THYSSENKRUPP UHDE

Clean ammonia production – challenges and solutions

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The traditional use of ammonia as a feedstock for nitrogen fertilizers is long established and well known. Nowadays, however, ammonia's use as an energy and hydrogen vector is gaining more and more attention.

These emerging yet fast-growing end-markets are prompting the development of new process technologies and plant set ups for ammonia production, either via renewable energy ('green' ammonia) or by combining conventional fossil fuel processes with carbon capture ('blue' ammonia).

This article discusses the production challenges triggered by the growing demand for green and blue ammonia – and highlights the solutions developed by thyssenkrupp Uhde to address these.

Green ammonia – the process challenge

Green ammonia is produced from hydrogen generated from the electrolysis of water using renewable power. This process avoids CO_2 emissions – unlike the conventional natural gas based production of ammonia that predominates today.

The key challenge associated with green ammonia production is the fluctuation in renewable energy, i.e., the electricity supplied from a wind farm or solar PV power plant (Figure 1). These energy supply variations must be addressed and compensated for in the design of the downstream electrolysis and ammonia synthesis processes.

While most established electrolysis technologies have the capability to adjust to load changes from fluctuations in electrical output from renewable power plants, this is a major challenge for a conventional ammonia synthesis loop design – since traditional fertiliser production processes do not need to have the flexibility to cope with this kind of intermittency.

If not adequately addressed, with suitable process design and control measures, intermittent plant operations can have costly and damaging consequences – such as the collapse of the reaction in the ammonia converter and production curtailments.

Ultimately, such events will adversely affect the economic viability of the project by imposing capex and opex penalties. Therefore, to build a credible business case, the intermittency of renewable electricity, its varying price and other conditions, must all be considered early in the project's development phase.

Optimising green ammonia plant design – the RHAMFS® analysis tool

When it comes to the design of the green ammonia plant, the ideal solution should offer operational flexibility yet minimise technical inefficiencies. The key to this is combining:

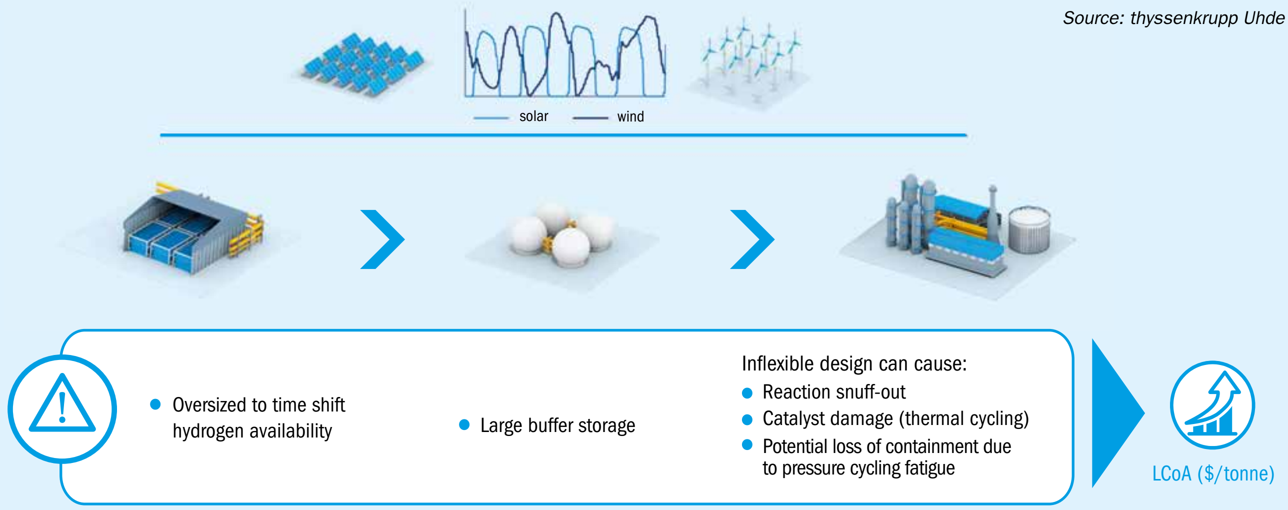
- **The most appropriately sized intermediate energy storage** – provided by batteries and/or buffer vessels for hydrogen
- **With inherent process flexibility** – in terms of the plant's turndown and ramp-up/ramp-down capabilities.

An important point to make here is that providing too much process flexibility, which can be both unnecessary and too costly, is also undesirable. Instead, a project-specific (technical-economic) analysis is needed to develop the optimum flowsheet for the green ammonia process.

thyssenkrupp Uhde has, in fact, developed an analysis and optimisation tool – known as RHAMFS® – specifically to perform such an assessment early in the project design stages. The RHAMFS tool determines the most viable energy storage size for the plant and the optimum process flowsheet using a life cycle cost

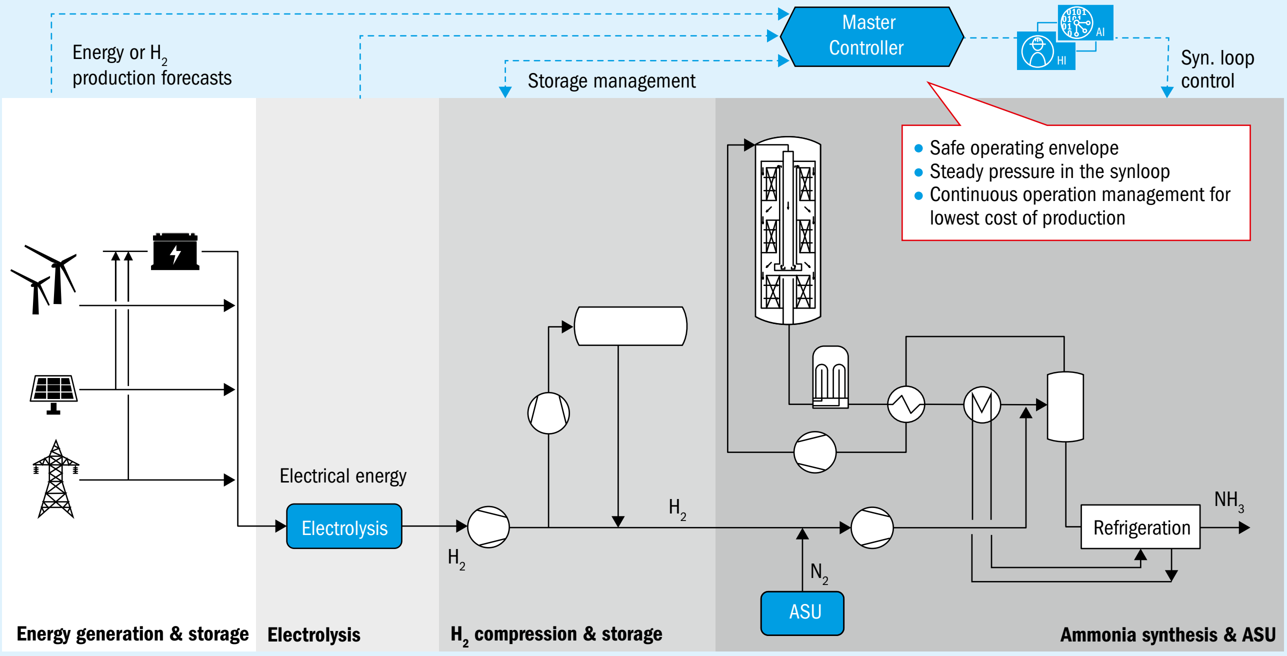
Fig. 1: **Green ammonia production via a conventional ammonia synthesis loop is costly and challenging due to its inflexible design***

Source: thyssenkrupp Uhde



**The electrolyser (left) needs to be oversized and large buffer storage (centre) provided to improve hydrogen availability and avoid catalyst damage and production curtailments (right). This results in large increases to the levelised cost of ammonia (LCoA).*

Fig. 2: **thyssenkrupp Uhde's integrated green ammonia plant**



Source: thyssenkrupp Uhde

approach. The assessment takes account of the project's renewable energy profile or grid power supply requirements (e.g., load shedding and power arbitrage). The tool also incorporates all of thyssenkrupp Uhde's technology and integration know-how.

Optimising green ammonia production – the Master Controller®

The reliable operation of today's green ammonia plants requires new process controls capable of seamlessly managing their dynamic production conditions.

In practice, the actual pattern of renewable energy supply is likely to deviate from the predicted or measured power profile used as the design basis of the plant. Under these circumstances, managing plant performance is a major challenge – one that can prove to be too difficult for conventional plant controls. Instead, a dynamic digital control system is generally necessary to ensure trouble-free plant operation, as well as minimising production costs at all times.

thyssenkrupp Uhde has developed such a proprietary advanced process control system. Known as Master Controller, this adjusts the load of the ammonia plant to the available and forecasted power, while also taking account of the loading and unloading of the intermediate storage elements (Figure 2).

Master Controller also considers a myriad of other technical and safety parameters – in the electrolysis, hydrogen storage and the ammonia unit – on a real time basis when setting up the plant for the forecasted power supply scenario. The control system offers the ability to:

- Maximise plant utilisation
- With a minimal hydrogen storage requirement
- While maintaining the efficiency benefits of an integrated approach.

In summary, thyssenkrupp's proprietary Master Controller:

- Offers seamless integration with upstream hydrogen generation
- Manages plant operations dynamically to ensure high availability against intermittent feed supply
- Maintains critical pressure and temperature parameters within the synthesis loop to keep these within the equipment and process design limits
- Can be deployed across any electrolysis technology to achieve end-to-end power-to-ammonia production.

Blue ammonia

Blue ammonia production combines a conventional, natural gas based ammonia process with carbon capture to reduce CO_2 emissions to the atmosphere. Carbon dioxide streams are generally removed using:

- Carbon capture and utilisation (CCU)
- Carbon capture and sequestration (CCS) to permanently store CO_2 underground in a suitable geological formation.

Although there is no recognised definition of blue ammonia production, in term of the necessary CO_2 capture rate, many current projects are calling for 90-95 percent removal.

Essentially, there are two alternative industrial methods for producing hydrogen and ammonia from natural gas – steam methane reforming (SMR) and the autothermal reformer (ATR) process. Both production routes have a similar overall energy consumption and generate similar volumes of carbon dioxide.

SMR and ATR also have two identical points in the process where CO_2 is emitted:

- **The reforming section.** This consist of steam reformer flue gas in the SMR process and flue gas from a fired heater in the ATR process – both being available at atmospheric pressure.

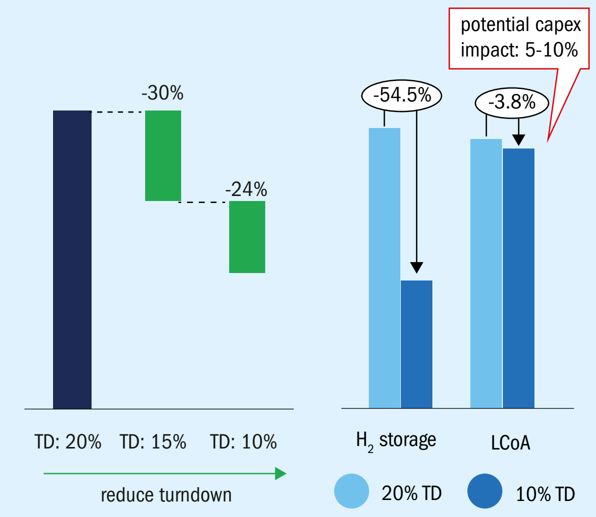
RHAMFS TOOL CASE STUDY

thyssenkrupp Uhde performed a RHAMFS assessment on a 700 t/d green ammonia plant in Australia. This was subject to a variable hydrogen feed which, throughout the day, ramped-up/ramped-down between 60-120 percent of the plant's nameplate capacity per hour.

The assessment identified that substantial reductions in hydrogen storage (>50%) were possible for a plant turndown as low as 10 percent, a threshold which is well within the capabilities of the Uhde ammonia synthesis loop design. The resulting saving in the levelised costs of ammonia (LCoA) amounted to 3.8 percent (Figure 3).

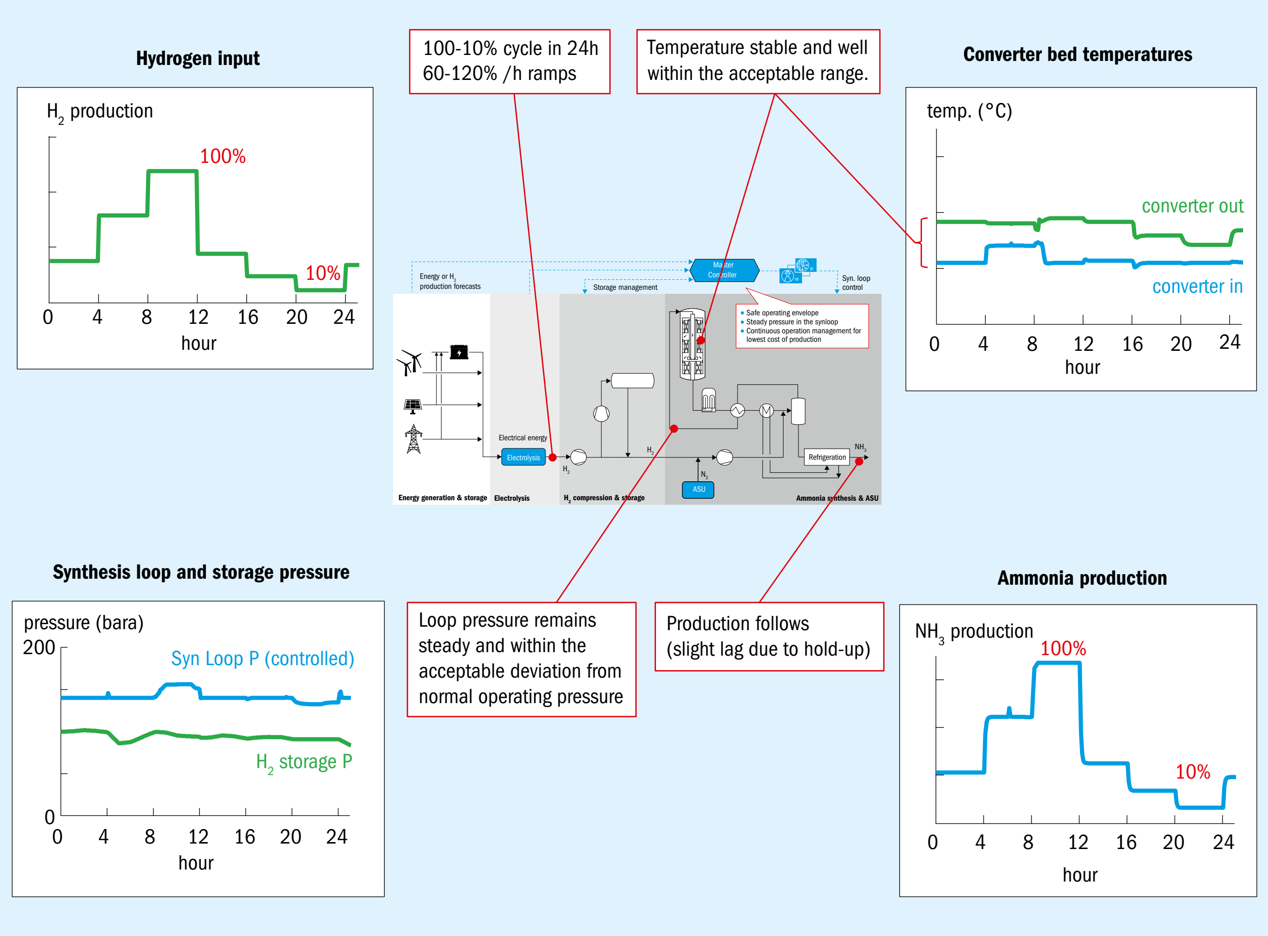
Based on the optimum flowsheet identified via RHAMFS, detailed process modelling was performed to mimic dynamic plant performance for location-specific renewable energy and hydrogen generation profiles. Master Controller, thyssenkrupp Uhde's digital plant control system, was then enabled to manage the plant's performance. As a result, the green ammonia plant operated trouble free at between 10-100 percent of nameplate capacity, with ramp-up/ramp-downs of between 60-120 percent of the maximum load possible per hour (Figure 4). ■

Fig. 3: **Plant turndown vs hydrogen storage for an Australian green ammonia plant (700 t/d capacity)**



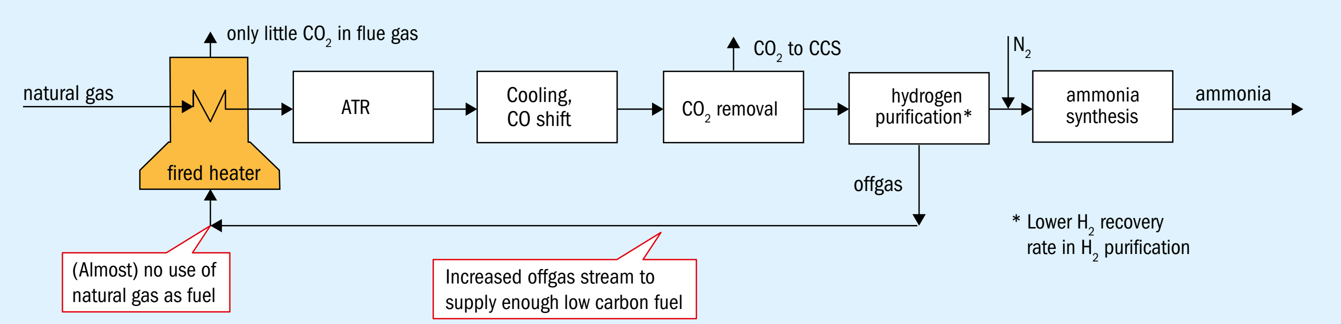
Source: thyssenkrupp Uhde

Fig. 4: **Maximising the performance of a dynamic ammonia plant (700 t/d capacity) with a Master Controller**



Source: thyssenkrupp Uhde

Fig. 5: **Blue ammonia production with an improved autothermal reformer can reduce CO_2 emission by more than 90 percent**



Source: thyssenkrupp Uhde/Mielke & Noelker (2023)

- **The CO_2 removal unit.** This is where carbon dioxide is separated from the process gas.

The carbon dioxide stream from the CO_2 removal unit is the larger of the two emissions points. It usually generates CO_2 with a purity of more than 99 percent and is sequestration-ready, i.e., it is a pure carbon dioxide stream generated by equipment that is already part of the ammonia process. It is therefore logical that the CO_2 emissions generated at this point are the first to be reduced, as the only additional capex is for compression and export infrastructure.

However, higher carbon capture rates require further effort and investment, as an additional unit (e.g. a scrubbing unit) for separating the CO_2 from the flue gas needs to be installed to generate a pure carbon dioxide stream, prior to compression for export.

One significant difference between SMR and ATR processes is the split in CO_2 emissions between these two points: about 70 percent of total CO_2 is generated at the CO_2 removal unit in the standard SMR ammonia process, while in the ATR process it is about 85-90 percent. (The reason for this is that CO_2 is left in the process gas in the ATR process, as the heat for the reforming reaction is supplied from the combustion of a portion of the feed gas, and not by external combustion.)

This means that, intrinsically, ATR can deliver a higher rate of CO_2 reduction, without the installation of an additional flue gas scrubbing unit. Normally, however, the ATR process will still need equipping with flue gas scrubbing, if reduction rates above 85-90 percent are required.

Some customers are understandably reluctant to do this because extra capex, opex and operator effort are required to install an additional process unit that is not present in a conventional ammonia plant.

The improved autothermal reformer

thyssenkrupp Uhde has therefore developed an alternative, more cost-effective solution for the ATR process that can reduce CO_2 emissions by up to 99 percent, if desired.

Much of the current focus for blue ammonia production is on ATR process technology. That is because future ammonia plants for the energy sector are expected to be large plants – and ATR plants offer a capex advantage over SMR plants, especially at larger production capacities.

A key feature of the thyssenkrupp Uhde ATR process is its ability to minimise/eliminate the carbon-carrying natural gas portion of the fuel used by the fired heater[1] (Figure 5). Instead, the amount of hydrogen-containing offgas supplied to the fired heater is increased to such an extent that it completely covers the energy demand of the fired heater. Natural gas supply to the heater is reduced to virtually zero as it is only needed during start-up.

The only CO_2 emissions generated by the fired heater are from residual amounts of CH_4, CO and CO_2 left by the hydrogen purification unit. Using this pre-combustion solution, 99 percent of CO_2 emissions can be avoided without the installation of an additional costly flue gas scrubbing unit (post combustion solution).

Geismar blue ammonia project

The number of clean ammonia projects has increased in recent months. This has been due to a combination of high ammonia prices and better financial incentives for reducing carbon emissions. At the end of 2022, the world's largest fertilizer producer Nutrien awarded thyssenkrupp Uhde the engineering contract for a 3,500 t/d, single-train ammonia plant in Geismar, Louisiana (*Fertilizer International* 511, p8). This world-leading blue ammonia plant will use the ATR process described here (Figure 5) and achieve a carbon capture rate above 90 percent for storage via CCS.

Summary

There is an emerging new market for low-carbon ammonia as an energy and hydrogen carrier.

Yet the intermittency of renewable energy poses a challenge for the economical production of green ammonia. To address this, thyssenkrupp Uhde has developed a flexible, safe and reliable proprietary process for green ammonia based on renewable energy. This process, when coupled with innovative digital control systems, can provide a fully integrated solution for green ammonia production.

thyssenkrupp Uhde has also developed an optimised and cost-effective autothermal reforming (ATR) process for new blue ammonia plants. This process can reduce carbon dioxide emissions by more than 90 percent – without the need for an additional flue gas CO_2 removal unit. The use of process gas as carbon-free fuel means more CO_2 can be captured. The engineering on a large scale blue ammonia plant using this process is already underway in the United States.

References

1. Mielke, B. & Noelker, K., 2023. Blue Ammonia for lower CO_2 Emissions. *CRU 2023 Nitrogen + Syngas Conference*, 6-8 March, Barcelona.