The Future of Ammonia Supply in Europe

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Executive Summary

As the world grapples with climate change, addressing the energy trilemma – energy security, sustainability and affordability –- is paramount.

Considering the significant number of recent Blue and Green[1] Ammonia project announcements, it is possible to dismiss the sheer number of announcements as overstated. The increasing interest in ammonia cracking projects would reinforce this view.

However, the threat of global warming is real, and we should address this challenge with a sense of urgency.

For countries and regions with limited domestic production of Blue and Green Hydrogen – molecules required to decarbonize their power, industrial, transportation and domestic sectors – import is the only option. Ammonia is touted as the prime hydrogen vector for the immediate future. Europe is probably the best example for a region that needs to face these challenges. In addition, Europe's forecasted ammonia supply-demand gap outlines the challenges ahead of us.

We will see a global hydrogen-energy-network developing, with Europe as one of the main future importers. There will be several hydrogen transport options that will be developed. The authors, like many other players in the market, believe that ammonia can and will play a leading role as the prime hydrogen transport molecule in the near and mid-term future.

This paper looks at the ammonia supply in Europe, based on detailed industrial data, forecasts and KBR's own view on the industry.

The political goals of the EU and the EU member states are not considered in this analysis, rather the focus is on real ammonia projects, industry dynamics and outlook.

The gap between ammonia demand and production in Europe is forecasted to be 7.2 million metric tons per annum (million MTPA) in 2030 and 12.9 million MTPA in 2050. Comparing this with the short-term outlook capacity in 2025, 18.4 million MTPA, a growth of circa 70% would be needed by 2050. The required dramatic increase in European ammonia production capacity is believed to be unrealistic.

Forecasts show that after a slight increase in European ammonia production capacity, the capacity growth flattens out again post 2040.

It is reassuring to note that multiple projects have announced a Final Investment Decision (FID) that promise to deliver approximately two million MTPA of low-carbon (Blue and Green) Ammonia to Europe in 2028[2]. However, these projects, publicly known today and with FIDs or with firm supply contracts, cannot close the gap.

This paper also considers a further increase from the already anticipated supply of Blue Ammonia from the U.S. and the start of Green Ammonia supply from South America to Europe as a very promising solution. There is a great likelihood that Europe's hunger for low-carbon ammonia will be satisfied.

And what makes the outlook with supplies of ammonia from the U.S. and South America a very promising one, is that the low-carbon ammonia from those regions can compete well with a benchmark price of 1,000 €/MT of renewable ammonia delivered to the Port of

[1] Concerning the color coding of ammonia (and hydrogen): Since many projects still designate their ammonia product in this fashion, this paper uses the "green" and "blue" ammonia terminology. There is a recent tendency in the market to start designating "low carbon", using specific carbon intensity ("CI") levels. This is consistent with jurisdictions defining products with CI-levels. For example, the EU Renewable Energy Directives define a threshold of 28.2 gCO_2eq/MJ (equivalent to 3.38 $kgCO_2eq/kgH_2$) that a fuel has to meet in order to be considered renewable.

[2] Based upon industry reports, data base information and press releases about project FIDs available until mid of August 2024.

Rotterdam, as published in the recent news. [3]

Blue Ammonia from the USGC, including tax credits, could potentially be supplied to Europe at a very competitive price of 510 - 550 $/MT after IRA 45Q CO_2 tax credits.

Green Ammonia from South America could be supplied with a levelized cost of approximately 700 $/MT. Here as well, shipping costs could potentially add 100 $/MT. Still, this is a very competitive cost of Green Ammonia delivered to Europe.

Even considering ammonia transport vessels operated on fossil fuels, the ammonia supplied is certainly within the achievable range of the European Carbon Intensity (CI) limits.

Economically produced low-carbon ammonia, in line with the European CI limit regulations, from attractive production regions can fill the gap in Europe.

Eventually, any such analysis should take into consideration a country's specific trilemma in utilizing carbon neutral molecules (e.g. hydrogen, ammonia) on the path towards climate neutrality. Not the least because realization of the energy transition is dependent to a large extent and for the foreseeable future on a supportive political and regulatory environment, including subsidies.

An earlier implementation of a supportive environment, combined with the elimination of bureaucratic barriers, would certainly help to accelerate the bridging of the gap.

Europe's Ammonia Supply and Demand – Present and Future

2024 began with a slight disenchantment of the robust future for ammonia (and hydrogen) as decarbonization fuels, primarily caused by a delay in the FID for some projects. These delays resulted from a variety of reasons: inflation, lack of financing, bureaucratic delays in implementing/clarifying regulations, permitting, lack of offtake agreements, etc.

Projects announced in early 2024 are discussed in this paper and are insufficient to address Europe's energy transition goals. Nevertheless, as the year progressed, other opportunities have surfaced that should further encourage everyone to keep on pushing for further decarbonization and for supporting the energy transition.

On the demand side, the delayed development of the Delta Rhine Corridor project supplying hydrogen and ammonia from the Port of Rotterdam into the European hinterland, mainly Germany, will cause distribution challenges. According to the news in July 2024 [2] there is a considerable delay of at least four years in the planning. The hydrogen pipeline, which could potentially transport high volumes of hydrogen from large-scale ammonia cracking in the Port of Rotterdam to Germany, cannot be commissioned before 2032 (previously targeted for 2028). The ammonia transport pipeline (and the "return" line for CO_2) will follow even later. There are alternatives for supplying ammonia (or hydrogen) to the consumers in the hinterland, although, these would require a more fragmented, complex and expensive approach.

On a positive note, is the announcement of the first auction for the supply of renewable ammonia into Europe by Hintco (an H2Global Stiftung company). An outcome of this auction is that a transparent price for low-carbon ammonia is publicly available, providing a benchmark for the market. Fertiglobe will supply ammonia and Hintco guarantees an annual minimum offtake of approximately 40,000 MT of ammonia from 2028 to 2033 [3]. The Fertiglobe supply and pricing will be put into perspective in the following discussion.

Figures 1 and 2 present the forecasted ammonia production and consumption tonnages for Europe.

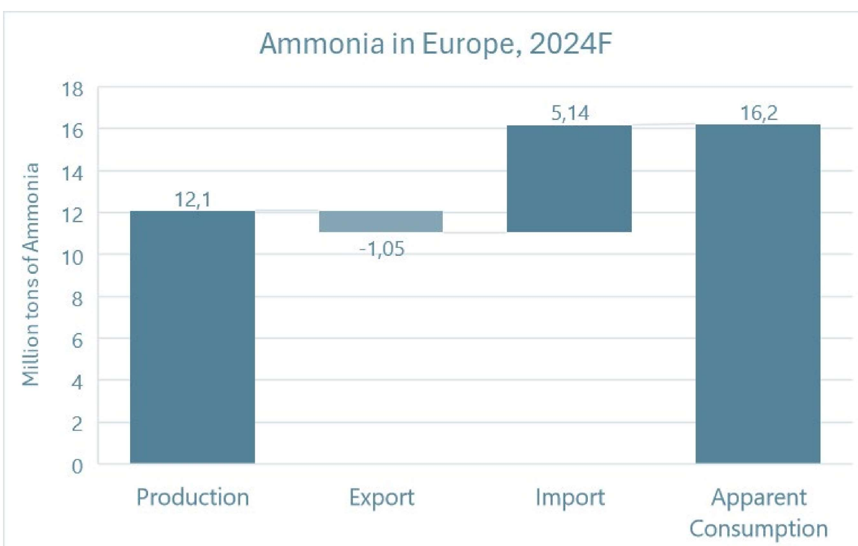

Figure 1: Forecasted data for 2024 ([1] edited by KBR)

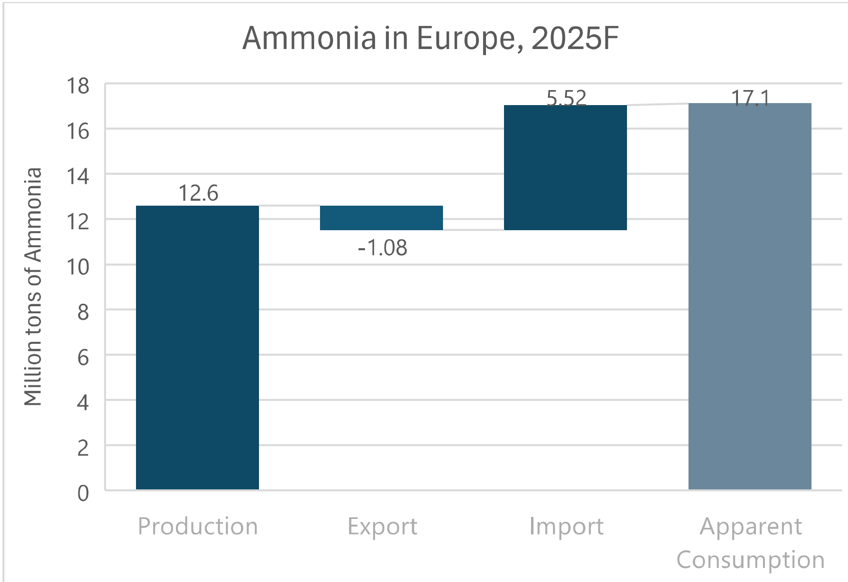

Figure 2: Forecasted data for 2025 ([1] edited by KBR)

Approximately 32% of the forecasted consumption in 2024 and 2025 will be served by imported ammonia.

Figure 3 presents the forecasted growth of ammonia capacity in Europe – an increase of the capacity until 2040 followed by a slight decline over the remainder of the forecasted period. Note that the forecasted capacities for 2040 and 2050 still include approximately 70 % of grey ammonia production. The balance is provided by Green (ca. 16 %) and Blue (ca. 14 %) Ammonia capacity – the projected Green and Blue capacity in MT does not significantly change from 2040 to 2050. This forecast is consistent with the earlier statement that with few low-carbon ammonia (hydrogen) projects reaching FID, the result is a stagnation of regional ammonia production capacity.

The rather high percentage of grey ammonia capacity in Europe (post 2040) offers the potential for revamping and/or upgrading to blue ammonia production or substituting it with low-carbon ammonia imports. However, this paper does not evaluate these options as it requires a detailed evaluation of the existing grey ammonia production units (age, capacity, reliability, revamp viability, economics, etc.).

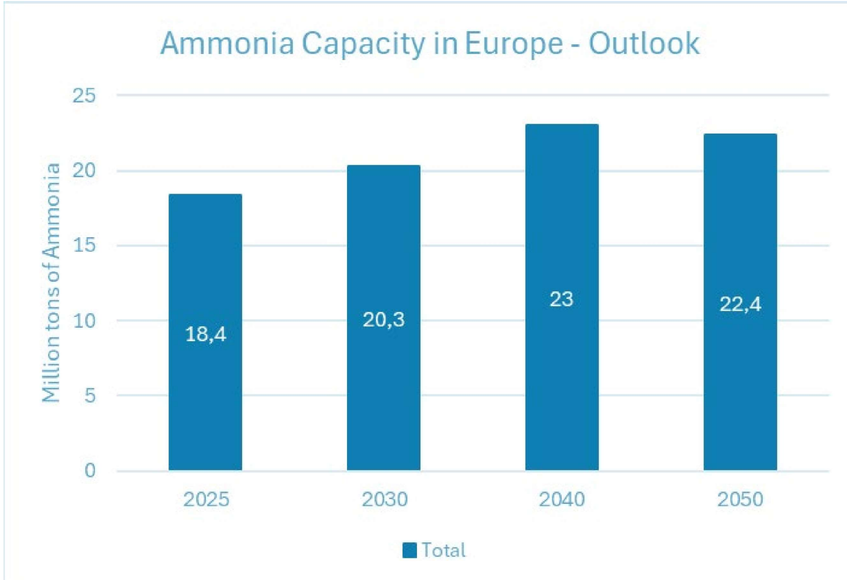

Figure 3: Forecasted Ammonia Capacity in Europe ([1] edited by KBR)

The increase in demand for ammonia in Europe is forecasted to pick up in 2030 with a steady increase across the years after 2030 and flattening out in 2050 and subsequent years. The main driver with approximately 46 % and 48 % of the total demand in 2040 and in 2050 respectively, is ammonia for hydrogen – for energy and industrial use.

Explanation of Europe's demand increase [1]:

- Europe, with an established and mature economy, is not characterized by the rapid growth of any commodity market. From 2010 to 2020, the demand for ammonia in Europe remained virtually unchanged.
- Over the next 25 years, however, experts expect European ammonia demand to grow by 18 million MTPA (from 17 to 35 million MTPA, also refer to figure 4), well ahead of other continents.
- Europe is a leader in the transition to renewable energy sources and consumes a significant quantity of hydrocarbons, and it will take a considerable amount of renewable energy to replace them. A sizable portion of this energy will be supplied from other regions (including in the form of ammonia).
- The RepowerEU program aims to produce 10 million MT of Green Hydrogen and import another 10 million MT by 2030 (equivalent to a total of 100 million MT of ammonia). Experts do not believe that this is realistic, but it is estimated that energy demand for low-carbon ammonia in Europe could reach 20 million MTPA by 2050.
- Other demand segments will either stagnate or shrink; fertilizer-grade urea is not expected to be produced in Europe by the mid-2030s.

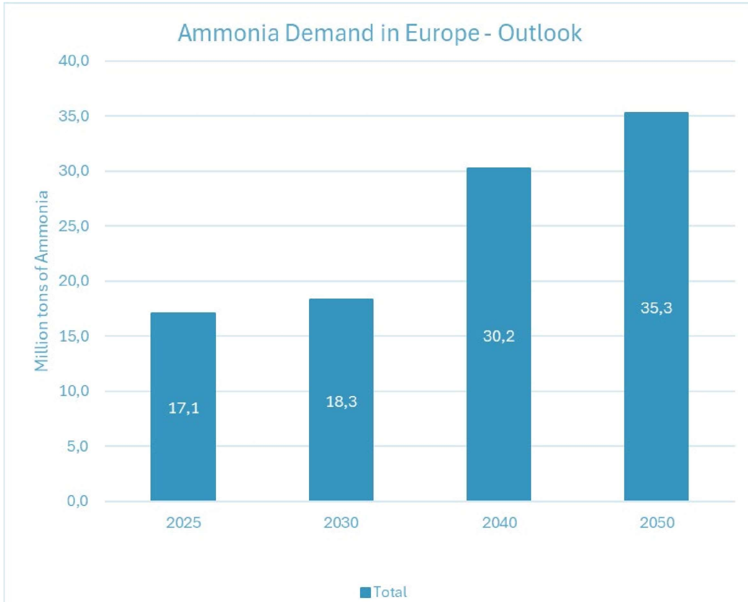

Figure 4: Forecasted Ammonia Demand in Europe ([1] edited by KBR)

The Gap between Demand and Capacity

Comparing capacity and demand forecasts for Europe, in the immediate future, the forecasted capacity will be able to satisfy the forecasted demand (figure 5). In 2040 and even more significant in 2050, the forecast predicts a gap between demand and capacity. It is estimated that the gap between forecasted production capacity and demand will begin in the year 2035. The gap between ammonia forecasted production capacity and demand in Europe is 7.2 million MT and 12.9 million MT of ammonia in 2040 and 2050 respectively.

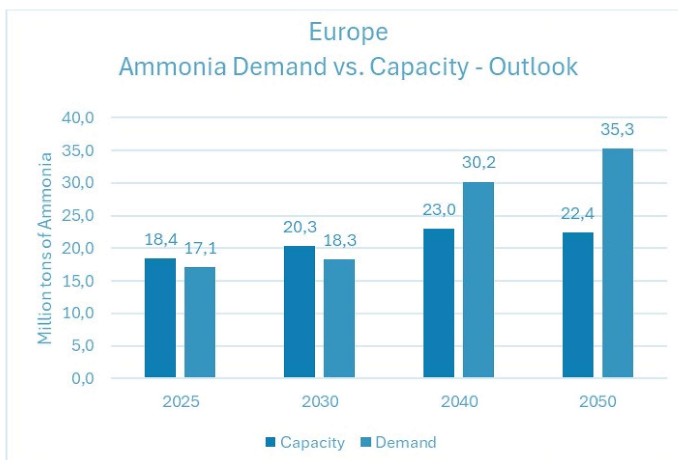

Figure 5: Ammonia Demand and Capacity Outlook for Europe ([1] edited by KBR)

Ammonia Projects with FID

Currently, there are a few projects with firm future supply sources that have reached FID and are capable of potentially delivering low-carbon ammonia to Europe.

The following projects, however, would deliver a fraction of the ammonia needed to fill the forecasted gap.

OCI Beaumont (Blue Ammonia)

In the U.S. the most advanced project is the OCI blue ammonia plant in Beaumont, Texas. The plant that is under construction will have a nameplate capacity of 1.1 million MTPA of Blue Ammonia using KBR's ammonia technology. The product will be delivered to both domestic and foreign markets, such as the European and Asian markets, while firm volumes for Europe are not published. The EPC contract was awarded to Tecnimont in September 2022, which would make this OCI project the first Blue Ammonia project to reach FID in the world. The plant startup is planned for 2025. Recently, it was announced that Woodside plans to acquire this plant/project from OCI. [7] & [8]

NEOM/Saudi Arabia (Green Ammonia)

The NEOM project, with a name plate capacity of 1.2 million MTPA, announced FID in May 2023. Currently, it is the largest Green Ammonia project, with Air Products, as partner and to offtake the product with plans to export the Green Ammonia to Europe (The Netherlands, Germany and the U.K.). The plant startup is planned to be in 2027 ([4] & [5]). Assuming a plant lifetime of 20 plus years, the NEOM plant could supply product to Europe during and past the year 2050.

Air Products Clean Energy Complex, USA (Blue Ammonia)

Air Products has announced a project in Ascension/Louisiana that will be designed to produce Blue Hydrogen and Blue Ammonia. However, apart from a statement about the investment decision during an Air Products earnings call in November 2023, there is little news on the schedule, product destination, construction start date or capacity. [7]

ADNOC/Fertiglobe, Ruwais/UAE (Blue Ammonia)

A Blue Ammonia production plant is under development at the new TA'ZIZ industrial ecosystem in the UAE by ADNOC/Fertiglobe. The facility is planned to have a capacity of 1 million MTPA of ammonia and this plant will use KBR's ammonia synthesis technology. Mitsui signed a loan agreement with Japan Bank for International Cooperation to finance the project's development and the EPC contract was awarded to Tecnimont in May 2024. Although export to Europe might be feasible, because of the project's location in the Middle East, there is a high probability that the ammonia product has been reserved for other specific regions. The plant is expected to come online in 2027. [7]

Fertiglobe/Egypt (Green Ammonia)

The German H2Global Stiftung announced the finalization of the first auction for the supply of low-carbon ammonia to Europe in July 2024 [3]. Hintco GmbH, a H2Global company, announced Fertiglobe as the successful bidder of the first H2Global pilot auction for renewable ammonia, funded by the German Federal Ministry for Economic Affairs and Climate Action. Fertiglobe will procure the supply of renewable hydrogen from Egypt Green Hydrogen as feedstock for production of partial volumes renewable ammonia at Fertiglobe's existing ammonia plant (built with KBR technology) in Ain Sokhna/Egypt. Fertiglobe will deliver under a guaranteed offtake contract 40,000 MT of Green Ammonia annually, starting in 2028. The supply could increase to an optional amount of approximately 60,000 MT of Green Ammonia. The contract term is from 2027 (with optional early supply) to 2032. On successfully fulfilling the contract, it is reasonable to assume that ammonia supply would be extended to beyond 2032.

The ammonia prices were also published:

- Total contract price delivered to Europe (Port of Rotterdam):
  EUR 1,000 per ton (incl. transport etc., w/o VAT)

- Average product price (FOB) net:
  EUR 811.3 per ton

These price data are valuable input or benchmarks for further analysis in subsequent discussion.

Ammonia Projects Summary

Considering the above projects, this paper will estimate the potential for future supply of low-carbon ammonia to Europe.

OCI Beaumont (Blue Ammonia) may deliver a portion of its total capacity (1.1 million MTPA) to Europe. The paper estimates that approximately 0.37 million MTPA (1/3 of the total capacity) may be exported to Europe, with a startup in 2025 and an estimated 100% production rate in 2026.

NEOM/Saudi Arabia (Green Ammonia) plans to deliver 1.2 million MT of ammonia to Europe, with a startup in 2027 and an assumed 100% production rate in 2028.

Air Products Clean Energy Complex (Blue Ammonia) may deliver a portion of its 1.3 million MTPA (capacity to be confirmed) to Europe. The paper estimates that approximately 0.44 million MTPA (1/3 of the total capacity) may be exported to Europe, with a startup in 2026 (to be confirmed) and an estimated 100% production rate in 2027.

Fertiglobe/Egypt (Green Ammonia) will have a guaranteed offtake of 40,000 MT of Green Ammonia annually, starting in 2028. In the supply summary below, the paper considers the maximum supply, including the optional increase to approx. 60,000 MTPA (0.06 million MTPA).

Figure 6 shows the graphical view of this supply summary, reaching approximately two million MT of low-carbon ammonia exported to Europe in 2028. While, prior to 2035 there is no demand-capacity gap forecasted, these known low-carbon ammonia supplies could contribute towards Europe's decarbonization efforts. However, the supply gaps of 7.2 million MT in 2040 and 12.9 million MT of ammonia in 2050 will not be bridged by these projects alone. More low-carbon ammonia capacity is required to bridge the gap.

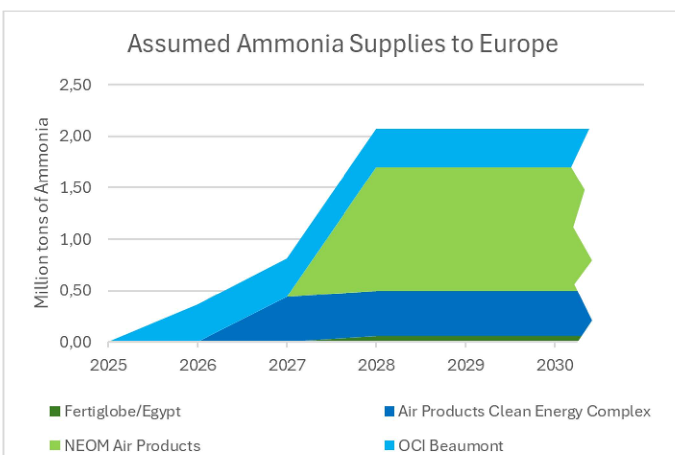

Figure 6: Assumed Ammonia Supplies to Europe (KBR's analysis)

Further Potential for Bridging the Forecasted Capacity/ Demand Gap

From the preceding discussion, it is imperative that additional supply options for low-carbon ammonia must be developed to satisfy Europe's need.

As with NEOM as an example for the region, the Middle East will most certainly play a crucial role in the supply of low-carbon ammonia to Europe. But for the Middle East as well as for North Africa, both blessed with an abundance of natural resources (i.e. natural gas for Bue Ammonia), favorable wind and solar radiation, the risk of regional tensions and instability has to be factored into the risk profile. Hence, other parts of the world, although further away from Europe, could become attractive regions for the supply of low-carbon ammonia to Europe. Regardless, diversification of energy supplies is essential to ensure energy security and economic stability.

A well-established gas industry and infrastructure and the Inflation Reduction Act (IRA) make the USA and the Gulf Coast ("USGC") in particular, an attractive region for developing Blue and Green Ammonia plants (subject to the detailed rules to be released before end of 2024 by the US IRS).

South America with an ample supply of renewable energy from wind and solar, this region could be a significant producer of Green Ammonia. It should be noted that some of the nations in this region could experience political turmoil and economic instability.

Both regions will very likely prove to be cost-efficient producers of low-carbon ammonia for the export to Europe.

In the following section details for such Blue and Green Ammonia supply options are discussed.

Blue Ammonia from the U.S.

a. Main variable costs of Blue Ammonia production

Depending on the desired degree of electrification, KBR's optimized ammonia technology can attain a specific natural gas consumption for large-scale Blue Ammonia production of around 30 - 33 million BTU (Lower Heating Value) per ton of ammonia. The power consumption will range from 200 - 380 kWh/metric ton of ammonia product. This includes import power, power for utilities and capture and compression of the CO_2. The main variable cost factors will be the natural gas and the import power for which it is safe to assume a long-term cost of natural gas ranging from 3 - 4 $/MMBTU, and with electrical power hovering around 40 - 60 $/MWh in the US Gulf Coast region.

b. Indicative production costs & CI (includes KBR-own data and input)[3]

Based on above data and the investment costs of the process and utility plants, the USGC (blue) levelized cost of ammonia ("LCOA") results in about 510 - 550 $/MT FOB[4] with a well to gate carbon intensity of 2 to 2.5 $kgCO_2eq/kgH_2$, assuming current Texas power carbon intensity

[3] Carbon intensity lifecycle includes direct, indirect and upstream carbon emissions. 98% carbon capture is considered. Argonne Lab GREET (2022) CI for Natural Gas of 9,652 $grCO_2eq$/MMBTU and Texas average CI of 340 $grCO_2eq$/kWh. No shipping emissions are assumed. Tax credits assumed for first 10 years of operation only. US Treasury rules for IRA application are under review, 45Q and 45V rules are per those announced by US Treasury in December 2023.

[4] Natural gas cost of 3.3 $/MMBTU, power cost at 30 $/MWh, cost of capital 12%

and Argonne Lab GREET upstream natural gas carbon intensity. With the Inflation Reduction Act (IRA) Section 45Q carbon capture tax credit, the LCOA drops to 300 - 330 $/MT FOB.

The IRA 45V hydrogen tax credit will be greater than the 45Q carbon capture tax credit if the ammonia overall well to gate carbon intensity is kept below 1.5 $kgCO_2eq/kgH_2$. Per KBR's CI models, to be below this threshold, the ammonia production plant will need to contract power with a CI under 50% of the current average Texas grid's CI and the natural gas shall have a CI that is under 60% of the Argonne Lab average value. In this case the LCOA is 270 - 300 $/MT of blue ammonia.

Shipping costs to Europe are assumed to be around 80 - 100 $/MT. So, considering a required internal rate of return of 18% and the IRA 45V tax credit, then USGC blue ammonia can reach Europe at a price of about 510 - 550 $/MT with a carbon intensity of 1.5 to 2.5 $kgCO_2eq/kgH_2$, which will be Europe RED III compliant assuming up to 0.72 $kgCO_2eq/kgH_2$ for shipping emissions.

c. KBR's Blue Ammonia technologies

KBR is a pioneer in ammonia technology and is a market leader with more than 50 % of the market share in ammonia technology licensing. KBR offers its Blue Ammonia technology with a steam methane reforming ("SMR") or an autothermal reforming ("ATR") front-end. For the sake of completeness, it shall be noted that the KBR ammonia synthesis loop can be coupled with a partial oxidation ("POX") front-end for the syngas production as well. The POX-based process specifics are not covered in this paper. Process and operational features of KBR's ammonia technologies PurifierPlus™ and Purifier-A℠ make them distinct from all other commercial technologies.

PurifierPlus™ is a technology that comes with an SMR front-end for the production of syngas and is based on KBR's decades of experience with SMR technology.

Purifier-A℠ is a technology that combines KBR's ammonia technology with the well-proven ATR technology from Air Liquide

KBR Purifier plants are inherently more energy efficient on sustained basis with higher on-stream factor and higher capacity utilization. Process parameters are distinctly mild compared to conventional technology – making equipment operation less demanding, improving reliability and increasing on-stream factor.

Purifier plants are more flexible in operation, addressing variable natural gas composition, ambient changes, and catalyst deactivation, all with minimal impact on production capacity and on-stream factor.

PurifierPlus™

This technology offers advantages including:

- Highest energy efficiency and low CO_2 generation
- Lowest capex
    - Single-train design
    - Reduced equipment count
    - 60% smaller primary reformer
    - No purge gas recovery unit

- No ASU — inherently simpler

- Lowest opex
  - Most energy efficient technology
  - Less methane (CH_4) consumption means less CO_2 production

- Highest reliability
  - Well-proven technology
  - Mild (low temperature) primary reformer
  - Secondary reformer with no metallic burner
  - Purifier stabilizes entire plant operation
  - Simple and precise control of H_2/N_2 ratio
  - Cold wall horizontal ammonia converter
  - Maintain production despite catalyst deactivation
  - 13 days more online time per year on average

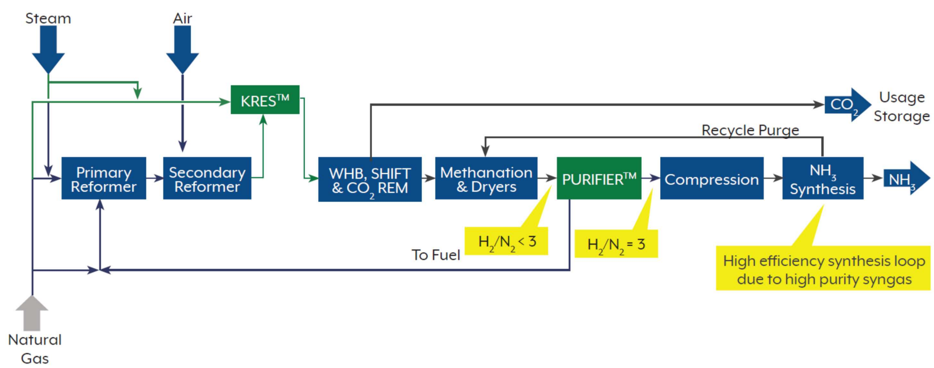

Figure 7: KBR's PuriferPlus™ Block Diagram

KBR's PurifierPlus™ technology combines:

- KBR's cryogenic Purifier™ syngas technology, the most cost-effective route to high purity synthesis gas in ammonia manufacturing plants, which simultaneously removes impurities (i.e. methane, argon) from syngas by stripping it with excess nitrogen while adjusting the hydrogen to nitrogen (H_2/N_2) ratio to three.

- KBR's Reforming Exchanger System (KRES™), which offers the potential for reforming up to 30% of the total natural gas fed to the plant by using high temperature process waste heat exiting the secondary reformer (or auto-thermal reformer) instead of burning fuel.

Purifier-A℠

The KBR Purifier-A℠ process is a low-energy natural gas reforming process offered and licensed by KBR using ATR-technology from Air Liquide.

KBR's Blue Ammonia Purifier-A℠ process technology is based on Air Liquide's well proven proprietary ATR Technology with over 40 references, of which more than 10 are

with a size equivalent to a 6,000 MT per day ammonia plant.
It offers benefits such as:

- Unique integration between reforming, air separation and ammonia sections to minimize carbon intensity and energy consumption and enabling CO_2 capture of up to 99% without a post combustion unit.
- Several proprietary carbon capture technologies can be offered in addition to amine technology.

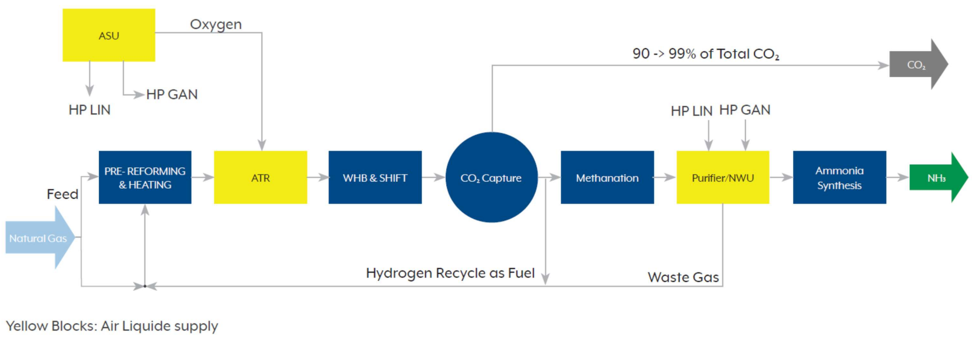

Figure 8: KBR's Purifer-A^{SM} Block Diagram

Green Ammonia from South America

a. Example process data (includes KBR-own data and input)

In the future, most of the Green Ammonia supplied from South America is foreseen to be produced using renewable power sources – singly or in combination, such as hydroelectric, wind and solar power. Ammonia is produced by converting the hydrogen from water electrolysis, powered by renewable energy, and nitrogen in the ammonia synthesis loop. Chile with a large number of announced projects, enjoys one of the highest onshore wind resources with a wind factor as high as 65 %[5] as well as high solar radiation for photovoltaic generation. This results in a renewable power levelized cost of electricity ("LCOE") ranging from 25 to 35 $/kWh.

b. Indicative production costs & CI

The levelized cost of ammonia is complex to estimate since a significant portion of the capex of the facility will be the electrolyzers cost and these costs are falling quickly. However, KBR models for an estimate, including wind farm, electrolysis and process plant capital and operational expenditure, show that Green Ammonia LCOA can be as low as 700 $/MT (FOB port of Chile) with a CI solely due to shipping emissions of about 1 $kgCO_2eq/kgH_2eq$ for those plants operating in an "island mode" or inside the meter.
For those plants that are connected to the grid for auxiliary power supply, it is still possible to be in compliance with the EU's Renewable Energy Directive and its CI threshold. To be counted as RNFBO[6], the molecules shall be produced and shipped to Europe with a CI under the

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[5] This factor is the so-called capacity factor, which is the ratio of the actual energy produced in a given period to the theoretical maximum possible energy that could be produced (i.e. running full time at rated power).
[6] RFNBO = renewable fuels of non-biological origin, according to the EU's renewable energy directives ("RED"), no. 2023/2413, passed on 18 October 2023.

threshold of 3.38 $kgCO_2eq/kgH_2$. When the CI contribution of shipping is considered, the resulting FOB CI is about 2.4 $kgCO_2eq/kgH_2$ which, as mentioned, is achievable.

The ammonia cost is competitive when compared with the Fertiglobe/Hintco case (see above), even with an estimated freight cost of 100 $/MT from the South of Chile to Europe. With the hardware costs coming down further over the next years the competitiveness of Green Ammonia from South America would even increase.

c. KBR's K-GreeN® technology

KBR has developed the K-GreeN® technology, which consists of a fully integrated solution for the synthesis of Green Ammonia via electrolysis of water to produce Green Hydrogen, separation of air to produce nitrogen and the KBR's proprietary Ammonia Synthesis process to produce ammonia.

The KBR design can accommodate different electrolysis technologies such as alkaline, PEM and SOE electrolysis; the latter bringing more attractive integration opportunities and significant overall efficiency improvements.

The KBR ammonia synthesis section is a proprietary design with proven unmatched reliability and lower energy consumption at lower capital cost (due to lower equipment count). In developing its K-GreeN® concept, KBR has leveraged its past 75+ years of experience in designing ammonia plants, from very small capacity (4 MT per day) to the largest single train capacity (6,000 MT per day).

Flexibility is paramount to most of the green ammonia facilities, KBR has extensive experience in flexible design and operation and has already designed and operated loops between 20% and 100% without changing the process, and with some alterations a 10% turndown capacity is also offered.

The figure 9 below exemplifies a typical block flow diagram for generic Green Ammonia plants.

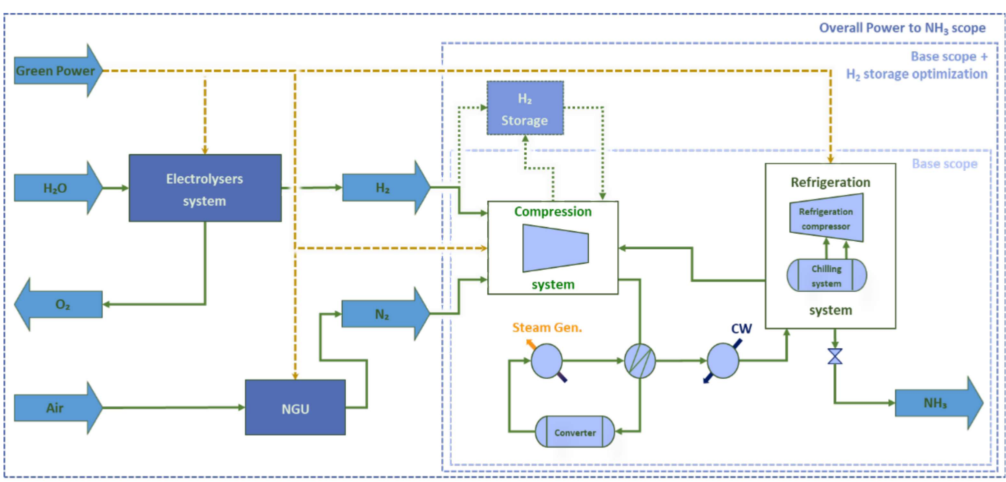


Figure 9: Typical Block Flow Diagram for KBR's K-GreeN® Process

The advantages of the K-GreeN® process scheme are:

- Well-proven design
- Reduced number of optimized and modularized design of the high-pressure equipment, in particular the converter and the chilling system, reducing capex and construction time
- KBR's horizontal converter for achieving large capacities with a single converter, with its design well-proven since 1971
- Unitized chiller combining the feed/effluent exchanger, several chillers, and the compressor knock-out drums into one equipment
- Steam generation, superheated steam generation making the ammonia synthesis loop more energy efficient
- No startup boiler required
- Reduced opex due to lower loop pressure drop
- Reduced maintenance cost associated with fewer equipment pieces
- Robust, reliable steam generation and superheating with process gas

And KBR offers an end-to-end digitalization solution specifically designed and developed for Green Ammonia plants, which enables reliable and stable operation, while minimizing the levelized cost of Green Ammonia (LCOA). The solution is made up of modules, which can stand alone but are also appropriately interconnected and synergistic.

Last but not least, it is noteworthy that KBR, as the market leader in ammonia technology licensing in general, is able to also grow its success in the Green Ammonia licensing: On July 1st, 2024, KBR announced that its Green Ammonia technology, K-GreeN®, was selected by OCIOR Energy/India - the 10th KBR-licensed Green Ammonia plant. [6]

Conclusion

With Blue Ammonia from the U.S. and Green Ammonia from South America, there are attractive options, in the future, for supplying low-carbon ammonia to Europe from diversified global sources.

There is a potential to supply Europe with competitively priced molecules, compared with benchmark pricing for ammonia [3] and the CI values are comfortably lower than the EU threshold.

Blue Ammonia from the USGC, considering the 45Q carbon capture tax credit, could potentially be supplied to Europe at a very competitive price of 510 – 550 $/MT.

Although the CI value has to be assessed and calculated (and ultimately certified) - the European CI limits are most certainly within achievable range, even for the scenario when the ammonia transport vessels do not operate on low-carbon fuels.

Green Ammonia can be produced in South America (here: Chile) with a FOB levelized cost of approximately 700 $/MT. Although the forecasts currently show that Green Ammonia can be produced competitively, a 100% Green Ammonia production needs to become more economical globally, by reducing investment and operation cost, irrespective of project location. Green Ammonia from South America will have the advantage of higher load factors than other locations that results in better asset utilization thus lower product prices. Produced with 100% renewable energy, the CI value of Green Ammonia from South America will easily meet the respective European requirements.

Thus, economically produced low-carbon ammonia sources to bridge the gap in Europe are within reach.

Ultimately, supply timing has to match peaking demand, considering that project finance, export/import infrastructure etc. are in place to support transport and distribution to the end customer. Typical project development schedule ranges from two to five years for study work, finance arrangement, permitting, etc., and reaching FID. Following which another three to four years are required for the Engineering, Procurement and Construction ("EPC") phase to bring the plant online.

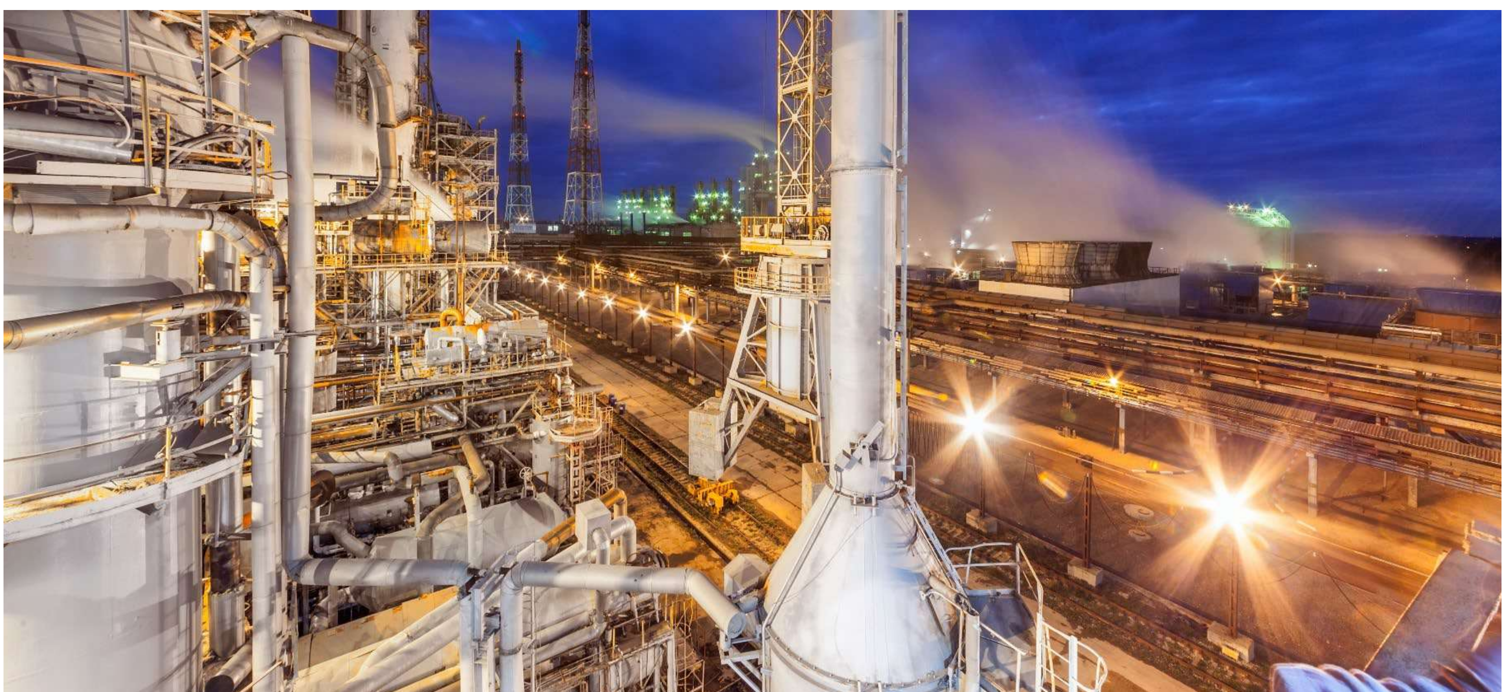
Given the typical project duration, and that demand surpasses capacity in approximately 10 years, there is still enough time to plan and build additional low-carbon ammonia plants. In parallel with plant build out, transport logistics and infrastructure are to be developed for receiving the molecules, converting and transporting them to the final consumers.

With energy transition ramping up in leading economies, and heavy dependence on energy imports (e.g. Japan and Korea), a global competition will develop for low-carbon ammonia imports. Even though further ammonia supply opportunities will develop to meet this anticipated demand, the timing for Europe will remain a major challenge.

A final thought for consideration: Even at the end of the projected period (i.e. 2050), Europe is predicted to produce 16 million MTPA of grey ammonia. Questions remain on (i) the economic viability of these facilities and the revamp potential for Blue Ammonia production (ii) replacement capacity when some of the plants are shut down due to poor reliability and equipment at the end-of-life. It is doubtful that enough new Green and/or Blue Ammonia capacity will be developed in Europe and the timeline for bringing new plants outside Europe is challenging.

Nevertheless, the requisite technologies are available now, real projects are already under development or under construction, further technology developments are anticipated, investment in infrastructure has started and is picking up speed and awareness of the challenges ahead of us is increasing.

KBR delivers technologies and a broad range of services for the energy transition to ease the burden of the challenges and unknowns that lie ahead of us.



For more information, please go to:

https://www.kbr.com/ammonia/

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