ENABLING DECENTRALIZED AMMONIA PRODUCTION WITH NX STAMI™ AMMONIA HP SYNLOOP – BEYOND THE BASE CASE

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SUMMARY

ABSTRACT

The NX STAMI™ Ammonia high-pressure (HP) synloop is designed for efficient and sustainable production of ammonia with capacities between 50-500 MTPD. Its base configuration delivers warm ammonia, ideal for direct use in fertilizer manufacturing, while also offering the option to produce cold ammonia for storage or shipping – especially valuable when using renewable energy sources. The process can be configured to recover and export steam, significantly reducing operational costs and external energy requirements. Seamless integration with green hydrogen production and inclusion of a Deoxo-Drying unit helps to remove oxygen and water, further optimize energy use, equipment needs, and catalyst protection. Emission reduction strategies are built in, either by integrating purge gas with a nitric acid unit—eliminating continuous emissions and lowering costs—or by refining the process for standalone units to minimize or eliminate purge, maximizing hydrogen efficiency. Collectively, these alternatives ensure that the NX STAMI™ Ammonia HP synloop remains competitive in terms of CAPEX-OPEX and environmentally responsible, supporting a wide range of plant configurations and future industry needs.

1 GENERAL INTRODUCTION

For over a century, ammonia has been produced on an industrial scale, and it is an important base molecule. In the coming decades, ammonia's role will extend far beyond traditional uses, becoming a critical energy vector.

Stamicarbon, the nitrogen technology licensor of NEXTCHEM (MAIRE Group), offers tailored process design packages with NX STAMI™ Ammonia high-pressure (HP) synloop or NX STAMI™ Ammonia medium-pressure (MP) synloop. The portfolio spans a wide range of capacities for ammonia plants between 50-3500 MTPD. This can be either a standalone ammonia unit or a plant integrated with front-end hydrogen generation technologies provided by sister companies within NEXTCHEM.

This paper aims to present a comprehensive overview of the NX STAMI™ HP synloop and its various process alternatives.

2 INTRODUCTION TO FIRST GENERATION OF NX STAMI™ AMMONIA HP SYNLOOP

2.1 Haber-Bosch process

There are different routes to produce ammonia. The one relevant here is the Haber-Bosch process for the ammonia synthesis. Ammonia is produced when 1 mole of nitrogen reacts with 3 moles of hydrogen to give 2 moles of ammonia:

$$N_2+3H_2 \leftrightarrow 2NH_3,\ \Delta H_{298K}= -91.44\ kJ/molN_2$$

Production of ammonia is an exothermic reaction, meaning heat is produced as product of the reaction, as shown in the reaction equation above. Further, the forward reaction results in a net decrease in the total number of gas moles (from 4 to 2). Hence, from chemical equilibrium considerations, low temperature and high pressure are favorable conditions.

The equilibrium between products and reactants at reaction conditions does not allow for full conversion of the reactants, thus requiring a recycle of hydrogen and nitrogen back to the converter, after product separation.

2.2 Background of the NX STAMI™ Ammonia HP synloop

Stamicarbon provides two distinct ammonia synthesis designs under NX STAMI™ Ammonia: one operating at high pressure and the other at medium pressure. The HP synloop is particularly well-suited for small to mid-scale applications (50 MTPD-500 MTPD) and referred to as HP ammonia synloop technology which will be the focus of this paper.

Feedstock to produce hydrogen can be based on renewable energy (e.g., solar, wind, hydropower, geothermal) or based on natural gas. The process steps for ammonia synthesis essentially remain unaffected by front-end hydrogen production method. Depending on the quantity of inerts in the make-up gas (hydrogen, nitrogen), it will affect the purge rate and conversion due to building of inerts in the ammonia synthesis loop.

2.3 Process - NX STAMI™ Ammonia HP synloop based on first generation

Hydrogen from hydrogen generation unit and nitrogen from nitrogen generation unit (NGU) are mixed in a 3:1 H_2:N_2 molar ratio and fed into the make-up gas compression stage of a multiservice reciprocating compressor.

The multiservice reciprocating compressor is electrically driven and handles three services: (a) make-up gas compression, (b) recycle gas compression, and (c) refrigeration compression.

After the make-up and recycle gases are compressed to synthesis pressure (≥ 300 bara), they are combined to form the feed gas. The feed gas is first cooled in the feed-gas exchanger by heat exchange with the purified feed gas, reducing overall heat duty. It is then cooled further in the feed-gas condenser, where ammonia condenses on the tube side; the liquid ammonia captures soluble or condensable contaminants (for example, water) and is withdrawn with the condensate in the feed-gas separator (see Sep 2 in Figure 1). The cooling duty for this step is provided by ammonia evaporation on the shell side.

The HP ammonia converter is axial-flow vertical design that includes a pressure shell, converter basket and internal start-up heater. Due to high pressure, the single pass hydrogen conversion is > 32% with ammonia concentration > 23.5% at the outlet of ammonia. The hot converter effluent is cooled down first with the air-cooler and then with cooling water which condenses majority of the product ammonia (~85%) in the product gas separator (see Sep 1 in Figure 1). This is due to the thermodynamic phase behavior of ammonia, as its saturation temperature increases with pressure. At elevated pressures, ammonia can condense at temperatures significantly above its normal boiling point, enabling the use of cooling water as the condensing medium.

Ammonia is recovered from the purge gas and flash gas in purge gas recovery section by scrubbing with water. Optionally, hydrogen can be recovered utilizing membrane which increases the overall hydrogen efficiency to 99.9% or hydrogen-rich gas can be directly utilized as a fuel for the flare burner.

Crude ammonia products from Sep 2 and Sep 1 (see Figure 1) contain unconverted, dissolved hydrogen and nitrogen, as well as inert argon which are almost fully removed by letting down/flashing in three let down separators arranged in series called as HP let down separator, MP let down separator and low-pressure (LP) let down separator.

Warm ammonia, as product, leaves the B.L. at ~15-17 bara and ambient temperature of max. 40 °C.

In summary, NX STAMI™ Ammonia HP process based on first generation produces warm ammonia as product, no steam generation, and is considered a standalone design.

The process flow diagram in Figure 1 gives an overview of the process.

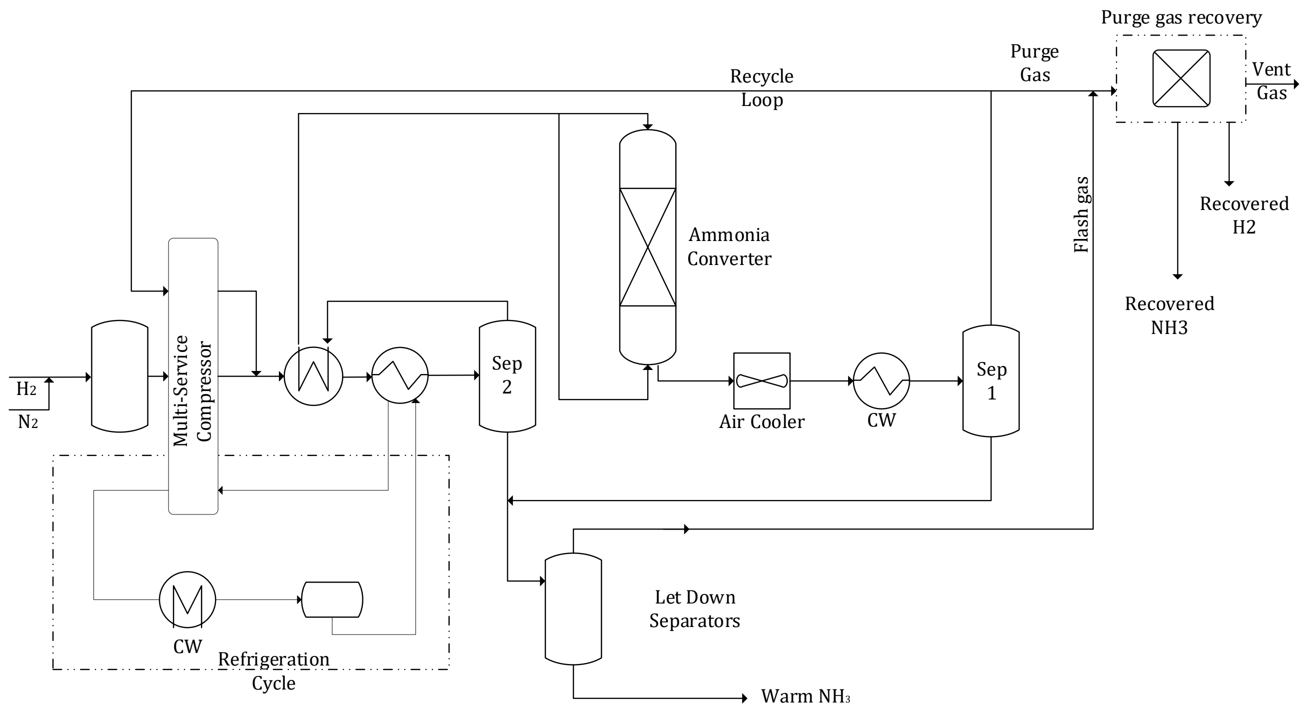

Figure 1: Simplified process flow diagram for Ammonia 1.0 based on HP technology, base case.

2.4 Reciprocating compressors

Reciprocating compressors are highly suitable for small- to mid-scale ammonia plants, covering capacities between 50-500 MTPD, operating at high pressure. Their key advantages include:

- High overall efficiency, typically ranging between 85-90%
- Capability to compress low molecular weight gases, such as hydrogen-rich mixtures
- Ability to handle significant variations in gas composition and density
- Effective operation at pressure ratios of 2 or greater
- Flexibility across a wide operating range, as they are not subject to surge or choke limitations

For these reasons, reciprocating compressors have been established as the standard choice for NX STAMI™ Ammonia HP synloop technology.

3 OBJECTIVE OF THE PAPER

The first generation NX STAMI™ Ammonia based on HP synloop design offers various advantages, including the following:

- Lean design resulting in lower CAPEX,
- High single pass conversion, overall high hydrogen efficiency,
- Utilization of reciprocating compressors.

Over the period since the launch of the first-generation process, there has been increasing demand to provide various process alternatives while still retaining all the benefits HP synloop design offers.

The objective of the paper is to highlight how these alternatives—ranging from product flexibility (warm and cold ammonia), energy integration (steam generation), seamless compatibility with green hydrogen production, and emission reduction strategies—can be tailored to meet specific project needs. By detailing the benefits of each configuration, the paper seeks to demonstrate how the NX STAMI™ Ammonia HP synloop supports economic competitiveness, considering CAPEX and OPEX, as well as environmental sustainability.

4 ALTERNATIVE A: AMMONIA PRODUCT, COLD AND WARM

Ammonia product is called warm ammonia when delivered at ambient temperature, and cold ammonia when it is delivered at temperatures at or below -33 °C.

Warm ammonia is produced for a fertilizer plant, when the final product in the overall process scheme is urea (granules/prills) or nitrogen-based fertilizer – warm ammonia is directly fed either to urea melt unit, nitric acid unit or other units, such as DAP, ammonium nitrate granulation units. In the first-generation HP ammonia synloop - only warm ammonia product has been considered due to downstream fertilizer application.

Cold ammonia product is important in a standalone ammonia unit. In this case, ammonia is stored in an atmospheric storage tank and/or shipped and utilized either as an energy vector to ship ammonia directly or stored for fertilizer production. Especially when hydrogen is produced with renewable energy through electrolysis process, there is a need to produce ammonia at ≤ -33 °C.

Ammonia from the Let Down Separators (see Figure 2) is further depressurized to atmospheric pressure in one or two steps. Due to the phase property of ammonia at atmospheric pressure, its temperature drops to ca. -33°C resulting in flashing of ca. 25% of its content. The flashed vapor ammonia needs to be recovered as well so it is sent to the Flash ammonia compression stage in the multiservice reciprocating compressor, which compresses the ammonia to LP let down separators' pressure. The CW condenser condenses the ammonia using cooling water. This stream is recycled back to LP let down separator. This is referred to as closed loop flash ammonia recycle.

Product ammonia leaves the B.L. downstream of the atmospheric let down separator at ca. 1.05 bara and -33°C.

The alternative process scheme has been highlighted in Figure 2.

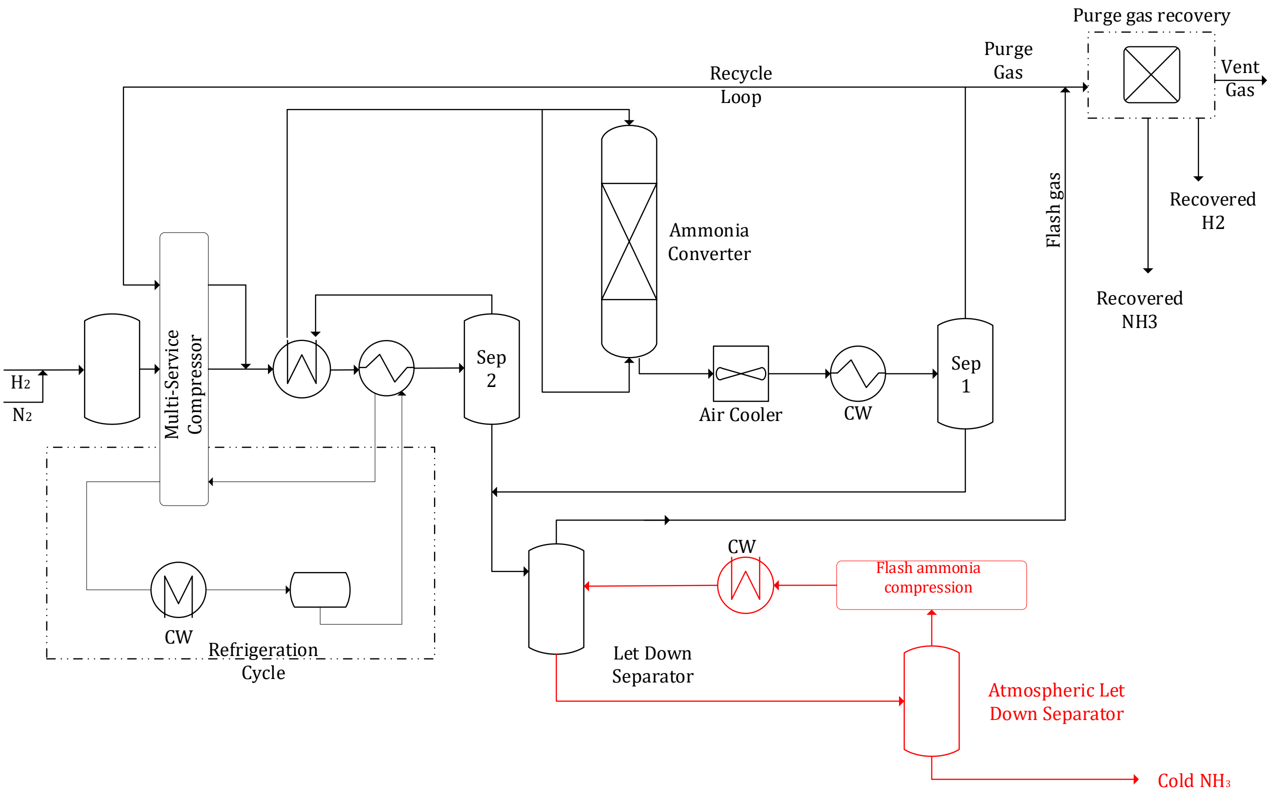

Figure 2: Process flow diagram for production of cold ammonia (ca. -33°C) product; modifications in red.

The advantages of the configuration are summarized in Table 1 below.

Configuration	Explanation and advantages
Figure 1: Base case based on warm ammonia product	• Warm ammonia product • Multiservice reciprocating compressor for three services (make-up gas, recycle gas, ammonia refrigeration)
Figure 2: Alternative A process scheme for cold ammonia product	• Cold ammonia product • Multiservice reciprocating compressor for four services (make-up gas, recycle gas, ammonia refrigeration, flash ammonia) • Closed loop flash ammonia recycle to produce cold ammonia product. Ammonia refrigeration does not require sub-zero temperature (< 0 °C)

Table 1: Explanation and advantages of Alternative A configuration for cold ammonia product.

5 ALTERNATIVE B: STEAM GENERATION

In the first-generation HP ammonia synloop, as indicated in Figure 1, there is no steam generation. The outlet of the HP ammonia converter is cooled down in an air cooler followed by converter effluent condenser that utilizes cooling water. HP ammonia converter has internal bottom heat exchanger downstream the catalytic section to further preheat the feed gas before it enters the catalytic section. This configuration is important when steam production is not desired, i.e. zero steam export. This is the case when there is already sufficient (electrical) energy available, ammonia plant is standalone, and no integration with respect to steam export is foreseen. This is explained in Figure 1.

When energy integration is required, such as exporting steam to the front end (hydrogen generation unit), supplying the back end (e.g., urea melt), or generating power via steam turbine generators (STGs), an alternative process scheme has been developed. This approach optimizes the plant's OPEX and reduces external electricity demand. When exported steam (with its equivalence to power generated) is considered, the specific power consumption within the ammonia battery limit can be reduced by approximately 30–35%, measured in kWh per metric ton of NH_3.

In this case, heat is recovered from the converter effluent stream, and MP steam can be generated. The Ammonia Converter (see Figure 3) is designed to maximize the outlet temperature of the hot effluent; the delta (ΔT) of the ammonia converter effluent stream between the steam generation case (alternative B) and the base case is +100 to +115 °C higher temperature resulting in +15% to +30 % additional steam generation compared to base case design of ammonia converter.

The alternative process scheme has been highlighted in Figure 3.

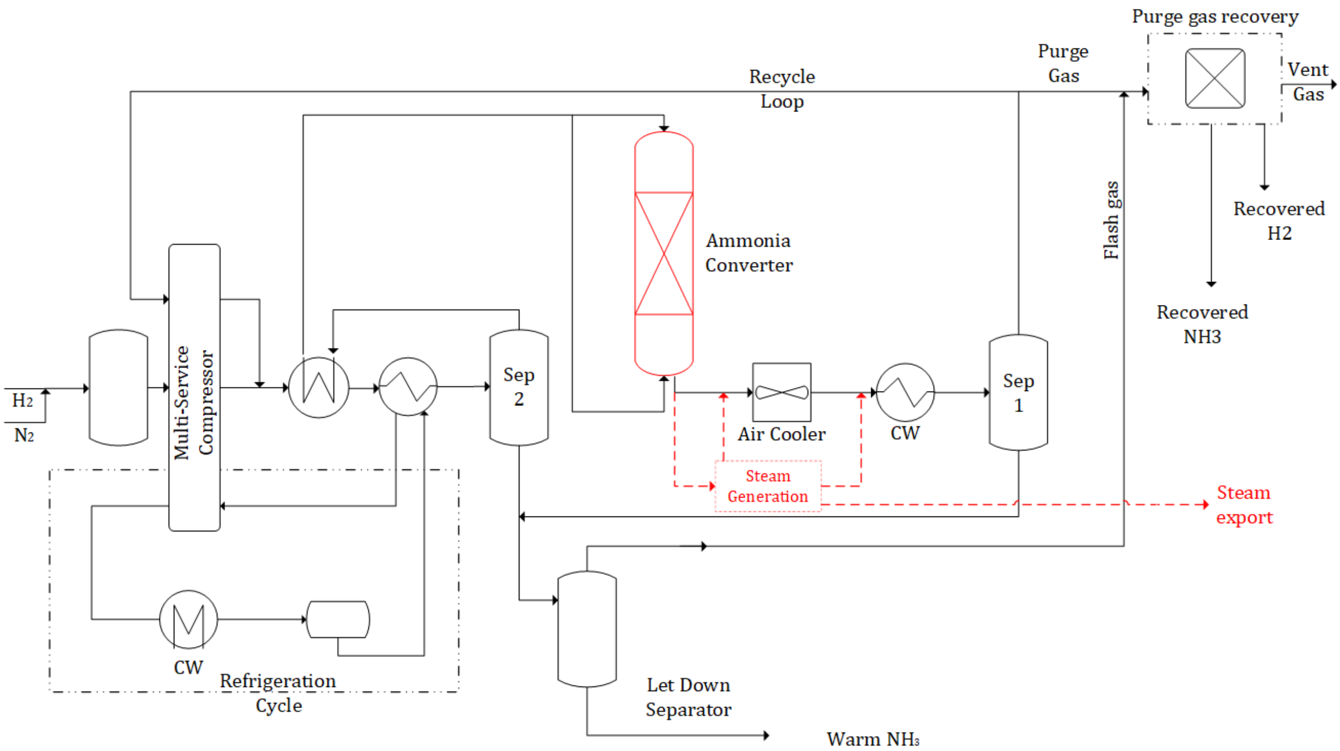

Figure 3: Process flow diagram for production of steam; modifications in red.

The advantages of the configuration are summarized in Table 2 below.

Configuration	Steam generated (kg/metric ton ammonia)	Utilization of steam
Figure 1: Base case	No steam generation	• Nil
Figure 3: Steam generation	1060-1180 kg/ton NH_3, considering 18 bara saturated steam	• Exported to urea melt or STG for power or export to B.L.

Table 2: Advantages of Alternative B configuration for steam generation.

6 ALTERNATIVE C: INTEGRATION WITH FRONT-END PROCESS FOR GREEN APPLICATIONS

In the first-generation HP ammonia synloop, as indicated in Figure 1, only standalone ammonia synthesis unit is considered. Make-up gas is hydrogen and nitrogen and product is ammonia.

When the front-end hydrogen production unit is based on electrolysis powered by renewable energy, NX STAMI™ Ammonia HP synloop provides ample opportunities for integration.

Energy integration by utilization of steam produced in the ammonia process to electrolyzer unit is a good example. Process integration includes utilization of multiservice reciprocating compressor stages for the pressure at which hydrogen (from electrolyzer unit) and nitrogen (from NGU) is available from the respective units. Stamicarbon can also include the Deoxo unit (to remove O_2) and Drying unit (to remove H_2O) within its scope.

The alternative process scheme has been highlighted in Figure 4 and explained in more detail in sections 7.1 and 7.2.

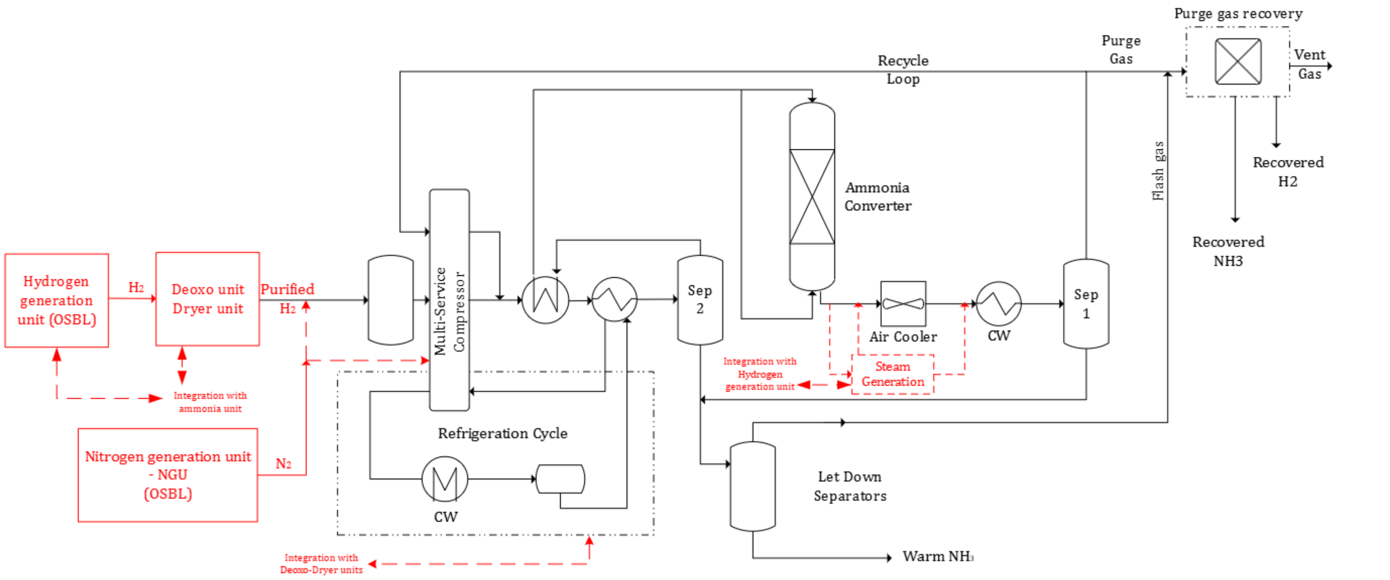

Figure 4: Process flow diagram of integration of green-based HP ammonia synloop with front end; modifications in red.

6.1 Alternative C1: Integration of an electrolyzer unit for hydrogen production using renewable energy

Using renewable energy, hydrogen can be produced through electrolysis. There are different types of electrolyzers, such as alkaline, proton exchange membrane (PEM) and solid oxide electrolytic cell (SOEC).

Energy integration:.

Steam generation within the ammonia unit (Section 3) enables energy integration with the front-end electrolyzer, if desired. In this configuration, steam produced in the ammonia unit is exported to the electrolyzer and utilized either for preheating demineralized water or directly as steam in case of SOEC. This integration reduces overall energy consumption across the combined system.

Process integration: Depending on the type of electrolyzer, the pressure of hydrogen to ammonia B.L. can be minimum 11 bara or higher. In this case, both hydrogen and nitrogen available at 11 bara are sent as a make-up gas to the first stage of multiservice reciprocating compressor. When hydrogen is available at high pressure (e.g., ca. 23 bara) and nitrogen is available at 11 bara from the NGU, there is a need for an additional booster nitrogen compressor to boost and equalize its pressure to be the same as hydrogen. For NX STAMI™ Ammonia process based on high pressure, it can utilize various stages at the multiservice reciprocating compressor and optimize the process configuration. In this case, nitrogen is sent to the first stage of compression, increasing its pressure from 11 bara to 23 bara, and hydrogen is injected at an interstage between the first and second stage of compressor. The second stage of multiservice compressor will compress combined stream of hydrogen and nitrogen. The advantage of this configuration will be saving additional rotary equipment (booster nitrogen compressor) and hence lowering the CAPEX.

6.2 Alternative C2: Inclusion of Deoxo-Drying unit within Stamicarbon scope

As a short recap, a multi promoted iron (Fe) catalyst is used to drive the synthesis of ammonia on an industrial scale. Oxygen-containing compounds, referred to as oxygenates (e.g., CO, CO_2, H_2O, O_2), poison the ammonia catalyst; therefore, the total atomic oxygen content—commonly reported as total oxygenates—should be limited to 10 ppmv. The total oxygen content is calculated as $2*O_2 + H_2O + CO + 2*CO_2$ of the combined stream of hydrogen and nitrogen. For the nitrogen stream, this requirement goes as a composition in the duty specification whereas it is important to remove these components from the hydrogen stream.

For the front-end process of hydrogen generation based on natural gas, CO, CO_2 and H_2O are present and they are removed either with methanation reaction followed by a drying step or with pressure swing adsorption (PSA) technique to purify hydrogen stream before it enters ammonia synthesis unit.

For the front-end process of hydrogen generation based on renewable energy, H_2O and O_2 present in the hydrogen from electrolyzer unit must be removed before entering ammonia B.L.

Depending on the purity of the hydrogen stream to the ammonia process, Deoxo-Dryer unit can also be included within the scope of Stamicarbon. This will ensure removal of oxygenate impurities like H_2O and O_2 in the combined make-up gas of H_2:N_2 3:1 and limit it to 10 ppmv.

Deoxo and Drying units are always arranged in a series where the Drying unit is placed downstream of the Deoxo unit with a process integration with the ammonia refrigeration unit.

Deoxo unit: The purpose of the Deoxo unit is to remove O_2 in hydrogen stream by converting it to H_2O. Catalyst used is either Palladium or Platinum on alumina.

Drying unit: The Drying unit is installed downstream of Deoxo unit and it is designed to remove H_2O through an adsorption process.. Typically, it is a single bed or two-bed process depending on the required configuration and need of the project.

Process integration and its advantage: The step to remove O_2 in the Deoxo unit is an exothermic reaction resulting in a temperature increase. In addition to gas-gas heat exchanger, there will be a second heat exchanger utilizing ammonia from the ammonia refrigeration loop to further cool down the hydrogen stream before it enters the Drying unit. After Deoxo and Drying units, the O_2 and H_2O content in the hydrogen stream is reduced to 2 ppmv and 5 ppmv respectively. This will be an advantage of including Deoxo-drying units within Stamicarbon’s scope.

6.3 Alternative C3: NGU

For ammonia synthesis based on natural gas, N_2 is introduced to ammonia unit from air separation unit (ASU), where O_2 is sent to catalytic partial oxidation (CPO) unit or from NGU when the front-end process of hydrogen generation is based on steam methane reforming (SMR).

For ammonia synthesis based on electrolysis powered by renewable energy, N_2 is introduced from NGU to ammonia unit.

NGU is based on the following three methods of N_2 generation:

- Cryogenic separation as ASU or dedicated nitrogen generation only,
- PSA,
- Membrane separation.

The typical specifications of N_2 composition suitable for ammonia unit are the following:

- N_2 (mol%) ≥ 99.99; Ar (ppmv) ≤ 100; H_2O (ppmv) < 3; O_2 (ppmv) < 5

N_2 flow requirement with respect to capacity will be 1375 Nm3/h (for 50 MTPD ammonia plant capacity) and 13750 Nm3/h (for 500 MTPD ammonia plant capacity).

Keeping in mind both composition and flow requirements, key highlights of NGUs are summarized in Table 3 below.

	Cryogenic separation	**PSA**	**Membrane separation**
N_2 purity	N_2 (mol%) ≥ 99.99 for all capacities	N_2 (mol%) range from 95% to 99.9%	N_2 (mol%) range from 95% to 99.9%
Does the nitrogen generation meet the composition requirement?	Yes. Matches with the specification requirement.	No. Adsorption behavior of N_2 and Ar is very similar. This will result in higher Ar content lowering the N_2 purity.	No. It will have higher Ar content lowering the N_2 purity.
To what capacity range is nitrogen generation applicable?	Applicable for all capacity range	Higher capacity will result in N_2 (mol%) purity of 95% and lower capacity will result in N_2 (mol%) purity of 99.9%.	Typically, suitable for small-scale applications.
Impact to NX STAMI™ Ammonia HP synloop	No impact	Argon is an inert for ammonia process. Higher content of argon increases inert in nitrogen gas. This will result in ammonia synthesis loop requiring more/frequent purge, lowering overall hydrogen efficiency of the process.	

Table 3: Key highlights of NGUs.

NX STAMI™ Ammonia, based on HP technology for capacities between 50-500 MTPD, recommends cryogenic method of separation for the full capacity range. Stamicarbon has positively received confirmation that the cryogenic method of nitrogen production is available as a standard package unit for the full capacity range of N_2 flow of 1375 Nm3/h (for 50 MTPD ammonia plant capacity) and 13750 Nm3/h (for 500 MTPD ammonia plant capacity).

7 ALTERNATIVE D: EMISSION REDUCTION OF AMMONIA UNIT

7.1 Alternative D1: Integration with nitric acid

In the first-generation HP ammonia synloop, as indicated in Figure 1, ammonia is recovered from the purge gas and flash gas in purge gas recovery section by scrubbing with water.

For the case when nitric acid unit is present downstream of ammonia units, Stamicarbon offers an integration of these units.

The amount of purge required is determined by the level of impurities present in the make-up gas. Typically, the purge stream contains approximately 15 wt% ammonia, with this value varying depending on whether the plant is at the start-of-run (SOR) or end-of-run (EOR) stage. By directly routing the purge gas from the ammonia synthesis loop to the ammonia burner in the nitric acid plant, it is possible to eliminate the need for a separate ammonia recovery section and its associated equipment, thereby reducing the plant's CAPEX. Additionally, this integration decreases the demand for ammonia within the nitric acid unit, resulting in lower OPEX. A further benefit is the absence of continuous emissions from the ammonia battery limits. Overall, this strategy supports both cost efficiency and environmental sustainability by minimizing capital and operational costs while reducing emissions.

Simplified process flow diagram is shown in Figure 7.

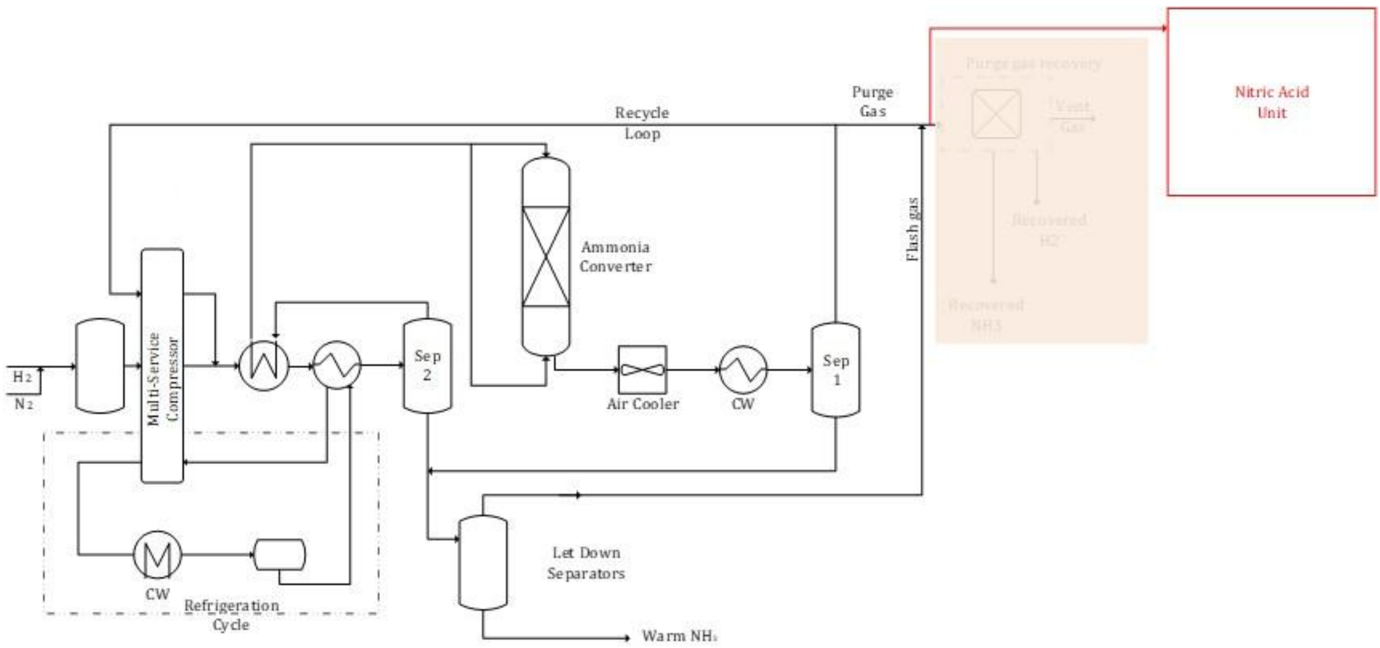

Figure 7: Integration of ammonia with nitric acid; elimination of purge gas recovery unit; modifications in red.

7.2 Alternative D2: Emission reduction for standalone ammonia unit

Although the volume is small, the continuous release of purge gas in ammonia plants can be classified as a persistent emission if not repurposed. To address this and enhance overall hydrogen efficiency, Stamicarbon has introduced further refinements to its HP ammonia synloop technology.

Nitrogen purity with minimal argon (Ar) impurities (e.g., Ar ≤ 10 ppmv): Under these conditions, the ammonia synthesis loop can operate without a purge stream, maintaining process integrity and eliminating continuous emissions.

Nitrogen purity with moderate argon (Ar) impurities (e.g., Ar ≤ 100 ppmv): In this case, the purge gas may be released on an intermittent basis. However, this approach can lead to gradual accumulation of argon within the synthesis loop, which may negatively impact single-pass hydrogen conversion efficiency. To mitigate this, periodically opening the purge valve helps reduce the buildup of argon in the system. High-fidelity NX STAMI™ Digital Technology Training Simulator for HP ammonia synloop has now been finalized. Upcoming dynamic simulations will evaluate the impact of inert buildup over time and determine optimal intervals for non-continuous purge release.

Simplified process flow diagram is shown in Figure 8.

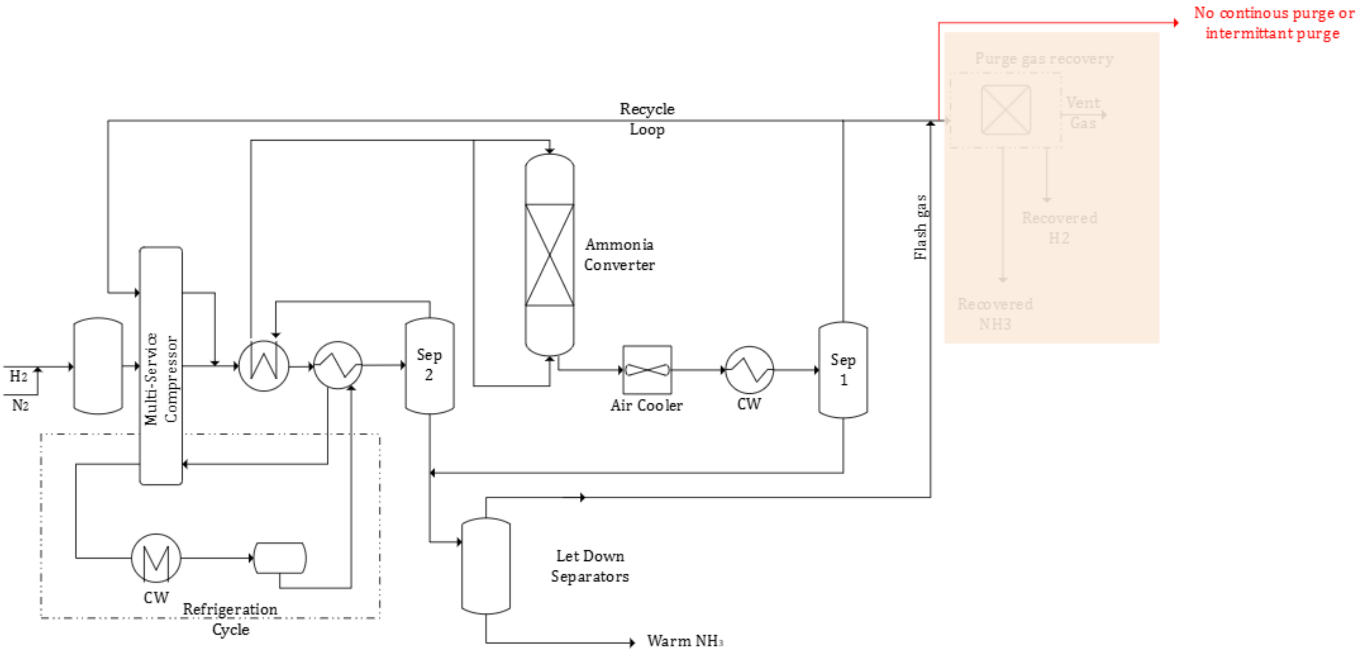

Figure 8: Proposed process flow diagram; no continuous purge/intermittent purge; modifications in red.

8 CONCLUSION

The NX STAMI™ Ammonia HP synloop is designed to offer high H_2 efficiency, low CAPEX, with several process alternatives tailored to meet a wide range of operational and market requirements with further optimizing OPEX. In its base configuration, the process delivers warm ammonia, which is ideally suited for fertilizer plants where ammonia is consumed directly in downstream units such as urea-melt, nitric acid, or other nitrogen-based fertilizer production. This process benefits from reciprocating compressors, ensuring high efficiency.

For applications requiring greater product flexibility, the process can be adapted to produce cold ammonia at temperatures at or below -33°C. This is particularly valuable for standalone ammonia units where storage or shipment is necessary, and it is especially relevant when hydrogen is sourced from renewable energy and product ammonia is utilized as an energy vector.

When energy integration is a priority, the process can be configured to recover and export MP steam. This steam can be used in upstream hydrogen generation, downstream urea melt, or for power generation via steam turbines. By exporting steam, the plant's specific power consumption can be reduced by 30–35%, significantly lowering operational expenditure and reducing reliance on external electricity. The design is flexible enough to support both zero steam export for standalone operation and maximum steam integration, depending on site-specific needs.

The NX STAMI™ Ammonia HP synloop also supports seamless integration with green hydrogen production via electrolyzers powered by renewable energy. In this scenario, steam produced in the ammonia unit can be exported to the electrolyzer, resulting in lower overall energy consumption. The process allows for flexible compressor staging, which reduces the need for additional rotary equipment and lowers capital expenditure. Furthermore, the inclusion of Deoxo and Drying units ensures the removal of oxygenates and moisture from the feed gas, protecting the catalyst and enhancing process reliability. For nitrogen generation, cryogenic separation is recommended to achieve high purity and efficiency, supporting a wide capacity range and minimizing the buildup of inerts.

Finally, the process offers robust solutions for emission reduction. When integrated with a downstream nitric acid unit, purge gas from the ammonia synthesis loop can be routed directly to the nitric acid plant, eliminating the need for a separate ammonia recovery section. This integration reduces both capital and operational expenditure and eliminates continuous emissions from the ammonia plant. For standalone units, process refinements allow for intermittent or even zero purge operation, depending on nitrogen purity, which minimizes emissions and maximizes hydrogen efficiency. Technology training simulators further support optimal purge management.

The NX STAMI™ Ammonia HP synloop offers multiple tailored options, delivering low CAPEX and OPEX while supporting sustainability goals.

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