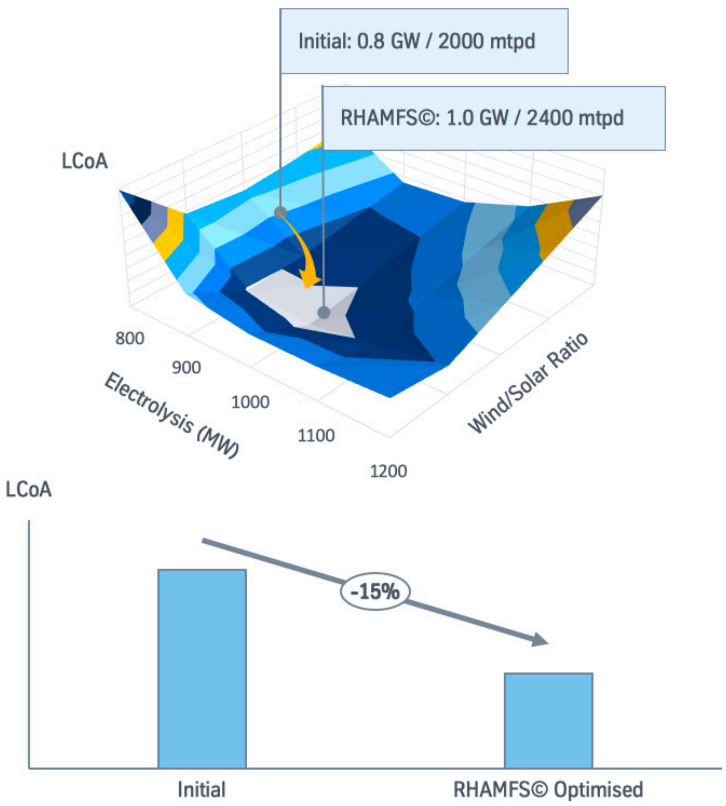

Figure 5. Concept optimisation using RHAMFS (source: thyssenkrupp Uhde).

Solutions

Today, thyssenkrupp offers integrated solutions covering the entire renewable ammonia value chain from production, storage and transport to reconversion back to hydrogen.

Focusing more on the green ammonia production, thyssenkrupp Uhde offers modularised, single train green ammonia plant solutions in the range of 50 – 5000 tpd. Based on the proprietary Uhde converter design, these plants offer a safe, efficient, and reliable operation.

Flexibility and integration are key to economic green ammonia production. In line with this philosophy, the company has developed integrated green ammonia plant solutions, which are suitable for dynamic operation. The development of these designs is underpinned by dynamic simulations for the full power-to-ammonia value chain, which are based on real locations and renewable type specific energy profiles. An overarching proprietary digital control system has also been developed to ensure plant operation within the acceptable range of key performance parameters.

The flexible green ammonia solutions developed offer the benefit of maximum plant utilisation, with minimal hydrogen storage requirement, whilst maintaining the efficiency benefits of an integrated approach. This solution is depicted in Figure 3.

Concept optimisation

thyssenkrupp Uhde has developed a facility sizing and optimisation tool, RHAMFS©, to apply the aforementioned technology innovations in the early stages of the green ammonia project development. The tool utilises the renewable energy profile, or grid power supply considerations (e.g. load shedding and power arbitrage) to model the most optimum flowsheet based on a life cycle cost approach.

The RHAMFS assessment is based on project and location-specific annual energy profiles and the price of electricity for renewable energy sources, along with any potential grid interactions and constraints. This ensures that the facility configuration is tailored to the project boundary conditions and the insight gained from the assessment can be used to support the investment decisions for the project.

Using the new tool, an optimised technical concept that minimises the total cost of ownership (TCO) can be delivered. This assessment determines the optimal sizing of key unit operations and equipment within the power-to-ammonia value chain of the specific project, along with the recommended operating philosophy. The result is a concept that minimises hydrogen storage and improves plant utilisation. The overarching proprietary advanced process control solution offered during the implementation then ensures the plant continues to operate within the key performance parameters, even in the off design conditions.

Case study

Selection of an optimal configuration for mid-scale power-to-ammonia plant in Asia

An assessment was performed using RHAMFS to determine the optimal plant configuration for a green ammonia facility in Asia, targeting an annual production of 600 000 tpy. Electricity supply is mainly via an on-site wind and solar PV plant, with limited grid support. An initial assessment had been performed by the client based on the constraints of the conventional ammonia production technology, which resulted in:

- Low plant utilisation (<50%).
- High energy curtailment i.e. energy produced but not used (>25%).
- Large hydrogen storage.

A combination of the above factors led to a high cost of production and an unfavourable economic position.

Using RHAMFS, an optimised plant configuration was explored based on thyssenkrupp Nucera electrolysis and thyssenkrupp Uhde high flexibility ammonia technology. Multiple grid import/export scenarios were explored together with a Li-ion battery solution for minimising energy curtailment. Carbon footprint constraints imposed by the demand side requirements were also considered in the scenario analysis.

Based on the dynamic ammonia synthesis technology, the selected facility concept resulted in a 15% reduction in the levelised cost of ammonia compared to the initial plant configuration. Figure 5 presents the outputs of the assessment.

In summary, the favourable position resulted in:

- Utilisation improvement to ~70%.
- Energy curtailment reduction to <5%.
- Hydrogen storage reduction by 40%.
- Ideal wind plant size of 1.6 GW and solar PV plant of 1.0 GW.

Summary

Green ammonia is set to play an increasingly crucial role in the energy transition, both as a low emissions feedstock for the fertilizer and chemicals industry, as well as a renewable energy vector. Its properties are conducive to the large-scale and affordable transportation of renewable energy.

The intermittency of renewable energy poses a challenge for the economical production of green ammonia. The mitigation of this issue necessitates careful end-to-end consideration of the plant set-up, right from the early development phase of the project. Technology improvements to specifically enable dynamic operation in the synthesis loop are also crucial. WF