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nitrogen+syngas

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North American nitrogen

Methanol as a bunker fuel

Blue hydrogen and ammonia

Emission control in nitric acid plants

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Cover: Farm machines, combine and semi-truck harvesting corn.
Photo: JamesBrey/iStockPhoto.com

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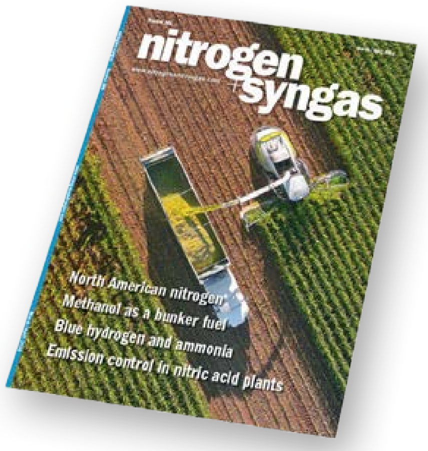
Europe's nitrogen dilemma



> **"It may leave quite a different European nitrogen industry from the one that existed in 2019..."**

Nitrogen magazine, as it originally began life in It has been a tough few years for the European nitrogen industry, and between covid, gas price spikes and Russian sanctions, not all companies have weathered the storm. Now that the initial shock of the sky-high ammonia prices that the closure of the Black Sea and the cutting off of almost 40% of Europe's gas supplies has passed, and the world gas and ammonia markets have largely adjusted to the new reality, prices are coming back down. But it seems that in its wake it may leave quite a different European nitrogen industry from the one that existed in 2019.

On the gas side, Europe has managed a remarkable transformation in the way that it receives and uses natural gas. The share of Russia's pipeline gas in EU imports dropped from over 40% in 2021 to about 8% in 2023. For pipeline gas and LNG combined, Russia accounted for less than 15% of total EU gas imports. Instead Europe has switched wholesale to LNG imports, mainly from the US, which accounted for 50% of EU LNG imports in 2023. Even the remaining Russian gas imports are mainly LNG. This has inevitably pushed up the base cost of gas. LNG requires expensive liquefaction and regasification facilities and specialised refrigerated tankers as compared to the pipeline imports from Russia. It has also impacted upon demand, with EU gas demand falling 13% in 2023 compared to 2021. Much of this demand reduction has come from the power sector, but industrial uses have also declined, of which ammonia production has been one of the most gas intensive. European TTF gas prices have come down from their record levels of over $200/MMBtu in 2022 but are still comfortably higher than the rest of the world, and were still at $9-10/MMBtu at time of writing.

As a consequence European ammonia production dropped by 70% between February and September 2022. While much of this had recovered by September 2023, with only 19% inoperative, by January 2024 that was back up to 39% due to winter price pressures. Margins for nitrogen production in Europe are just barely positive at the moment, but they are much better and more stable for ammonium nitrate and its derivatives than for ammonia and urea. Many plants are running nitrate capacity using imported ammonia.

There was a theory that falling costs of renewable electricity production might make green EU ammonia production viable, once the new Carbon Border Adjustment Mechanism (CBAM) was taken into account, at least at times of higher ammonia prices. However, it is beginning to look as though low carbon blue ammonia produced using natural gas in the US Gulf Coast and exported to Europe may still end up being cheaper. It is possible for Europe's nitrogen industry to continue producing using imported ammonia – India's DAP industry has done so for many years – but it makes it much more vulnerable to supply side shocks. There have been a number of permanent closures in the past few years, and it is possible that there may be more to come. ■

Richard Hands, Editor

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Price Trends

Ammonia pricing in the US Mid-West stood at $625/st f.o.b. in February, with applications to field continuing to ramp up. Prices in the US Gulf remain pegged in the low-to-mid-$400s/t f.o.b. Recent production outages in the region have largely subsided, though an unexpectedly early uptick in seasonal demand from local buyers is likely to provide a degree of price support moving forward. The Tampa ammonia settlement for March has been settled by Yara and Mosaic at a $445/t c.fr rollover, largely in line with market expectations. The North American market remains detached from the considerably more oversupplied global ammonia scene.

Spot prices in NW Europe fell to around $465-470/t c.fr. With month-ahead natural-gas prices at the Dutch TTF hub trading as low as $8/MMBtu, theoretical ammonia costs of production continue to fall, to the low-to-mid-$300s/t region, well below latest import prices.

In North Africa, phosphate major OCP continued to source ammonia via a variety of spot and contract shipments. Jordanian phosphate producer JPMC was also in the market for a March ammonia cargo. Middle East ammonia activity was constrained, with producers largely focusing on contractual commitments. In Saudi Arabia, Ma'aden reported netbacks on its latest contractual shipments around the $295/t f.o.b mark.

Far East markets were quiet, with contract prices remain pegged at $300-350/t c.fr, though Chinese imports could soon begin to pick up to feed downstream fertilizer production.

CRU's crop price index has declined to 120, its lowest level since September 2020, as strong supply continues to outweigh lackluster demand. The latest round of US and European Union (EU) sanctions on Russia do not include measures against the agricultural sector, despite concern this week among many in the industry that new measures against Russian fertilizers would be implemented as part of the package. Nitrogen production costs have been volatile over the past three years. The cost curve dramatically steepened in 2021 and 2022 as European gas prices ballooned. But markets have since stabilised.

In the US, granular urea barge prices kept climbing with rumours of shortages for the spring spurring buyers despite corn prices taking a turn for the worse. Sentiment remained positive with good volume and early spring weather in the north also supporting the market.

Baltic prices were stable with support coming from increases seen in granular markets such as Brazil and the US. Prices are suggested at around $300-310/t f.o.b. Granular demand is also fairly thin with northern Europe quiet, Brazil picking up just small quantities and Mexican interest for forward shipments yet to translate into firm enquiries/sales.

In China, unlike phosphates, there is no clear indication when urea exports will resume. The market is not expecting exports to restart before 1 May. Because of the adverse weather across the country, urea demand has been limited. Prices declined in mid February, but rebounded slightly from 27 February. ■

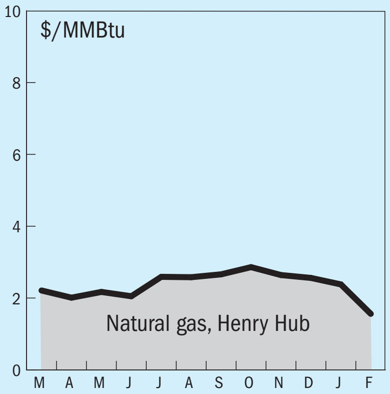
Table 1: **Price indications**

Cash equivalent	**mid-Feb**	**mid-Dec**	**mid-Oct**	**mid-Augn**
Ammonia ($/t)				
f.o.b. Black Sea	n.m	n.m.	n.m.	n.m.
f.o.b. Caribbean	395	475-575	525-575	260-3100
f.o.b. Arab Gulf	270-350	470	445-550	290-320
c.fr N.W. Europe	470-480	535-545	620-680	380-410
Urea ($/t)				
f.o.b. bulk Black Sea	300-320	273-290	320-390	340-400
f.o.b. bulk Arab Gulf*	345-352	298-302	340-405	346-400
f.o.b. NOLA barge (metric tonnes)	355-360	330-334	370-418	390-400
f.o.b. bagged China	330-335	360-370	365-405	370-395
DAP ($/t)				
f.o.b. bulk US Gulf	550-570	560	550-589	573-600
UAN (€/tonne)				
f.o.t. ex-tank Rouen, 30%N	255-260	309-310	284-315	302-324

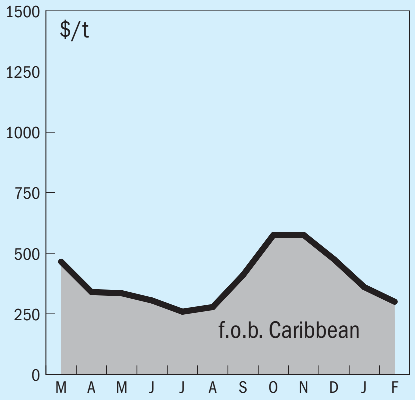
*Notes: n.a. price not available at time of going to press. n.m. no market. * high-end granular.*

END OF MONTH SPOT PRICES

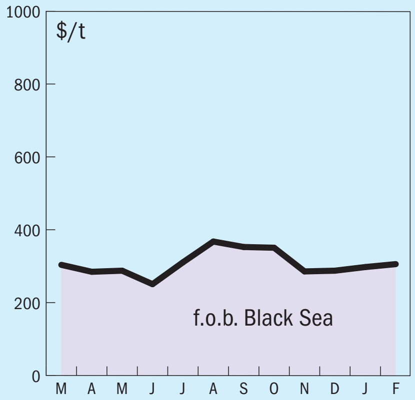
natural gas



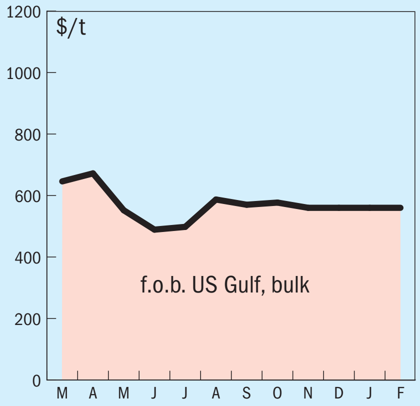
ammonia



urea



diammonium phosphate



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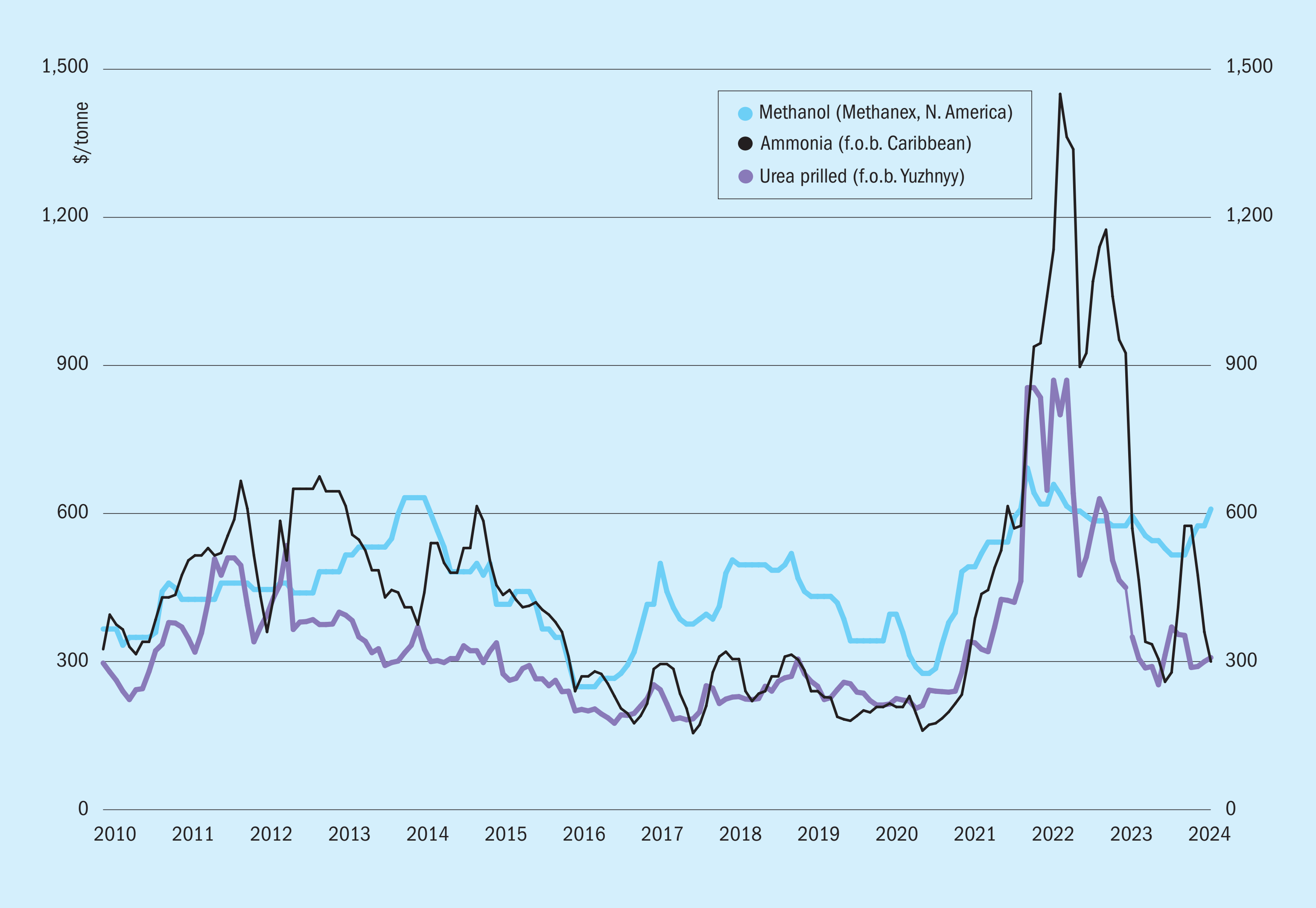
Market Outlook

Historical price trends $/tonne



Source: CRU

AMMONIA

- Prices will remain stable-to-soft across the board, though benchmarks could remain slightly more supported in the short-term than previously thought, with more significant declines likely in Q2-Q3.
- Parna Raya in Indonesia is reported to be initiating a turnaround at its KPI plant in March, adding to the two Petronas units recently curtailed in Malaysia. Still, these turnarounds are not expected to provide major support for prices, with overall regional availability still healthy and demand from the Far East still limited for the time being.
- Import demand from India may be stimulated in the coming weeks following a 38% increase in nutrient-based subsidy (NBS) rates for phosphate fertilizers, with news of fresh phosphate export quotas in China also likely to encourage ammonia producer sentiment. Industrial demand in the Far East still remains slack, however.

UREA

- NOLA is bullish whereas other price points are under pressure. The NOLA market is tight whereas supply needs to find a home from places such as Egypt. A return to the market by European buyers could help to support prices in Egypt and the Black Sea.
- Some buying interest is expected to re-emerge in Europe, although the wet weather continues to cause some disruption and warm weather in Romania has slowed down demand.
- According to CRU's February estimates, the Indian urea market outlook remains relatively stable, with opening stocks ranging from 6.85 to 7.15 million tonnes, production projected between 2.45-2.65 million t, and sales anticipated to reach 2.1 to 2.4 million tonnes. Import volumes are expected to range from 450,000-650,000 tonnes. Speculation remains that India will not return to the market to tender until the second-half of March.

METHANOL

- Methanol prices have been rising through Q4 2023 into 2024 due to a number of production outages, including Iranian plants having gas supplies reduced for winter and gas supply difficulties in Trinidad.
- At the same time there was increased demand, mainly in China, leading to a draw down on inventories and increasing methanol prices. There is little new methanol to olefins capacity, but as olefins prices recover, better MTO affordability may generate more demand. However, with Chinese GDP stagnating demand increases will not be as significant as in the past.
- As production returns prices should fall, though there is little new capacity expected onstream outside of China for the next few years. China continues to set the floor price depending on whether there is tightness and therefore room for arbitrage in the pricing. ■

Nitrogen Industry News

INDIA

Mangalore and Paradeep announce merger

Indian fertilizer producers Mangalore Chemicals & Fertilizers (MCFL) and Paradeep Phosphates (PPL) have announced that the companies intend to merge, allowing them to consolidate their operations, according to a company statement. The new merged company, to be called PPL, will have a total production capacity of 3.6 million t/a of fertilizers.

MCFL is based in Karnakata in the south of India. It produces urea, DAP, NPS and other speciality fertilizers. PPL has two phosphate plants located in Paradeep and Zuarinagar, with 1.8 million t/a and 1.2 million t/a of production capacity, respectively. Both producers have formed a merger implementation committee to oversee the merger process. ■

CIL fined $713,000 by Tamil Nadu after Ennore ammonia leak

Indian fertilizer manufacturer Coromandel International Limited (CIL) has been fined INR 5.92 crore ($713,000) by the Tamil Nadu state government following a recent ammonia leak at the group's Ennore facility. The leak, which occurred 26 December and resulted in the hospitalisation of around 44 local residents, was attributed to a damaged undersea pipeline close to the shore.

The Tamil Nadu Pollution Control Board (TNPCB) noted that CIL should, in future, provide adequate ammonia sensors around the Ennore plant, both in close proximity to where the pipeline crosses a local highway and throughout surrounding villages. CIL has also been asked to carry out onsite and offsite emergency preparedness studies by credible agencies for both ammonium phosphate potash sulphate (APPS) and ammonia storage along with an offshore pipeline facility, local media said.

Yara to receive low carbon ammonia from Acme

Norway-based Yara has signed a binding agreement with Acme Cleantech subsidiary GHC SAOC for long-term offtake of low-emissions ammonia from Acme in India. The long-term offtake agreement between Yara and Acme covers the supply of 100 000 t/a ammonia. In the base case, the ammonia will be supplied by Acme from Phase-1 of its Oman project, with an expected start date in 2027. The supply will comply with the EU RFBNO and Renewable Energy Directive requirements. In July, ACME raised $488 million in funding to commence its green hydrogen and ammonia project in Duqm, Oman.

The companies had previously signed a non-binding offtake term sheet. The current deal concludes 18 months of negotiations, during which the regulatory framework and certification regime have evolved significantly, creating a suitable environment for such long-term contracts, Yara said.

"Yara Clean Ammonia is a frontrunner in enabling the hydrogen economy across the shipping, food, power, and industrial sectors, said Magnus Ankarstrand, president of Yara Clean Ammonia. "The renewable ammonia from Oman will be part of our scalable distribution system, developing a reliable, safe, and cost-efficient supply chain for low emission ammonia across different market segments. This agreement demonstrates the power of partnerships and collaboration to develop value chains that reduce emissions."

Deepak Fertilisers inks 15-year LNG supply contract with Equinor

India's Deepak Fertilisers and Norwegian-headquartered energy firm Equinor have inked a 15-year LNG supply contract with deliveries to India to begin in 2026. This portfolio will be the base of supply to Deepak, which will use the gas mainly as feedstock for production of ammonia in its newly commissioned plant for manufacturing fertilizers and petrochemicals. The agreement covers supply of around 650,000 t/a LNG for 15 years starting from 2026, Equinor said.

"We are very happy to enter into this long-term agreement with Equinor for supply of LNG. The agreement will provide reliable supplies of feedstock which will further strengthen Deepak Fertilisers' value-chain from gas to ammonia, the key ingredient in fertilizers," Deepak Chairman Sailesh Mehta said. "The agreement will help us absorb global volatility as well as enhance overall margins. We also look forward to exploring with Equinor further collaboration on feedstock and carbon footprint reduction initiatives," Mehta added.

CIL to invest in ammonium nitrate plant

Coal India Ltd (CIL) and Bharat Heavy Electricals Ltd (BHEL) have signed a joint venture agreement to set up an ammonium nitrate plant using surface coal gasification. The plant will be located in Odisha's Lakhanpur area, using coal supplied by CIL subsidiary Mahanadi Coalfields Ltd, and is planned to produce 2000 t/d (660,000 t/a) of ammonium nitrate according to a statement by India's coal ministry. Full production will require 1.3 million t/a of coal. BHEL would supply its own pressurised fluidized bed gasification technology to convert the coal into syngas feed for the ammonia plant.

GERMANY

Mabanaft completes study on ammonia import terminal

German-headquartered energy firm Mabanaft has successfully completed a so-called scoping meeting ahead of the approval procedure for the construction of its planned ammonia import terminal in the Port of Hamburg, the company said in a press statement.

In addition to Mabanaft, authority representatives, directly affected neighbours, environmental associations and other experts were invited to the meeting, which lasted several hours, the purpose of which was to determine the scope of the environmental impact assessment, the statement said.

In July 2023, Mabanaft went through a voluntary hearing for the construction of an ammonia import terminal in the Port of Hamburg, in which the company outlined the necessary construction measures. These included the construction of a liquid ammonia storage tank at its Blumensand Tank Terminal in the Port of Hamburg, operated by Mabanaft subsidiary Oiltanking Deutschland.

In November 2022, Mabanaft and its anchor customer Air Products announced the construction of a large-scale terminal for green energy. While Mabanaft plans to build, own and operate the facilities required for the handling of ammonia, Air Products plans to build, own and operate the facilities required for the production and handling of hydrogen for which green ammonia will be the feedstock.

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"Our planned ammonia import terminal on our land in the Port of Hamburg has the potential to bring significant quantities of energy products to Hamburg that can support the energy transition," Director of New Energy at Mabanaft Philipp Kroepels said.

"A voluntary environmental impact assessment along the way is very important to us. We are now getting ready to officially initiate the permit process," Kroepels added.

In January 2023, Mabanaft signed a memorandum of understanding (MoU) with Hapag-Lloyd to evaluate options for the supply of ammonia as a bunker fuel to in and around the Port of Hamburg, Germany and the Port of Houston, Texas, USA.

PORTUGAL

Green ammonia and hydrogen plant

Maire Group says that Tecnimont has been awarded a FEED contract by MadoquaPower2X to develop an integrated green hydrogen and green ammonia plant located in the industrial zone of Sines, Portugal. MadoquaPower2x is a consortium comprised of Madoqua Renewables, Power2X and Copenhagen Infrastructure Partners (CIP), through its Energy Transition Fund.

The project involves the production of green hydrogen using alkaline-water electrolyser technology and production of green ammonia through the Haber-Bosch process. Green ammonia will be transported by pipeline to the Port of Sines and loaded for export and/or used as maritime fuel.

Tecnimont's scope of work entails the design of the electrolysers' integration, an air separation unit for nitrogen production, and the ammonia production plant, as well as storage and ship loading facilities. As part of the agreement, Tecnimont will also submit an engineering, procurement and construction proposal for the construction activities of the plant. The final notice to proceed is expected by 22 March 2024.

This award follows a pre-FEED carried out by NextChem Tech, Maire's sustainable technology solutions subsidiary. As such, Tecnimont will provide its EPC expertise leveraging on NextChem Tech's technological competences for hydrogen production and storage.

MadoquaPower2X will use renewable energy generated by solar and wind assets under development in Portugal and up to 500 MW of electrolysis capacity to produce up to 1,200 t/d of green ammonia. It will be the first facility in Sines, the largest industrial and logistic hub in the Iberian peninsula, to produce clean energy at an industrial scale and with the highest environmental and safety standards. The project is geared towards the set-up of an export energy carrier value chain between the Port of Sines (Portugal) and Northwestern European Hub.

Alessandro Bernini, Maire CEO, commented: "This award shows the Group's strength in the green hydrogen and ammonia production segment, which helps supporting the transition to a clean energy system".

EGYPT

Stamicarbon to supply urea melt and granulation plant

Maire Group says that NextChem, via its nitrogen technology licensor Stamicarbon, has been awarded a licensing and equipment supply contract for a urea melt and granulation plant 100 km southeast of Cairo for El-Nasr Company for Intermediate Chemicals (NCIC). The plant is expected to have a production capacity of 1,050 t/d of urea. The technology selected by NCIC plays a pivotal role for the urea melt and granulation plant, especially in terms of process optimisation, operational safety, enhancing yield and minimizing energy consumption. NCIC is one of the key players in the chemical and fertilizer industry in Egypt, embracing cutting-edge nitrogen technologies able to ensure superior product quality.

Alessandro Bernini, Maire CEO, commented: "This award is evidence of the reliability of our value proposition in offering nitrogen-based technology solutions worldwide. We are proud to contribute to NCIC's industrial development plans in the fertilizer sector, thus consolidating our market leadership in licensing urea technology in Africa."

Delta Fertilizers, thyssenkrupp Uhde to restart Egypt ammonia facility

Egypt's Delta Company for Fertilizer and Chemical Industries (Delta Fertilizers) has signed a contract with the Egyptian subsidiary of German engineering firm thyssenkrupp Uhde to revamp an existing ammonia plant complex located in Dakahlia, Talkha, Egypt, the latter said in a 22 February press statement.

Responsible for the front-end-engineering-design (FEED), thyssenkrupp Uhde will provide engineering solutions for the revamp of the ammonia plant as well as the ammonia offsite and central utility units, the group said. The company will also supply its state-of-the-art technology for the production of ammonia and urea. Together with the FEED solution, this technology will enable the plant to be re-commissioned after a three-year shutdown, while at the same time increasing the plant's capacity from 1,275 t/day ammonia to 1,400 t/day, the statement continued.

"We are very proud to have been selected as the partner to execute this project and enable the re-commissioning of the ammonia plant together with a capacity increase. Our proven ammonia technology and our innovative engineering solutions guarantee the production of high-quality ammonia and urea worldwide," thyssenkrupp Uhde Egypt CEO Thomas Kufahl said.

JAPAN

Heraeus invests in Japanese ammonia startup

Heraeus has invested in Japanese startup Tsubame BHB, which has been developing a new environmentally friendly and efficient technology for decentralised ammonia production. Tsubame BHB, based in Yokohama, was founded in April 2017 with the goal of implementing the world's first on-site ammonia synthesis system. Heraeus says that the Tsubame technology complements the company's offering of sustainable, precious metal based technologies. The innovative process is based on an electride catalyst and enables cost-effective ammonia production. It meets previously unmet needs in the ammonia market for local or "close-to-use" ammonia production, saving transportation cost and avoiding the risk of supply disruptions. The process is also suited to produce renewable ammonia from low carbon hydrogen and therefore supports the decarbonisation of the ammonia value chain.

"Japan is a market where innovation is born – especially in the area of advanced materials. As a globally leading material technology company, Heraeus sees great potential in a stronger collaboration with Japanese companies, universities, and research institutes. Our investment in Tsubame BHB is a great example how Japanese and German companies can profit and grow together in future markets." added Hideto Yamauchi, Representative Director, President of Heraeus K.K. in Japan.

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IRAN

Iran to boost ammonia production capacity by 450,000 t

The head of Iran's National Petrochemical Company (NPC) has stated that following the implementation of the Persian Gulf Star Oil Company (PGSOC)'s ammonia plant, 450,000 t will be added to the country's ammonia production capacity, the Tehran Times reported 23 February.

The necessary permits have been issued for the establishment of the PGSOC plant, the implementation of which is set to also prevent the wastage of more than 95,000 t hydrogen, NPC Head Morteza Shahmirzaei was cited as saying.

"The total gas consumption of petrochemical complexes is less than 8% of the country's total gas consumption, and this gas should be converted into added value and final products should be produced to reduce crude sales and complete the value chain," Shahmirzaei said.

CHINA

Stamicarbon to supply low energy urea melt plant

Jiangsu Huachang Chemical Company has awarded Stamicarbon licensing and equipment supply contracts for a urea melt plant in China. The plant, located in Zhangjiagang, Jiangsu province, will have a capacity of 1860 t/d and use Stamicarbon's Ultra-Low Energy design with a highly efficient pool reactor concept. This urea melt plant will serve as a replacement for an outdated facility of similar capacity and will use the existing prilling unit. Stamicarbon will provide the license, proprietary equipment, including high-pressure equipment made of super duplex stainless steel, and associated professional services.

Stamicarbon's Ultra-Low Energy design, uses high-pressure steam three times instead of two, making the process more energy efficient than the conventional CO_2 stripping. This heat recovery scheme results in a 35% reduction in steam consumption and a 16% decrease in cooling water use.

"At Stamicarbon, we are committed to pioneering sustainable solutions, and Ultra-Low Energy design stands out as a testament to our dedication. We believe that this project marks a significant milestone in Jiangsu Huachang 's journey towards a more sustainable and efficient future. This project marks the ninth worldwide implementation of our groundbreaking technology, a testament to its global recognition as the industry's benchmark for energy consumption and efficiency," said Pejman Djavdan, Stamicarbon CEO.

SOUTH KOREA

Topsoe's technology selected for new hydrogen project

Topsoe has signed an engineering agreement with South Korean industrial supplier of hydrogen Approtium to convert low-carbon ammonia into hydrogen using its H2RETAKE technology. Topsoe says that technology will be used in Approtium's project in Ulsan, South Korea, where the latter plans to build an ammonia cracking plant to produce 75,000 t/a of low-carbon hydrogen. Production will start in 2027.

Elena Scaltritti, Chief Commercial Officer at Topsoe, commented: "We are excited to embark on this project with Approtium, showcasing not only the potential of our innovative technology but also the strengths of ammonia as a key energy carrier. Greenhouse gas emissions need to be reduced drastically on a global scale and through this project, Topsoe delivers a strong contribution to support South Korea's decarbonization targets."

James Kim, CEO of Approtium, stated: "Our ultimate goal has been to provide clean hydrogen to clients and contribute to accelerate carbon neutrality in Korea. This collaboration with Topsoe marks a significant milestone in our relentless pursuit of that goal and signifies our commitment to providing value to both our clients and society."

Wärtsilä to deliver ammonia fuel system for two MGCs

Finland's Wärtsilä Gas Solutions, part of technology group Wärtsilä, will deliver a fuel supply system for two new gas carriers that will operate with ammonia fuel. The ships will be built at the Hyundai Mipo Dockyards (HMD) in South Korea for shipowner Exmar LPG, a joint venture between Exmar, a multi-disciplinary maritime and offshore solutions provider, and Seapeak, one of the largest independent owner-operators of liquefied natural gas vessels. The Exmar Midsize Gas Carriers (MGCs) will be the first ever oceangoing vessels to be propelled by dual-fuel engines capable of operating with ammonia, with these engines provided by marine technology developer Winterthur Gas & Diesel Ltd. (WinGD).

The full scope of Wärtsilä's supply includes the Liquid Ammonia Fuel Supply System along with process engineering and dynamic simulation. The system is skid mounted with low- and high-pressure fuel pumps, controls for fuel pressure and temperature, and heat exchangers. Delivery to the yard is scheduled for 2025, the company says.

"When operating with ammonia fuel, the carbon dioxide emissions will be reduced with about 90%. This is fully in line with Wärtsilä's strategy for enabling decarbonised shipping operations, and is an endorsement of our capabilities to deliver future-proof systems capable of handling a new generation of marine fuels," Head of Marine sales at Wärtsilä Gas Solutions Stein Thoresen said.

RUSSIA

Ammoni JSC to launch UAN production in March

Ammoni JSC is set to launch UAN production at its newly constructed nitrogen facility in Tatarstan in March 2024, TASS reported 30 January, citing company Deputy General Director Yuri Razbezhkin. The project is expected to reach design capacity of 150,000 t/a in 2024, with plans to expand production to as high as 300,000 t/a in the future, Razbezhkin said.

Production at the new complex had originally been slated to begin in Autumn 2023, though delays in procuring the relevant equipment have pushed the project start date back to March this year. Russia is largely unable to directly purchase technical equipment from countries it deems 'unfriendly' following the full-scale invasion of Ukraine in February 2022.

MALAYSIA

Petronas, Sarawak government weighing up blue ammonia JV

Malaysia's Petronas and the government of the Malaysian state of Sarawak are reportedly mulling a joint venture (JV) for a large-scale blue ammonia plant, according to local press reports. Further details, including the planned production capacity of the plant, are unclear, though sources have estimated that any investment could amount to around $1 billion. A preliminary agreement to facilitate discussions and to assess the feasibility of the project will be signed before the end of this month.

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Sarawak is already developing a low-carbon project in the state. In January 2022, South Korea's Samsung Engineering, Posco and Lotte Chemical signed a memorandum of understanding (MoU) with SEDC Energy, a subsidiary of the Sarawak Economic Development Corporation, to develop a green hydrogen and ammonia site at Bintulu.

UNITED STATES

CF and Mitsui to decide on blue ammonia project in H_2

CF Industries and Mitsui completed a front-end engineering and design (FEED) study in the fourth quarter 2023 on their greenfield blue ammonia facility CF's Blue Point Complex in Louisiana, CF announced in its Q4 results. The plan is for a steam methane reforming (SMR) ammonia facility with carbon capture and sequestration (CCS) technologies.

The FEED study estimates the cost of the project to be in the range of $3 billion, with approximately $2.5 billion allocated to the ammonia facility and CCS technologies and approximately $500 million allocated to scalable common infrastructure for the site, such as ammonia storage and vessel loading docks. CF and Mitsui are progressing two additional FEED studies focused on technologies with the potential to further reduce the carbon intensity of the proposed plant. These include a previously announced study evaluating autothermal reforming (ATR) ammonia production technology and a recently added FEED study assessing the cost and viability of adding flue gas capture to an SMR ammonia facility. Both FEED studies are expected to be completed in the second half of 2024.

The companies also expect greater clarity later in 2024 regarding demand for low-carbon ammonia, including the ammonia carbon intensity requirements of offtake partners as well as government incentives and regulatory developments in partners' local jurisdictions. They are thus targeting the 2024 H_2 for a final investment decision on the proposed plant.

Mitsui and CF first announced 3 May they had secured an exclusive right to acquire a site in the US Gulf Coast region suitable to construct an export-oriented blue ammonia production facility. CF will have 52% and Mitsui will have 48% ownership of the intended joint venture in which the parties will have proportional capital investment and economic returns. Mitsui will lead the marketing and distribution for the blue ammonia into Asia. The announcement came after the companies in August 2021 signed a memorandum of understanding (MoU) to jointly explore the development of blue ammonia projects in the US.

Clean ammonia project in Louisiana

Idemitsu Kosan has agreed with Mitsubishi and Proman to participate in the development of a proposed clean ammonia project in Lake Charles, Louisiana. The project aims to produce approximately 1.2 million t/a of low carbon clean ammonia by 2030, and is currently in the front-end engineering design (FEED) process. According to Idemitsu, it will use Topsoe's SynCOR technology, and Mitsubishi Heavy Inudstry's Advanced KM CDR Process, developed collaboration with Kansai Electric Power. Ammonia produced at the facility will be primarily exported to Japan as a clean fuel. ■

NORWAY

NextChem to supply technology for biofuels plant

NextChem Tech, has signed a contract with Paul Wurth SA, a subsidiary of SMS group, and Norsk e-Fuel AS for a licensing and engineering design package relating to its NX CPO (catalytic partial oxidation) technology, which will be used in an industrial scale plant producing sustainable aviation fuel (SAF) from green hydrogen and biogenic CO_2 in Mosjøen, Norway. NextChem's NX CPO technology produces synthesis gas via a very fast controlled partial oxidation reaction. When applied to synthetic fuel production, it can improve carbon efficiency recovery yield. The first plant developed by Norsk e-Fuel will have a production capacity of 40,000 t/a of green fuel and will enter operation after 2026. Based on the initial design, two additional facilities with a capacity of around 80 000 t/a each are planned to be built by 2030. The fuels will current aviation emissions.

Karl Hauptmeier, CEO Norsk e-Fuel said: "Our collaboration with NextChem Tech is another step towards improving carbon efficiency of our production processes while simultaneously reducing costs."

NX CPO technology converts hydrocarbon or biologically based feedstocks via a controlled partial oxidation in presence of a catalyst that facilitates the conversion into syngas through an entirely heterogeneous very fast reaction. ■

Eidesvik Offshore launches methanol-powered vessel

Norwegian shipowner Eidesvik Offshore is joining forces with Agalas to build a state-of-the-art construction support vessel (CSV) to perform subsea and offshore wind operations, equipped with methanol engines and a battery hybrid system. The vessel will be owned by Eidsvik Agalas AS, a joint venture company with Eidesvik retaining a majority stake of 50.1%. The remaining shares will be owned by Northern Norway shipowners Agalas. Eidesvik Agalas AS has been granted options for 4 additional vessels.

Eidesvik has a history of innovation, being a first mover in the adoption of LNG and battery technology for offshore vessels, and now will introduce what it says is the world's most eco-friendly vessel within its operating segments. Using a battery hybrid system alongside dual fuel engines capable of operating on either methanol or marine gasoil (MGO) is a significant leap forward in environmental sustainability for the industry. The ship will be built at the Sefine Shipyard in Turkey, with delivery in early 2026. It will be equipped to perform inspection, maintenance and repair work, and upon delivery will enter into a 3 to 5-year time charter with Reach Subsea. Full management of the vessel, including crewing, will be provided by Eidesvik.

"This new asset aligns perfectly with our strategy, which is founded on sustainable shipping solutions and long-term partnerships with our clients. The versatile vessel is designed to meet the demands of both the oil & gas sector and the offshore wind industry. This flexibility increases our capabilities and competitiveness in the future energy mix", said CEO and president of Eidesvik Offshore, Gitte Gard Talmo.

CHINA

Collaboration on sustainable energy solutions

BASF process catalysts has announced a new collaboration with Envision Energy, a leading green technology provider, to further develop the conversion of green hydrogen and CO_2 into green methanol through novel process design. The two companies aim to optimise the process of producing green methanol from green hydrogen and CO_2, paving the way for a more sustainable energy landscape. This collaboration will see BASF provide its SYNSPIRETM catalyst technology, which Envision Energy will integrate with its innovative energy management system. The two organisations plan to demonstrate the viability of the advanced process design next year, at Envision Energy's Chifeng site in Inner Mongolia, China.

BASF says that the new catalyst it has developed represents a "significant breakthrough" in enabling efficient conversion of green hydrogen and CO_2 into methanol. Methanol offers immense potential to replace fossil fuels and derivatives gasoline by providing an alternative source of energy for road, shipping and air transport, as well as other industries without a change in infrastructure, and which be stored at room temperature and ambient pressure.

Envision Energy will design a process package that maximises the efficiency of the catalyst technology while fully enabling the dynamic conversion of green hydrogen and CO_2 into methanol, using the onstream time of wind power. Envision Energy will leverage its AIoT (Artificial Intelligence of Things) platforms to optimise the novel, dynamic mode of chemical plant operation.

Detlef Ruff, Senior Vice President, process catalysts at BASF, said: "BASF process catalysts looks forward to working with Envision Energy in our shared mission to drive sustainable energy solutions. By combining our innovative catalyst technology with Envision Energy's deep expertise, we are confident we can unlock the full potential of green hydrogen and CO_2 conversion to e-methanol."

ITALY

Contract awarded for hydrogen plant

KT – Kinetics Technology has been awarded an engineering, procurement and construction contract by Eni to build a hydrogen plant at Eni's Livorno refinery. The value of the contract is €123 million, and the project is scheduled for completion in 2026. It will process natural gas and biogenic feedstocks to create hydrogen for the production of biofuels for mobility at the Livorno site, processing various biogenic feedstocks, mainly waste such as cooking oils and animal fats, and residues from the agribusiness industry. In addition, the plant is designed so that a residual CO_2 capture unit can be implemented at a later stage.

The construction of the new unit is part of Eni's project to convert its Livorno plant into a biorefinery.

Alessandro Bernini, CEO of KT's parent company Maire, commented, "We are proud of this important achievement with Eni."

New model for carbon neutral chemistry

NextChem Tech has launched a new computer model for its "e-factory for carbon-neutral chemistry". This model has been developed via a cooperation

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agreement with newcleo to produce, on an exclusive basis, a conceptual study for carbon-neutral hydrogen production using nuclear technology.

Sister company Tecnimont (through its Integrated E&C Solutions business unit) will provide high-level consultancy services for newcleo's plan for the implementation of an innovative power plant based on newcleo's LFR-AS-200 technology, a small modular lead-cooled fast reactor fuelled with MOX fuel thanks to Tecnimont's modularisation approach to optimise construction and planning methodology, reducing time and costs. This enables the production of electrolytic hydrogen and sustainable chemicals, in line with the recent European Union's decision to include innovative Gen-IV nuclear technology like the newcleo one within the EU taxonomy of environmentally sustainable economic activities.

SOUTH KOREA

Ammonia cracking plant for Approtium

Topsoe has signed an engineering agreement with Approtium to convert low-carbon ammonia into hydrogen using its H2RE-TAKE™ technology. Approtium plans to build an ammonia cracking plant to produce 75,000 t/a of low-carbon hydrogen. The plant will be built in Ulsan, South Korea, and production is expected to start in 2027. It will support South Korea's growing need for co-firing in the power generation sector. The project is also expected to contribute significantly to South Korea's target of reducing greenhouse gas emissions with 40% in 2030 (from a 2018 baseline).

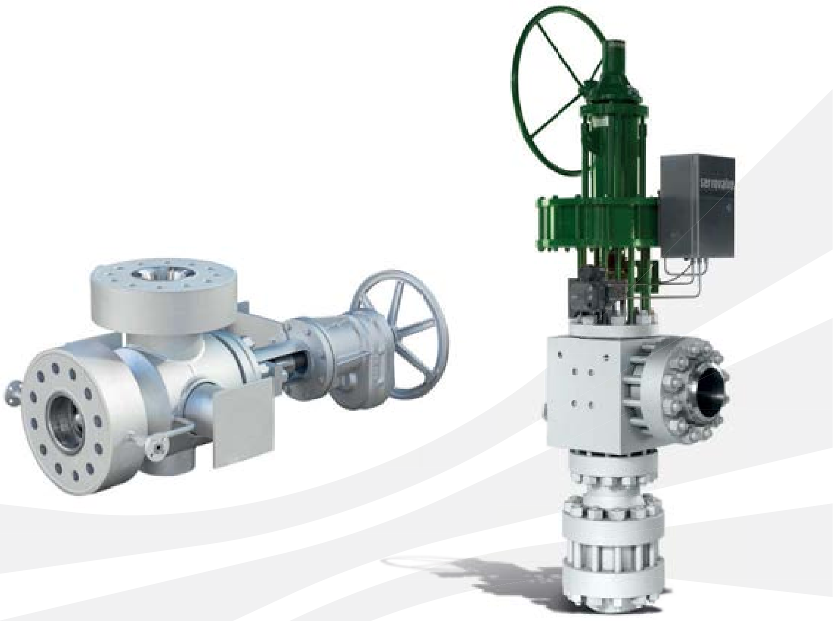
Elena Scaltritti, Chief Commercial Officer at Topsoe, said: "We are excited to embark on this project with Approtium, showcasing not only the potential of our innovative technology, but also the strengths of ammonia as a key energy carrier. Greenhouse gas emissions need to be reduced drastically on a global scale and through this project, Topsoe delivers a strong contribution to support South Korea's decarbonization targets."

James Kim, CEO of Approtium, said: "Our ultimate goal has been to provide clean hydrogen to clients and contribute to accelerate carbon neutrality in Korea. This collaboration with Topsoe marks a significant milestone in our relentless pursuit of that goal and signifies our commitment to providing value to both our clients and society."

AUSTRALIA

Green methanol plant for South Australia

Hamburg-based energy company Mabanaft has received a grant approval from Projektträger Jülich in Germany. The funding marks a crucial milestone for the potential construction of a new green methanol plant in Port Augusta, South Australia. Together with Australian renewable energy company Vast, Mabanaft is assessing to build a demonstration plant with a capacity of around 7,500 t/a of green methanol. Project developer Vast specialises in concentrated solar thermal power (CSP) energy systems, and Mabanaft intends to build a solar methanol plant using a 10 MW electrolyser. The planned demonstration plant could be operational in the beginning of 2027, and would then provide customers with green methanol based on renewable energy. In the future, and after evaluation of effectiveness, other project sites in or near Europe could be added. ■



People

Agropolychim has announced that CEO **Philippe Rombaut** will become chairman of Agropolychim's board of directors, with a focus on steering the company's strategic development. His new appointment will make way for **Teodor Petsov** to assume the role of head of production operations. Petsov has 22 years of production experience and a management background. In his capacity as the new production director, he will be responsible for orchestrating, overseeing, and coordinating all aspects of the company's production activities.

Sara Aslam has been appointed as the interim CEO of Pakistan's National Fertilizer Corporation (NFC) by the federal cabinet following the resignation of the previous CEO. Aslam is a seasoned professional in the fertilizer industry, with over 20 years of experience. She was previously Secretary in the Ministry of Industries & Production. Her appointment is for a period of three months or until the privatisation of NFC, whichever comes first, although the privatization of NFC has been planned by the government since March 2020, and NFC has had no permanent CEO for over four years. In a press statement, NFC said that it "looks forward to a future filled with promise and potential. [Aslam's] appointment is not just a step towards privatization, but a leap towards a brighter, more prosperous future for the corporation and the fertilizer industry as a whole." The federal cabinet said that their decision to appoint Aslam reflects their confidence in her ability to navigate the complexities of privatisation, while also maintaining NFC's strong presence in the Indian market.


Jan Toschka

Sasol and Topsoe have appointed **Jan Toschka** as CEO of the joint venture established by the two companies to develop, build, own and operate sustainable aviation fuel (SAF) ventures and to market the products. Previously Toschka was president of Global Aviation for Shell, responsible for Shell's global network of operations, joint ventures and sales of fuels, lubricants and sustainable solutions to the aviation industry. During his tenure at Shell, he has led teams across sales, mergers and acquisitions, trading, and retail businesses globally, spanning various industries including Marine and Retail. Toschka will assume his new role as CEO on 1 March 2024 and the joint venture will be launched during the same month. The new company will be headquartered in The Netherlands.

Fleetwood Grobler, Sasol President and CEO said: "Jan, a distinguished leader in the global aviation fuel industry, enriches our new joint venture with his extensive experience and industry expertise. His strong customer-centric approach reflects a deep understanding of the industry and both the challenges and opportunities faced by the market. I am delighted he is joining us and eagerly anticipate witnessing the venture flourish under his leadership, as we seek to contribute significantly to the decarbonisation of the aviation industry."

Roeland Baan, CEO at Topsoe, said: "I'm excited, that Jan Toschka has accepted the position as CEO for the joint venture. Jan holds unique competencies from having already been working with the aviation industry, and he has a highly entrepreneurial mindset, which is what we need to get the joint venture off to a great start. There's no time to waste in boosting production of SAF to decarbonise the aviation industry, and with Jan joining, I am confident that the joint venture will deliver a remarkable contribution to the world's global ambition of reaching Net Zero."

Jan Toschka said: "The joint venture is formed by two industry leaders, and their ambition to take on one of society's biggest challenges, to help reduce carbon footprint of the aviation industry. This industry is close to my heart, and I am very excited to lead the new company."

On January 24, 2024, the board of directors of PetroVietnam Fertilizer And Chemicals Corporation approved the appointment of **Phan Cong Thanh** as Chief Executive Officer, following the resignation of **Dao Van Ngoc** as head of the executive board. The move follows the removal of Hoang Quoc Vuong, CEO of state-run PetroVietnam in December, and a number of Ministry of Industry and Trade officials following allegations of financial impropriety regarding incentives for solar and wind energy, and his replacement with Le Manh Hung for a five year term. ■

Calendar 2024

MARCH

20-24

11th Annual Gasification Summit,
GHENT, Belgium
Contact: Mohammed Ahsan, ACI
Tel: +44 203 141 0606
Email: mahsan@acieu.net

APRIL

15-17

Nitrogen+Syngas Conference USA,
Oklahoma, USA
Contact: Michelle Bingham, CRU
Tel: +44 (0)20 7903 2159
Email: michelle.bingham@crugroup.com

MAY

20-22

IFA Annual Conference, SINGAPORE
Contact: IFA Conference Service,
49 Avenue d'Iena, Paris, F75116, France
Tel: +33 1 53 93 05 00
Email: ifa@fertilizer.org

JUNE

6-7

NH3 Event, ROTTERDAM, Netherlands
Contact: Stichting NH3 event Europe,
Karel Doormanweg 5, 3115 JD Schiedam,
The Netherlands
Tel: +31 10 4267275
Email: info@nh3event.com

13-14

34th IMPCA Methanol Mini-Conference,
PRAGUE, Czech Republic
Contact: IMPCA, Avenue de Tervueren
270 Tervurenlaan, 1150 Brussels,
Belgium
Tel : +32 2 741 86 64
E-mail: info@impca.be

SEPTEMBER

9-12

AIChE Ammonia Safety Symposium,
SAN DIEGO, California, USA
Contact: Ilia Kileen, AIChE
Tel: +1 800 242 4363
Web: www.aiche.org/ammonia

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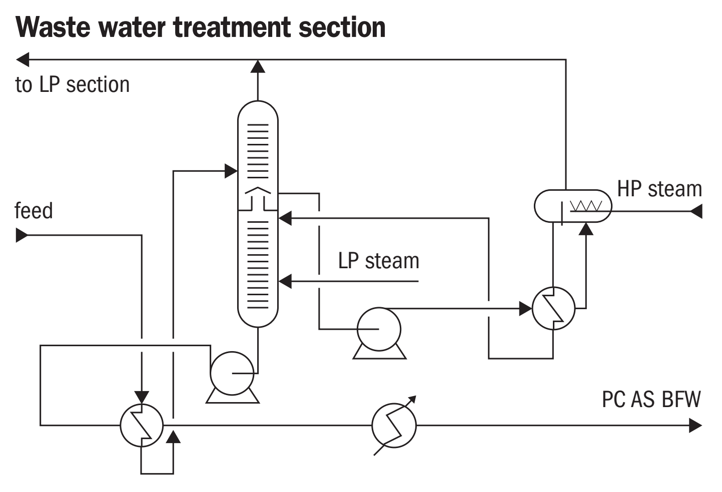
Plant Manager+

Problem No. 72 Reuse of off-spec wastewater

Every urea plant is also a water plant as the overall reaction starts with two molecules of ammonia and one molecule of carbon dioxide resulting in one molecule of urea and one molecule of water. Further water is added to the process via the steam ejectors in the evaporation section. All this water, which is contaminated with ammonia, carbon dioxide and urea plus possibly other contaminants like formaldehyde, methanol, oil, etc is collected in an ammonia water tank and then sent to a wastewater treatment section. The purpose of the wastewater treatment section is to reduce the ammonia, carbon dioxide and urea levels to acceptable levels. First the wastewater is treated in a first desorber column, where LP steam is used to strip off the ammonia and carbon dioxide, reducing the ammonia content from approx. 6-8 wt-% ammonia to approx. 1 wt-% ammonia. Nothing happens with urea in the first desorber as temperatures are too low to hydrolyse the urea back to ammonia and carbon dioxide. This takes place in the next step, in the hydrolyser, which can be quite a large counter current column operating with MP steam at approx. 23 bar (Stamicarbon design) or a horizontal deep hydrolyser operating at approx. 33 bar (Saipem design, refer to figure). Downstream of the hydrolyser there is another desorber column to strip off the remaining ammonia and carbon dioxide. Nowadays, boiler feed water quality can be realised by modern wastewater treatment. But at higher plant loads the operating margin in the wastewater treatment can become too small leading to higher ammonia and urea levels during certain operating conditions… ■



Niraj Nimje of RCF Thal in India initiates this round table discussion: In our Saipem plant, after the booster ejector and condensers in the vacuum section, we face problems due to a change in concentration of the wastewater section feed tank and off spec condensate is generated which is then wasted as effluent. What methods are available to treat this off-spec condensate to make it boiler feed water grade? I have heard of a polishing unit being used for such cases, but what is the maximum concentration of the contaminants that is permitted in such cases and what arrangements need to be in place to ensure a proper quality?

Prem Baboo, retired from NFL, India and Dangote Fertilizers, Nigeria shares his wide and valuable experiences: We have done the following modifications in the vacuum section:

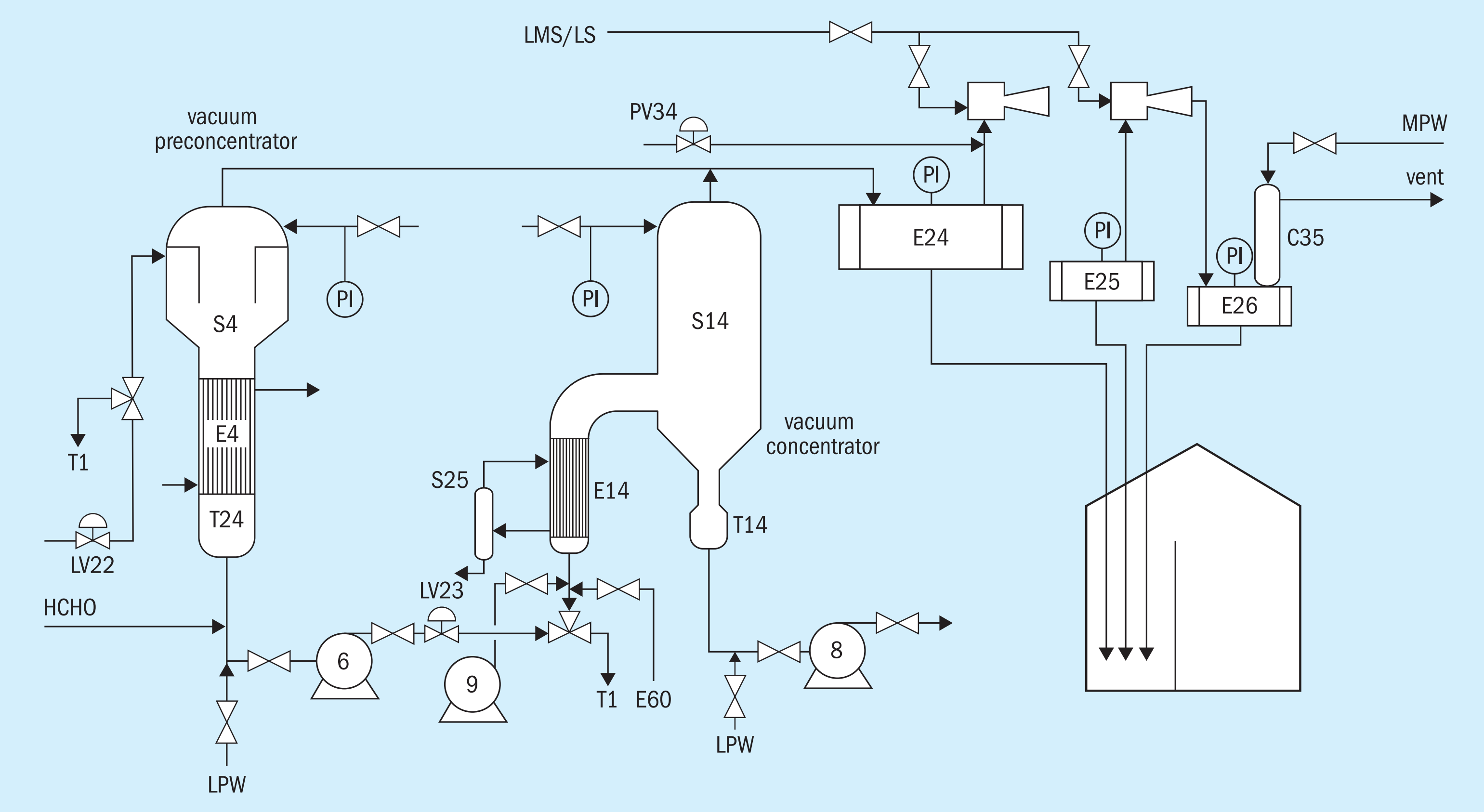
- The crown flushing of 2nd stage vacuum separator (cone flushing) has been changed to 99.7% urea melt to minimise the water load and to minimise prilling diversion.
- The condenser flushing has been changed to wastewater (wastewater to distillation); a 2-inch line is taken from the distillation tower (desorber) feed pump for flushing, minimising the water load on the wastewater section.
- Water monitoring and a water balance is prepared in each shift.
- We take wastewater containing 1.0 ppm urea and 2-3 ppm ammonia to the demi water plant and this suitable for demi water production. We maintain the following parameters:
  - ❍ Distillation (desorber) pressure 1.8 kg/cm^{2}g, temp in top 112°C and in bottom 132°C. Low pressure steam to distillation flow is 11.0 t/hr.
  - ❍ Wastewater flow is about 80-82 m^3/hr at 3,500 t/d plant load.
  - ❍ Hydrolyser pressure 34 kg/cm^{2}g and temperature 232°C. Steam to hydrolyser about 5.0 t/hr.
  - ❍ Wastewater analysis is 5.5 to 6.0% ammonia and 0.9 to 1.0 % urea.

Nagaraju from Notore Fertilizer in Nigeria shares his experiences: The purified waste water from our 2nd desorber contains really high levels of ammonia and urea. In our plant (Stamicarbon) it is typically about 100 ppm urea and 50 ppm ammonia, how is that possible?

Prem replies: Wastewater with such a high concentration of ammonia and urea cannot be used as demi water. It means your hydrolyser is not working properly. The hydrolyser outlet urea should be less than 1-2 ppm. Please clarify your hydrolyser pressure and temperature and desorber temperature.

Niraj responds: We are already doing all you have mentioned and we are getting boiler feed water quality water without any polishing unit. Our hydrolyser and distillation units are working fine with 25 kg/cm^2 and 1.8-2 kg/cm^2 respectively but after crown washing, condenser booster ejector washing, or during any upset, the wastewater tank (V6) concentration changes (temporarily) and off-spec wastewater is generated. During these situations we increase the steam flows to the hydrolyser and distillation column. After a revamp our wastewater load also increased from 40 to 50 m^3/hr. So, it is sometimes difficult to maintain the quality of water generated after performing the activities mentioned above. As we don't have a polishing unit, we are looking forward to it, and want to convert even small quantities of off spec wastewater into boiler feed water.

Fig 1: **Vacuum concentration section of urea plant**



Mark Brouwer of UreaKnowHow.com, the Netherlands joins the discussion: I agree with Prem that water with ammonia and urea concentration 1~3 ppm is acceptable for use as boiler feed water after passing through a polisher.

@Prem Are you using this purified waste water in the boilers as boiler feed water directly? Did you observe any corrosion in the boiler or steam lines?

Prem replies: For boiler feed water, ammonia is not a problem because the ammonia is added anyway for raising the pH of the boiler feed water. The problem is the high urea content due to a problem with your hydrolyser. The hydrolysis reaction is a function of temperature: you cannot raise the temperature beyond 223°C at a pressure of 25 kg/cm². With the revamp you should be able to also revamp this section, either by increasing the residence time or raising the pressure. The residence time of the hydrolyser is reduced after revamp.

Phong of Petro Vietnam Ca Mau Fertilizer in Vietnam also joins this discussion: Our plant use Saipem technology for urea synthesis and Toyo technology for granulation. Our MMU section didn't work well so we decided to stop operating the MMU section and feed formaldehyde directly to the P06 pump suction line (see figure above). In this case our wastewater after treatment still has presence of HCHO (more than 500 ppm). The parameters at the top and bottom of the distillation tower are 4.2 bar and 130°C (top) and 4.7 bar and 157°C (bottom). The condition in the hydrolyser is 31 bar and 230°C.

How does HCHO at concentrations above 500 ppm affect boiler feed water, and how do you treat it?

Mark replies: Formaldehyde will convert into formic acid in the hydrolyser. Depending how one reuses the purified process condensate one needs to take additional measures to avoid corrosion problems. For example, reuse as cooling water make-up may be possible without further treatment, while reusing is as boiler feed water for 40 bar steam will require further purification. One could send the purified process condensate to the inlet of the demi water section where the carbon filter and ion bed exchangers will take care of the formic acid.

Prem adds: The best answer was given by Mark. The formaldehyde and methanol are controlled by the ammonia plant: the formaldehyde formation is in the LT CO shift converter and the methanol is formed in the HT CO shift converter. Both come with the CO_2 feed. Generally, the methanol is separated in the CO_2 compressor interstage cooler with separators. In the urea plant itself there is nothing one can do except control the compressor inter stage temperatures so that maximum methanol / formaldehyde can be separated through separators.

Mark adds another suggestion: If you are injecting the HCHO as anti-caking agent for granulation/prilling section, it should normally be injected to the discharge of P8 and not P6, in this case you will have much less HCHO in your wastewater treatment section.

Nikhil Kamat from India also joins the discussion: What should the ammonia and urea content in the treated wastewater be if it is to be used as boiler feed water?

Prem replies: In our plant, the treated waste water contains about 2 to 3 ppm ammonia and 0.5 to 0.8 ppm urea. This treated water is directly sent to the demi water plant (cation/anion/mixed bed) and then used as boiler feed water. The turbine condensate and steam condensate are sent to the demi water plant for iron removal only i.e cation unit and then used as boiler feed water. ■

Methanol and shipping

Methanol continues to be a front runner among alternative fuels for the shipping industry. However, concerns remain over the availability and cost of green and blue methanol.

Methanol demand stands at just over 100 million t/a worldwide. The methanol industry has seen several major changes over the past few decades, as larger plants and lower production costs encouraged its take up first by the fuel and fuel derivatives markets, as an oxygenate in gasoline (MTBE) or LPG (DME), and then as an oil-free path to olefins and plastics production (MTO/MTP), with these new uses coming to outstrip the traditional chemical derivatives like formaldehyde and acetic acid. But now there is the promise of another step change as methanol becomes a preferred fuel for shipping, possibly leading to a four or five fold increase in methanol demand over the next two decades. This time, it is the use of low carbon methanol as a fuel which is the potential driving force.

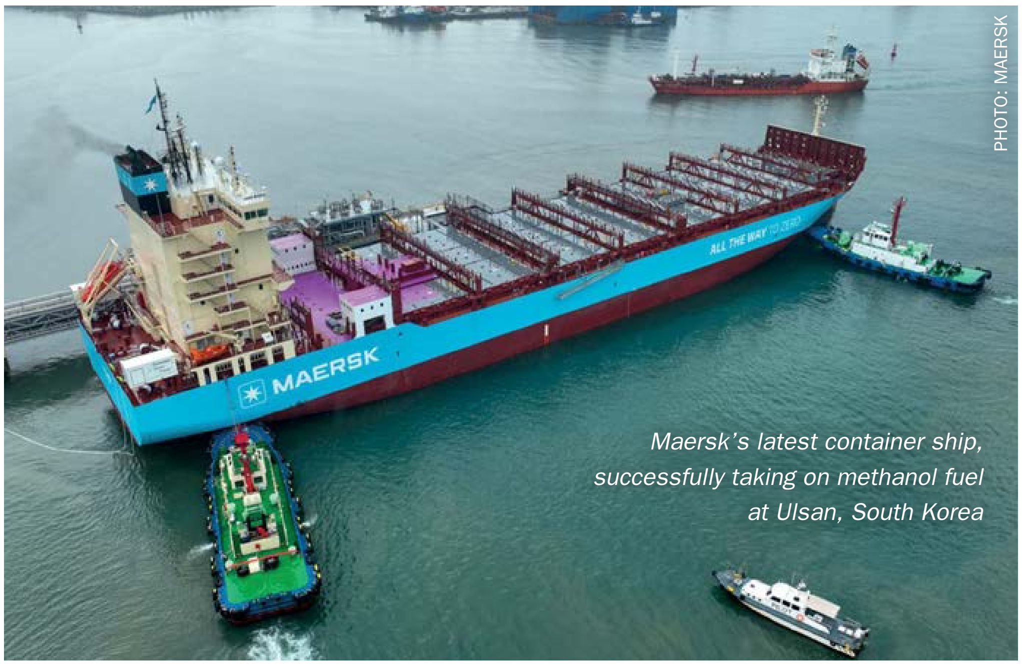


PHOTO: MAERSK

Maersk's latest container ship, successfully taking on methanol fuel at Ulsan, South Korea

Methanol as a fuel

Methanol has been used as a fuel extender by blending into gasoline, primarily in China, for some time. It has also been used as a shipping fuel by methanol producer Methanex for its fleet of tankers, operated by subsidiary Waterfront Shipping. However, it is regulatory pressure coming from the International Maritime Organisation (IMO), the UN body that regulates the shipping industry, which is leading to the current interest in methanol. The IMO has set the target of cutting the sector's carbon emissions by 40% in 2030 compared to 2008 levels. While there are numerous rival fuels, including low carbon ammonia, low carbon methanol has started to gain momentum after shipping giant Maersk began to focus upon it, arguing that: "it is the most mature from the technology perspective; we can get an engine that can burn it.". Other fuels still have to overcome hurdles of technical readiness, commercially available engines, and regulatory approval as well as availability.

Part of the push is that the way that the IMO measures emissions is changing. On a 'tank-to-wake' basis methanol – because it burns more cleanly – produces around 5-7% less CO_2 than marine gasoil (MGO), about 10% less than low sulphur fuel oil (LSFO) and up to 15% less than heavy fuel oil (HFO). But the IMO is moving towards measuring emissions on a 'well-to-wake' (i.e. life cycle) basis, encouraging the development and take up of green, renewable fuels.

Rapidly expanding demand

Stena Line has also been an early adopter, with the Stena Germanica car ferry operating in the Baltic on methanol. In 2022, the Proman Stena bulk joint venture vessels Stena Pro Patria and Stena Pro Marine became the first ships to bunker methanol in South Korea. Two more methanol powered bulk carriers: Stena Promise and Stena Prosperous, were completed in 2022, and two further vessels in 2023-24. Japanese shipbuilder Tsuneishi Shipbuilding is building a 67,500 dwt Ultramax bulk carrier capable of running on either methanol or conventional marine oil, with delivery planned in 2025. Mitsui E&S will provide the dual-fuel engine, expected to reduce emissions of NOx by 80%, sulphur dioxide by 99% and carbon dioxide by 10% compared to existing bunker fuels. Tsuneshi is also building two methanol-fuelled Kamsarmax bulk carriers for US-based trading firm Cargill. Qingdao Beihai and China Shipbuilding Development Company (CSDC) have brought forth a groundbreaking 250-meter long vessel, featuring an MAN ES two-stroke dual-fuel engine, equipped with methanol capability, and the Overseas Shipholding Group (OSG) has lined up four Alaskan-class tankers for lifecycle engine upgrades under a contract with Germany's MAN Energy Solutions. The vessels will see the 48/60 type engines refitted to include readiness for methanol fuel. Last year saw dozens more orders from shipping giants Evergreen, Wallenius Wilhelmsen, Ocean Network Express and COSCO Shipping.

But undoubtedly the greatest boost has come from Danish shipping giant Maersk. In January Maersk launched the first of 18 planned large methanol powered container ships from the Hyundai shipyard at Ulsan in Korea. The 16,200 teteu Ane Maersk will be deployed on Maersk's AE7 service between Asia and Europe from February. Maresk says that the vessel will be fuelled with green methanol for its maiden voyage and also says that it "continues to work diligently on sourcing green fuels for 2024 – 2025".

Maersk has also signed a memorandum of understanding with the City of Yokohama, and Mitsubishi Gas Chemical (MGC) for the development of green methanol bunkering infrastructure at Yokohama, Japan to help support Maersk's fleet of methanol powered vessels. Ulsan in Korea has also begun green methanol bunkering. Methanex and OCI NV have both estimated methanol demand for shipping in 2027-28 at 100-120 vessels and 3 million t/a of potential demand.

Advantages and disadvantages

Methanol has a number of advantages as a fuel compared to say, LNG, ammonia and hydrogen. Amongst the most persuasive is that it is a liquid at ambient temperatures and pressures, making it one of the easiest 'drop in' fuels available. It's also far less toxic than ammonia, spillages of methanol disperse harmlessly in water, and as an alcohol, it burns relatively cleanly with few particulates and no sulphur emissions. Methanol is also simpler to bunker, with a variety of supply options and established best practices and guidelines for bunkering. This means a lower up-front capex cost, as compared to e.g. LNG, which attracts a considerable premium due to expensive cryogenic fuel tanks and gas handling systems. Methanol is also a product with a highly diversified consumer base, widely available and transparently traded. Finally, although methanol has a lower energy density than hydrocarbon fuels and thus occupies a larger volume for a given amount of energy, on an energy equivalent basis methanol pricing has been competitive with marine gasoil for the past five years. It is also possible to fairly easily blend small volumes of green or blue methanol with grey to deliver short term greenhouse gas savings.

However, there is a cost premium for green methanol. The IEA puts a best cast cost of hydrogen production for methanol at current electricity and renewables prices of around $420 per tonne of methanol, with another $30-80/t for the carbon content. Add in the cost of synthesis, distribution, bunkering and presumably a profit margin, and it begins to look very expensive compared to current shipping fuels like very low sulphur fuel oil (VLSFO). Subsidies such as the US Inflation Reduction Act, which places a price of $3/kg on green hydrogen help make this a lot more affordable, but it remains to be seen how long the US government will be prepared to put this much public money into the industry, and ships will need to fuel outside the US.

Low carbon methanol

Blue methanol, i.e. conventional methanol produced in combination with carbon capture and storage, offers a lower emissions profile without adding as many of the costs, and is quickly becoming the preferred route to low carbon methanol, but there are a number of green methanol projects as well. The Methanol Institute has identified over 130 blue and green methanol projects around the world, but the largest capacity is coming from blue methanol. Some are already up and running, including a 110,000 t/a blue methanol plant in China using carbon capture co-designed by Carbon Recycling International, owners of the Iceland geothermal facility. There are a number of low carbon plants based on waste or biomass gasification and the 50,000 t/a FlagshipONE green methanol plant in Sweden which collectively could add another 1.0 million t/a out to 2026-7.

OCI Global is looking to double its green methanol production capacity to approximately 400,000 t/a, with plans including entering into supply agreements for more than 15,000 MMBtu/day of renewable natural gas (RNG), as well as securing the waste and development rights from the city of Beaumont, Texas, where OCI is building a large blue ammonia facility. Production of RNG is slated to start in Q1 2025. As well as reducing carbon dioxide emissions, obtaining biogas from landfill has the benefit of using methane that would otherwise escape and accelerate global warming.

Other projects are more speculative. There is a project being backed by a currently unnamed developer, Lake Charles Methanol II, which is looking at a $3.2 billion methanol plant using carbon capture and storage. This is the second iteration of Lake Charles Methanol, after a previous project at the site did not proceed almost a decade ago. While there is a tentative completion date of 2027, a final investment decision was due on the project in 2023, however this has now been pushed back to mid-2024. The developer insists that all of the financing is in place, but reportedly a $2 billion loan guarantee from the US Department of Energy remains under discussion. The is to use Topsoe autothermal reforming technology, as did the first version of the project, which was backed by Aquamarine Investment Partners (the investor behind developer First Ammonia). Excess carbon produced at the site would be transported off-site via a specially-built pipeline constructed by Exxon-owned CCS specialists Denbury, with which LCM II has a 20-year carbon transport and sequestration agreement.

At the COP 28 summit, an agreement to development a net zero world-scale methanol project in Mexico was announced, with the International Finance Corporation (IFC) – part of the World Bank– and Transition Industries signing the agreement to jointly develop the 6,000 t/d Pacifico Mexinol project. Around 300,000 t/a of this would be green methanol using renewable hydrogen, and the remaining 1.8 million t/a blue methanol from natural gas with carbon capture. A final investment decision is due to be reached this year, with commercial operations hoped to start in late 2027.

However, actual final investment decisions are proving more elusive, and some projects have gone by the board. Nauticol last year abandoned a similar blue methanol project in Alberta which had a price tag of $4 billion, citing delays due to the covid pandemic.

A shortage of methanol?

OCI has projected growth in the low carbon methanol market of incremental demand of more than 6 million t/a by 2028, due to the adoption of green methanol as a shipping fuel, based on the 225 dual-fuelled methanol vessels now on order. At the moment, however, it remains uncertain whether enough low carbon methanol projects will be completed by that time to fuel the ships. Maersk has conceded that it has "mountains to climb" to secure sufficient low carbon methanol to fuel its new fleet of ships. Having more demand than supply to meet it is a nice problem to have if you are a supplier, but it could harm methanol's uptake in the shipping industry in the longer term. This year looks to be a crucial one for approvals of blue and green methanol projects if targets are to be met. ■

North American nitrogen

The US is experiencing a new boom in nitrogen projects, with a number of carbon capture ammonia plants under development.

PHOTO: OCI

OCI's Beaumont site in Texas, showing ground cleared for the new blue ammonia facility.

Global ammonia capacity continues to grow. Capacity was assessed at 239 million t/a in 2023, but this could grow by another 15 million t/a to 254 million t/a by 2028 in terms of firm projects, and speculative projects could take that much higher. North America is the epicentre of many of these new projects, with abundant cheap shale gas and an established offshore oil industry in the Gulf of Mexico which can take sequestered carbon for enhanced oil recovery or other long term storage. There are already over 20 blue hydrogen to ammonia projects announced in the US, and while many will not get final investment approval, some already have. It could turn the US into the leading exporter of low carbon hydrogen within just a few years, depending upon how many of these projects come to fruition.

Carbon capture

Autothermal reforming (ATR) is becoming the preferred technology for carbon capture. Heat for the reaction is generated inside the reformer rather than the furnace typical for a steam methane reformer (SMR). This means that all of the carbon dioxide produced in the reaction is entrained in the process stream, making it easier to separate carbon from the feed and removing the need for flue gas treatment. However, it also requires an oxygen feed for the process, which means an expensive air separation unit (ASU). This is why most existing 'grey' ammonia capacity is based on less capital intensive SMR plants. For ammonia production, though, this does also mean that the ASU can be a source of nitrogen for the reaction. It is however why many of the new projects are centred around new ATR-based ammonia plants rather than conversions of existing SMR ammonia units.

Current projects

Of the raft of blue ammonia projects announced over the past couple of years, the one that is closest to completion is OCI's new 1.1 million t/a blue ammonia plant development at Beaumont, Texas, where the company already operates 300,000 t/a of ammonia and 1.4 million t/a of methanol capacity. One of the ways that OCI has shared the project risk is by subcontracting the plant's hydrogen supply to Linde. As a result, OCI is 'only' having to spend less than $1 billion on the ammonia synthesis section, with Linde – already a major supplier of hydrogen to a network of refineries and other industrial customers in the US Gulf Coast – supplying blue hydrogen 'over the fence' from a new clean hydrogen facility. Linde will build, own and operate a $1.8 billion on-site hydrogen complex which will include autothermal reforming with carbon capture, plus a large air separation plant to supply nitrogen to the ammonia plant and oxygen to the reformer. The new complex will be integrated into Linde's extensive Gulf Coast industrial gas infrastructure. Up to 1.7 million t/a of carbon dioxide will be sequestered. Ground was broken on the project in late 2022, and according to OCI it remains on course for start-up in 2025.

Other projects have yet to clear the FID hurdle, but many major players are actively involved in project development. CF Industries has announced a 52-48% tie-up with Mitsui to develop blue hydrogen and ammonia production, though of a slightly darker shade of blue, as only 60% of emissions are planned to be captured. The companies have secured a site in the US Gulf Coast and are looking at ammonia technology providers. CF Industries would operate the plant and Mitsui would offtake

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the ammonia and sell it into Japan and elsewhere in Asia. Front end engineering design was completed in 4Q 2023, and the companies are now looking at ways to reduce the project's carbon footprint further via two new studies, one evaluating autothermal reforming technology as an alternative, and a second looking at the cost and viability of adding flue gas capture to a steam reforming ammonia plant. Both FEED studies are expected to be completed in 2H 2024.

Last year BASF and Yara announced a collaboration on a 1.2-1.4 million t/a blue ammonia plant for the US Gulf Coast with 95% carbon capture. Yara would sell clean ammonia for fertilizer production and BASF would integrate it into its downstream chemical business. The two companies already jointly operate a conventional ammonia unit at BASF's Freeport, Texas site using hydrogen supplied by Praxair. The project is also at the FEED stage at present.

LSB Industries is partnering Japan's Inpex on a 1.1 million t/a blue ammonia project in the Houston Ship Channel, with KBR selected as ammonia technology supplier. A pre-FEED study is expected to be completed in 2Q 2024, with a full FEED study to follow. Also involved is Air Liquide, who will work with Inpex on syngas and hydrogen production using Air Liquide's autothermal reforming technology, and its own carbon capture technology. The project aims to capture at least 95% of direct CO2 emissions from hydrogen production with 1.6 million t/a of CO_2 captured and permanently sequestered from this project. Air Liquide would also be responsible for onsite nitrogen and oxygen production, using its own air separation unit technology. Inpex and Air Liquide have already worked together on a 700 t/a blue ammonia pilot project in Niigata, Japan, which started construction last year.

Other potential projects include Air Products in Ascension Parish, Louisiana. The $4.5 Louisiana Clean Energy Complex would feed into Air Products hydrogen pipeline network, which stretches from Texas City to New Orleans. Air Products said last year it was proceeding with the project, though there has been local opposition. Finally, and far more speculatively, St. Charles Clean Fuels, co-owned by Sustainable Fuels Group and Copenhagen Infrastructure Partners, is budgeting $4.6 billion for up to 8,000 t/d of blue ammonia production with 90% carbon capture.

Alternative to LNG

One possible driver for blue ammonia exports from America is the potential for restrictions to US LNG exports. President Biden recently paused new approvals for US LNG export projects, and it remains uncertain how long that pause will be for. If it continued into a second Biden term, for example, it might drive the expanding US gas industry to look for other ways to monetise its production, for example as ammonia. However, at present the pause is only for LNG projects aimed at exporting gas to countries that do not have a free trade agreement with the US, and will not affect any projects that are currently in operation or under construction. Donald Trump has also said that he would remove the restrictions "on day one" of a new term of office, if elected.

Do costs add up?

In spite of all of this project activity, though, it has not been all plain sailing for blue ammonia projects. Nutrien last year shelved plans for a $2 billion, 1.2 million t/a blue ammonia plant at its existing nitrogen complex in Geismar, Louisiana. The plant would have used autothermal reforming with carbon capture and storage to produce blue hydrogen from fossil gas with 90% emissions reduction. An offtake agreement was already in place with Mitsubishi for 40% of production. However, project costs had risen, and clearly the existing offtake agreement was not enough. In its notice suspending work on the project, Nutrien cited "continued uncertainty on the timing of emerging uses for clean ammonia", and said that there was not yet sufficient evidence to justify the assumption of a premium in the near term for low carbon ammonia. Even IRA tax credits "didn't get us over the hurdle in terms of the economics of the project at this point", according to Trevor Williams, Nutrien's president for nitrogen and phosphates. ExxonMobil is likewise backing away from a blue hydrogen project at its Baytown refinery in Texas, saying IRA credits for blue hydrogen are not sufficient to justify the investment.

The US inflation reduction act (IRA) has helped kickstart this tsunami of blue ammonia via its 45Q tax credit. This offers producers $85/t of CO_2 sequestered geologically in deep gas basins, or $50/t of CO_2 used for enhanced oil recovery (EOR). At present, it is likely that most of the CO_2 generated in these plants will be used for EOR.

CRU estimates that the additional cost of carbon capture and storage for blue ammonia production increases the cost by around $120/tonne ammonia. Producing one tonne of ammonia generates between 1.6 and 3.2 tonnes of carbon dioxide, depending on the technology. For autothermal reforming it is 1.6 tonnes/tonne NH_3, for steam reforming around 1.8 tonnes/tonne, and the highest figures are for coal gasification. This means that 45Q is only crediting producers with $76/t ammonia if they use the ATR route and capture 95% of emissions (although this figure goes up to $129/t for geological storage). The gap between the tax credit and the additional cost of production means that blue ammonia must be regarded by consumers as a premium product for which they are willing to pay an additional premium. Enhanced oil recovery is a way of recovering some cost – around $40/t CO_2, or about $60/t ammonia, again meaning that in theory the process breaks even. But it means that costs can be quite marginal and there are all kinds of variables – the distance that the CO_2 must travel to be pumped, the nature of the underground field and expected rates of oil recovery etc.

On the demand side, it remains to be seen whether low carbon fertilizers can charge an additional premium, and that depends upon food retailers being able to differentiate products made with them to consumers. This is likely to be a longer term process and unlikely to make farmers pay more in the short term. On the other hand, power plant operators in e.g. Japan and ship owners are more of a captive market, in that they must use a low carbon fuel, and if they have engines or plants designed to run on ammonia, they have little choice but to buy low carbon ammonia at the going rate.

Likewise, cheap US gas costs mean that carbon taxes such as Europe's CBAM mean that blue producers could have a ready premium market just across the Atlantic. But this may depend upon producers meeting more stringent EU regulations on exactly how low carbon the blue ammonia is; carbon capture rates of 60% may not cut it with European authorities. This is still an evolving market, and how customers value low carbon ammonia and what additional value they put on it could be critical to some of the large investment decisions coming up, and whether they pay off. ■

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Nitrogen project listing 2024

Nitrogen+Syngas's annual listing of new ammonia, urea, nitric acid and ammonium nitrate plants.

Contractor	Licensor	Company	Location	Product	mt/d	Status	Start-up date
AUSTRALIA							
Daelim	KBR	NeuRizer	Leigh Creek, SA	Ammonia	1,600	DE	2027
Daelim	Stamicarbon	NeuRizer	Leigh Creek, SA	Urea	2,850	DE	2027
Technip FMC	Topsoe	Strike Energy	Geraldton, WA	Ammonia	2,400	DE	2027
Technip FMC	Saipem	Strike Energy	Geraldton, WA	Urea	4,200	DE	2027
Saipem, Clough	Topsoe	Perdaman	Karratha, WA	Ammonia	3,500	UC	2027
Saipem, Clough	Saipem, TKFT	Perdaman	Karratha, WA	Urea	2 x 3,100	UC	2027
n.a.	KBR	H2Perth	Kwinana, WA	Ammonia	1,800	DE	2027
n.a.	n.a.	CSBP	Kwinana, WA	Ammonia	900	P	2028
n.a.	Topsoe	Allied	Gove, NT	Ammonia	2,500	FS	2029
BANGLADESH							
MHI, CNCIC	Saipem, TKFT	BCIC	Ghorasal Polash	Urea	2,800	C	2023
BULGARIA							
Casale	Casale	Agropolychim	Devnya	Nitric acid	n.a.	DE	2027
Casale	Casale	Agropolychim	Devnya	Ammonium nitrate	n.a.	DE	2027
CANADA							
Black & Veatch	Stamicarbon	Confidential	n.a.	Urea	+300	RE	2024
CHILE							
TOYO	KBR	HyEx	Tocopilla	Ammonia	55	DE	2025
Wood Group	n.a.	Total Eren	San Gregario	Ammonia	2,600	FS	2027
CHINA							
n.a.	Casale	Henan Jindadi	Luohe, Henan	Ammonia	1,800	UC	2024
n.a.	Casale	Jiangsu Huachang	Zhangjiagang	Ammonia	1,800	UC	2024
n.a.	Casale	Henan Shenma Nylon	Pingdingshan	Ammonia	1,200	UC	2024
n.a.	Stamicarbon	Shandong Lianmeng	Dongping, Shandong	Urea	2 x 2,330	DE	2024
n.a.	Stamicarbon	Henan Xinlianxin	Jiangxi	Urea	2,330	UC	2024
n.a.	Topsoe	Mintal HET	Baotou, Mongolia	Ammonia	1,800	CA	2025
n.a.	Casale	Hubei Jinjiang	Jingzhou, Hubei	Ammonia	2,000	UC	2024
n.a.	Casale	Jiangsu Jinmei	Xuzhou	Ammonia	2,000	UC	2024
n.a.	Casale	Shanghai Huayi	Shanghai	Ammonia	860	DE	2025
n.a.	Casale	Anhui Haoyuan	Fuyang, Anhui	Ammonia	1,540	DE	2025
n.a.	Stamicarbon	Jiangsu Huachang	Zhangjiagang	Urea	1,860	DE	n.a.
n.a.	Stamicarbon	Xinjiang Xinji	Xinjiang	Urea	3,800	DE	2026
n.a.	Stamcarbon	Shaanxi Shanhua	Weinan	Urea	n.a.	RE	n.a.
n.a.	Stamicarbon	Jiangxi Xinlianxin	Jiujuang, Jiangxi	Urea	3,850	DE	2027
DENMARK							
n.a.	n.a.	CIP	Esbjerg	Ammonia	1,810	FS	2028
EGYPT							
thyssenkrupp IS	thyssenkrupp IS	MOPCO	Damietta	Ammonia	3 x 113%	RE	n.a.
thyssenkrupp IS	thyssenkrupp IS	MOPCO	Damietta	Urea	3 x 113%	RE	n.a.
Tecnimont/Orascom	Espindesa	Kima	Aswan	Nitric acid	600	DE	2026
Tecnimont/Orascom	Espindesa	Kima	Aswan	Ammonium nitrate	800	DE	2026
n.a.	n.a.	Scatec	Ain Sokhna	Ammonia	210	DE	2026
n.a.	n.a.	AMEA Power	Ain Sokhna	Ammonia	910	DE	2027
n.a.	Stamicarbon	NCIC	Ain Sokhna	Urea	1,050	DE	n.a.
GERMANY							
n.a.	Topsoe	First Ammonia	Wilhelmshaven	Ammonia	300	P	2025

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Contractor	Licensor	Company	Location	Product	mt/d	Status	Start-up date
HUNGARY							
Casale	Casale	BorsodChem	Kazincbarcika	Nitric acid	1,360	UC	2026
INDIA							
TOYO	KBR	Deepak Fert & Chem	Taloja	Ammonia1,500	C	2023	
thyssenkrupp IS	thyssenkrupp IS	Deepak Fert & Chem	Vadodara	Nitric acid250	C	2023	
n.a.	Casale	Deepak Fert & Chem	Gopalpur	Nitric acid900	UC	2024	
n.a.	Casale	Deepak Fert & Chem	Gopalpur	Ammonium nitrate	970	UC	2024
n.a.	n.a.	Deepak Fert & Chem	Dahej	Nitric acid1,450	DE	2026	
Wuhuan Engineering	KBR	Talcher Fertilizers	Talcher	Ammonia2,200	UC	2025	
Wuhuan Engineering	Stamicarbon	Talcher Fertilizers	Talcher	Urea 3,850	UC	2025	
n.a.	n.a.	ACME	Mangalore	Ammonia360	P	n.a.	
Larsen & Toubro	Casale	Chambal Fert & Chem	Gadepan	Nitric acid600	RE	2025	
Larsen & Toubro	Casale	Chambal Fert & Chem	Gadepan	Ammonium nitrate	700	RE	2025
INDONESIA							
n.a.	Casale	PT Pupuk Kalimantan	Bontang	Ammonia	1,800	RE	2025
Wuhuan	KBR	PT Pupuk Sriwidjaja	Palembang	Ammonia	1,350	BE	2027
Wuhuan	TOYO	PT Pupuk Sriwidjaja	Palembang	Urea	2,750	BE	2027
IRAN							
PIDEC	Topsoe	Hengam Petrochemical	Assaluyeh	Ammonia2,050	C	2023	
PIDEC	Saipem, TKFT	Hengam Petrochemical	Assalyueh	Urea 3,500	C	2023	
Namvaran	KBR	Kermanshah Petchem	Kermanshah	Ammonia2,400	UC	2024	
Namvaran	Stamicarbon	Kermanshah Petchem	Kermanshah	Urea 2,000	UC	2024	
Hampa	Casale	Zanjan Petrochemical	Zanjan	Ammonia2,050	UC	2024	
Hampa	Stamicarbon	Zanjan Petrochemical	Zanjan	Urea 3,600	UC	2024	
ISRAEL							
Saipem	Topsoe	Haifa Chemicals	Mishor Rotem	Ammonia	300	UC	2024
n.a.	KBR	Haifa Chemicals	Mishor Rotem	Nitric acid	+35%	RE	2024
KAZAKHSTAN							
Tecnicas Reunidas	n.a.	KazAzot	Aktau	Ammonia	2,000	CA	2027
Tecnicas Reunidas	n.a.	KazAzot	Aktau	Urea	1,750	CA	2027
Tecnicas Reunidas	n.a.	KazAzot	Aktau	Nitric acid	1,200	CA	2027
Tecnicas Reunidas	Espindesa	KazAzot	Aktau	Ammonium nitrate	1,500	CA	2027
MEXICO							
thyssenkrupp IS	thyssenkrupp IS	Proman	Topolobampo	Ammonia	2,200	DE	2027
NIGERIA							
n.a.	n.a.	OCP	Tarfaya	Ammonia	3,300	P	2027-30
NORWAY							
n.a.	Topsoe	Barents Blue	Markoppneset	Ammonia	3,000	DE	2028
n.a.	Technip	Iverson eFuels	Sauda	Ammonia	600	P	2029
OMAN							
n.a.	KBR	Green Hydrogen & Chem	Duqm	Ammonia	300	UC	2025
POLAND							
n.a.	Casale	Grupa Azoty	Kedzierzyn	Urea	780	RE	2023
QATAR							
thyssenkrupp IS	thyssenkrupp IS	Qafco	Mesaieed	Ammonia+CCS	3,500	BE	2027
RUSSIA							
CNCCC	Topsoe	ShchekinoAzot	Pervomayskyy, Tula	Ammonia	1,500	UC	n.a.

KEY

BE: Basic engineering	*DE: Design engineering*	*P: Planned/proposed*	*Conversion:*
C: Completed/commissioning	*FS: Feasibility study*	*RE: Revamp*	*1 t/d of hydrogen = 464 Nm³/h*
CA: Contract awarded	*n.a.: Information not available*	*UC: Under construction*	*1 t/d of natural gas = 1,400 Nm³/d*

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Contractor	Licensor	Company	Location	Product	mt/d	Status	Start-up date
CNCCC	Stamicarbon	ShchekinoAzot	Pervomayskyy, Tula	Urea	2,000	UC	n.a.
NIIK	Casale	JSC Metafrax	Gubakha	Ammonia	1,000	C	2023
NIIK	Casale/MHI	JSC Metafrax	Gubakha	Urea	1,700	C	2023
Tecnimont	KBR	EuroChem	Kingisepp	Ammonia	3,000	UC	On Hold
Tecnimont	Stamicarbon	EuroChem	Kingisepp	Urea	4,000	UC	On Hold
SAUDI ARABIA							
Larsen & Toubro	Topsoe	Neom	Neom	Ammonia	3,500	UC	2026
SOUTH KOREA							
n.a.	KBR	Hanwha	Yeosu	Nitric acid	1,200	UC	2025
SPAIN							
n.a.	n.a.	Iberdrola	n.a.	Ammonia	330	P	2026
TURKEY							
Tecnimont	Stamicarbon	Gemlik Gubre	Gemlik	Urea	1,640	C	2023
Tecnimont	n.a.	Gemlik Gubre	Gemlik	UAN	500	C	2023
UNITED STATES							
n.a.	Stamicarbon	Confidential	n.a.	Urea	+1180	RE	2025
n.a.	Stamicarbon	Confidential	n.a.	Urea	1500	CA	2025
n.a.	KBR	Monolith Materials	Hallam, Nebraska	Ammonia	830	DE	2025
Tecnimont	KBR/Linde	OCI	Beaumont	Ammonia+CCS	3,300	UC	2025
n.a.	Topsoe	Air Products	Ascension, LA	Ammonia+CCS	n.a.	DE	2026
n.a.	n.a.	CF Industries	Donaldsonville	Nitric acid	n.a.	RE	2025
n.a.	n.a.	First Ammonia	Victoria, TX	Ammonia	300	DE	2026
thyssenkrupp IS	thyssenkrupp IS	Nutrien	Geismar, LA	Ammonia+CCS	3,500	DE	On hold
thyssenkrupp IS	thyssenkrupp IS	CF Industries	US Gulf Coast	Ammonia+CCS	3,300	DE	2027
KT-Kinetics Tech	Stamicarbon	Confidential	n.a.	Ammonia	450	CA	2026
n.a.	Topsoe	Proman/MHI	Lake Charles, LA	Ammonia+CCS	3,600	DE	2030
UNITED ARAB EMIRATES							
thyssenkrupp IS	thyssenkrupp IS	Fertiglobe	Ruwais	Ammonia	x125%	RE	FS
UZBEKISTAN							
n.a.	Casale	Ferkensco	Karakul	Ammonia	1,500	UC	2026
n.a.	Casale	Ferkensco	Karakul	Urea	1,800	UC	2026

KEY
BE: Basic engineering
C: Completed/commissioning
CA: Contract awarded
DE: Design engineering
FS: Feasibility study
n.a.: Information not available
P: Planned/proposed
RE: Revamp
UC: Under construction

Conversion:
1 t/d of hydrogen = 464 Nm³/h
1 t/d of natural gas = 1,400 Nm³/d

Pictured, right: The site for Proman's new Topolobampo ammonia plant, Mexico.

PHOTO: PROMAN

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Nitrogen+Syngas 2024

A summary of papers presented at CRU's Nitrogen+Syngas conference, this year held at the Gothia Towers in Gothenburg, Sweden.

Gothenburg city in Sweden

PHOTO: ANDERM/SHUTTERSTOCK.COM

CRU's Nitrogen+Syngas conference continues to provide a meeting ground for the nitrogen and allied syngas-based industries like methanol, combining market presentations from CRU's own team of analysts with a large number of technical papers covering all aspects of the industry. Meeting at the Gothia Towers hotel and conference centre in the Swedish port city of Gothenburg once again this year, attendance was just under 600, and the accompanying exhibition was full with all 88 stands occupied.

Nitrogen markets

The first day was given over to a series of short technical showcase presentations in the morning, and a number of market and commercial papers in the afternoon. The first paper was of course the nitrogen market overview, this time presented by CRU's new lead Mony Belon. Major gas benchmarks continue to fall, she said, and gas storage in the EU is at very high levels. There is more secure supply, and demand has fallen, leading to rising confidence in energy security in Europe. Ammonia prices are close to historical averages, back down after the spike following the Russian invasion of Ukraine. While up to 70% of EU ammonia capacity was shuttered in September 2022, this had fallen to 19% by September 2023, and while there have been some more closures bringing off-line capacity to 39% in January 2024, downstream nitrogen margins remain positive for ammonium nitrate production in the EU, and around zero for ammonia and urea for the next few months.

Most new nitrogen capacity additions are based on lower carbon supply – the pipeline for traditional ammonia production seems to be drying up, although some of the additional ammonia export availability in 2024 is coming from Russia as export becomes easier again. Incremental new merchant ammonia capacity is also coming onstream in the US (1.3 million t/a), Trinidad (600,000 t/a), and the Middle East (500,000 t/a).

On the downstream side, urea prices have followed the downward trend of gas and ammonia inputs. Russia remains essentially unhindered from exporting urea, with exports of 8.5 million t/a in 2023 and a similar figure likely for 2024. Another 4.7 million t/a of urea capacity is due to commission in 2024, mostly (3.2 million t/a) in China, as well as 0.8 million t/a in Russia. Indian imports continue to decline as new capacity comes onstream,. Indian production has risen 3.6 million t/a from 2022-24. Conversely, Brazil continues to rely heavily on imports and there is an optimistic outlook for crop production and urea demand. Brazil is becoming the largest global importer of urea, up to 7-8 million t/a. New urea import demand will come from Brazil, Argentina, Africa, Australia and the US.

Low carbon production

Marina Simonova, now with OCI, gave a producer's perspective on lower carbon ammonia. The company is developing its new Texas Blue Clean Ammonia project, which will have a capacity of 1.1 million t/a when it starts up in the first half of 2025. OCI is also expanding its ammonia import terminal in Rotterdam to accept cargoes from overseas, with capacity rising from 400,000 t/a to 600,000 t/a and ultimately 2 million t/a. It is also doubling green methanol capacity to 400,000 t/a via a renewable natural gas pathway with green hydrogen from New Fortress Energy and biogenic carbon dioxide using biogas from the Beaumont City landfill site. At Beaumont, 95% of carbon dioxide will be captured and directed via a partnership with Linde and ExxonMobil for enhanced oil recovery in the US Gulf. OCI is also developing a low carbon ammonia value chain. It has signed a supply agreement with Rohm to supply low carbon ammonia for methyl methacrylate production, and is looking at ISCC+ certification.

Looking to the future, Marina saw demand for low carbon ammonia being driven by regulatory frameworks which are leading to use in power generation in Japan and Korea, demand for maritime fuel, and as a hydrogen carrier – Europe may need additional hydrogen volumes to meet its 2030 RePower targets. At present, global nitrogen trade (for all ammonia derivatives) stands at 115 million t/a ammonia equivalent, about half of this as urea. By 2030, the 19 million t/a of traded merchant ammonia may have nearly doubled to 18 million t/a of conventional ammonia and 15 million t/a of low carbon ammonia, and looking out to 2050, grey ammonia trade will be minimal and low carbon ammonia trade could reach 80 million t/a.

Eric van Dijk of TNO presented a different angle on low carbon nitrogen production, using carbon captured from steel production to make urea. The EU INITIATE project takes basic oxygen furnace gas (BOFG) from steel making – a mixture of carbon monoxide, nitrogen and water - and combines it with green hydrogen in a process called SEWGS – sorption enhanced water gas shift; a TNO development – which combines carbon dioxide separation with a shift reaction. The CO$_2$ is then partly sequestered while the hydrogen and nitrogen are used in a Stamicarbon green ammonia converter using JM catalysts, then more CO$_2$ is passed back to urea production. A 2.5 t/d pilot plant reactor is being developed, with the project aiming to ultimately make a bankable case for a 50,000 t/a demonstrator unit. The basic oxygen furnace is a batch process, leading to a dynamic feed to the reaction, and one of the INITIATE project goals is dealing with this dynamic feed composition.

Rob Stevens of Topsoe and Horisont Energi looked at some of the forecasts for green ammonia and methanol demand over the next 25 years. Increasing low carbon methanol demand is likely to run ahead of the ability to supply biogenic carbon to manufacture it. Topsoe is looking at alternative pathways, including green Fischer-Tropsch and green methanol production using captured carbon. Horizont Energi is developing the Barents Blue ammonia plant, which will capture 99% of carbon emissions. A final investment decision is expected late this year or early next, with production of 1 million t/a by 2029.

Oksana Melnyk of the German Society for International Cooperation (GIZ) highlighted the work of the German federal government in encouraging sustainable production and use of fertilizers. On the nitric acid side, it has encouraged the installation of nitrous oxide abatement technology via the Nitric Acid Climate Action Group (NACAG), as N_2O emissions offer a significant source of CO_2 equivalent emissions (around 100 million t/a) which can be abated with relatively cheap technology (around 1-3 euros per tonne of CO_2 equivalent). GIZ has supported nine nitric acid plants with grants totalling 20 million euros and abated 2.2 million t/a of CO_2e. There are also ongoing tender processes in Jordan and Columbia and work continues with Thailand, Georgia and Uzbekistan. However, it is also working on a range of other issues across green hydrogen, food security, 'smart' farming etc.

Production costs

CRU's Charlie Stephen presented an overview of ammonia costs, beginning with a review of gas costs, especially in Europe, over the past few years. The average cost of ammonia production in Europe is expected to fall from its present level of around $390/t this year to around $350/t in 2028. Some of this fall is due to falling feedstock costs as new LNG export capacity worldwide, especially in the US, but also Qatar (and some – for the global market – from Russia) lowers the cost of gas imports. This will bring EU ammonia production costs below the level of Indian and Chinese producers.

Meanwhile, there is continuing pressure to reduce emissions and carbon taxes and trade schemes continue to proliferate. Chinese coal-based production remains the largest carbon emitter. The EU carbon dioxide price is rising as the number of free allowances decreases. By the 2030s, it could reach $160/t, and could add $165/t to the cost of ammonia production by 2028. However, delivered costs to the EU from the US will be lower than domestic European production costs even taking into account the carbon border adjustment mechanism (CBAM).

Low carbon ammonia applications could double the market for ammonia by 2050, but project announcements are not attracting finance and final investment decisions outside of the US where the 45Q tax credit has made a different. High costs for green ammonia means that additional incentives will be needed for a large scale uptake.

Pranshi Goyal of CRU looked at urea costs. The key exporting regions remain the Middle East, North Africa and Nigeria, Russia, China, and Southeast Asia. Europe, the largest regional importer, has been the marginal cost producer of urea since 2021. While costs have come down from their 2022 peak, they remain above the cost of Chinese coal-based production, which had been the marginal cost production capacity beforehand. Looking to the future, carbon costs will have an increasing impact on production costs, but Pranshi did not foresee a major change in trade flows due to Europe's carbon border adjustment mechanism. Nevertheless, it seems that Europe may become a premium paying market for urea.

Technical papers

With more than 90 papers in three parallel streams across two days, it would be impossible to mention all of the technical papers, but the following is a sample. Of note were the continuing improvements in process control and the use of AI and machine learning systems to improve plant operation.

Ammonia technology

Perhaps unsurprisingly the ammonia technology session focused on green ammonia production, and specifically the challenges of dealing with a variable energy feed from wind or solar power when running a continuous process like ammonia conversion. Total and EREN have are developing a large scale green ammonia plant at Magellanes in Chile using local off-grid wind power. The plan envisages a hydrogen powered power generation unit to cope with periods of low wind energy.

Kinetics Technology meanwhile has been experimenting with compressed air storage of energy to balance peaks and troughs of energy production as part of their GALCES (Green Ammonia Liquid and Continuous Energy Supply) process, which incorporates Green Ammonia Technology from sister company Stamicarbon. The heat from compression is integrated into the process including the air separation unit for producing stoichiometric quantities of nitrogen for the reaction.

KBR has been working with electrolyser supplier SolydEra to develop its K-Green ammonia process. SolydEra's stacks are used reversibly as electrolysers and fuel cells to balance power and hydrogen generation, which allows for more flexibility in operation and a reduction in the total investment cost of the plant by reducing the need for battery energy storage.

Topsoe looked at some of the problems in running dynamic ammonia synthesis. Lower flows of hydrogen mean that a recirculating synthesis loop must be used, but higher conversion rates can lead to lower pressure and stress fatigue from pressure changes. Topsoe's green ammonia loop can dynamically adjust its load by 3% per minute and operate reliably over sustained periods with loads as low as 10% of nameplate capacity. This dynamic flexibility results in greater uptime and less need for costly storage solutions for reserve supplies of green hydrogen or renewable power.

JM and Fertiberia have been experimenting with a side stream feed to Fertiberia's ammonia plant at Puertellano in Spain using hydrogen from a 20 MW electrolyser. The addition of hydrogen and stoichiometric quantities of air and the use of JM's higher activity Katalco 74-1 promoted synthesis catalyst means that the reformer can be run at lower duty, reducing gas consumption. A new monitoring and control too, the AMMCON Dashboard, has also helped with integrating the ammonia feed and optimising plant operating conditions.

Air Liquide has been working with KBR and Clariant on an autothermal based low carbon ammonia scheme, and updated the conference on work showcased last year. Johnson Matthey likewise use either a standalone ATR or an ATR coupled with a gas heated secondary reformer for their Leading Concept for Hydrogen (LCH) process, and this was also presented.

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Ammonia cracking

Ammonia's potential use as a carrier for hydrogen means that it must be broken down back into its components at the other end of the supply chain, and several papers looked at this process, the first session focusing on the catalysts required to accelerate the reaction. Casale showcased their MACH2 (Mega Ammonia Cracking for H_2) technology. It is open to the use of both nickel or ruthenium based catalysts – the former is cost competitive but requires high temperatures and higher capex, the latter can use lower temperatures but is more expensive. Catalyst choice is on a case by case basis. Casale is offering it in capacities of up to 1,300 t/d of hydrogen production.

Enercat is pursuing the ruthenium catalyst route, with alkali metals best as dopants, such as potassium or calcium oxide. A large megapore distribution leads to improved ammonia diffusion. Rare earth metal oxides such as cerium oxide as ruthenium carriers show promising benefits for the ammonia cracking reaction. Research work continues. Heraeus likewise has been experimenting with ruthenium catalysts and a number of different dopants.

KBR is developing its H2ACT process for hydrogen production up to 1,200 t/d, working with Clariant on the catalyst side. The process uses proven nickel catalyst at higher temperatures (>700°C).

Finally, Technip described a low intensity ammonia cracking process with recuperative high-grade heat recovery to sustain the cracking reaction. The design of the recuperative catalyst tube achieves higher throughput and higher heat recovery compared to a conventional pellet-packed tubular reactor layout.

Methanol

Toyo presented its g-Methanol (green methanol) technology, which uses direct synthesis from carbon dioxide and hydrogen. The Japanese government expects low carbon methanol to be used as a fuel and a chemical feedstock as part of its green transition strategy. At the moment there is a 10 t/d demonstrator plant for the process under construction in India, due for startup in 2Q 2024, using Toyo's proven MRF-Z reactor. Toyo is targeting full commercialisation in 2026, with a proposed scale up to 300-600 t/d, and has a Methamaster program which can optimise grid feed, battery or hydrogen storage to deal with fluctuating feeds based on the lowest levelized cost of methanol for any given site.

Clariant are offering a promoted version of their MegaMax catalyst series, MegaMax 900 DCARB, with even higher activity, for methanol synthesis from carbon dioxide as part of green methanol plants.

Urea technology

Green feeds are typically smaller than the world scale plants that gas-based ammonia production can offer. So Saipem presented a smaller scale modular urea plant design optimised for green ammonia feeds, down to 100 t/d, or blue feeds using an enzyme-based carbon capture system.

Stamicarbon, conversely, looked to an ultra-low energy reactor for large capacity urea plants, expanding the existing ULE concept from plant sizes of 2,000-2,500 t/d up to 3,850 t/d.

Casale offered HYPER-U, a new high efficiency self-stripping urea process which lowers the demand on medium-pressure steam and cooling water. The main innovation consists of an additional carbamate decomposition step upstream of the conventional medium pressure section.

Nitric acid

Umicore discussed the recent spike in the price of rhodium and looked at ways of reducing rhodium content in nitric acid catalyst to reduce cost. The laboratory work also managed to increase selectivity to produce less N_2O and increase yield for ammonia conversion by 1%, leading to potential savings.

Heraeus presented two cases of back flow in nitric acid converters, in the first case from time delays in valve openings and in the second due to leakage from the superheater, and recommended strategies for mitigating these faults and cleaning contaminated gauzes.

Abu Qir experienced a pressure drop in their EnviNox tail gas treatment unit, increasing over several weeks following a restart. It transpired that long service had led to creep and elongation of bolts holding the catalyst basket, leading to leakage of catalyst from the basket and broken catalyst entering the expander. The basket was re-welded and the catalyst replaced.

Finally, NobelClad described their explosive weld technique for coating steels with thin layers of protective coatings for corrosion resistance, including tantalum and zirconium cladding and super ferritic 470LI steel with low nickel content which offers good performance in urea and nitric acid environments. ■

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Reducing emissions in nitric acid production with tertiary abatement

To comply with environmental legislations, all new and most existing nitric acid plants must implement measures to reduce N_2O emissions to the atmosphere. This article explores the opportunities presented by Stamicarbon's tertiary abatement technology for both existing and grassroots nitric acid plants to enhance sustainability and efficiency and discover the advantages of incorporating these technologies into a green fertilizer complex.

Stefano Cicchinelli, Paz Muñoz, Carmen Perez, (Stamicarbon)

Like most industries, the fertilizer industry strives to reduce greenhouse gas emissions. Besides developing new technologies to achieve this, traditional technologies are evolving to cope with the climate goals to reduce environmental impact while meeting the latest emission regulations.

Existing greenhouse gas emissions regulations

The number of systems and initiatives for emission regulations worldwide is increasing as countries work to achieve the climate goals set in the Paris Agreement adopted by 196 parties at the UN Climate Change Conference in Paris. In the EU and several other regions of the world, Emission Trade Systems (ETS) are in place to regulate the amount of CO_2 emitted by companies, but also other GHG emissions – specifically nitrous oxide (N_2O) and perfluorocarbons (PFCs). In countries with an ETS in place, carbon credits are awarded to companies, allowing them to emit a fixed amount of carbon dioxide or the equivalent amount of another greenhouse gas.

With the need to reduce emissions, abatement systems that remove hazardous gases from the exhaust stream of processes, are getting more important. Many existing plants do not have such systems and still need to comply with environmental regulations. A tertiary abatement reactor provides a solution by removing nitrous oxide (N_2O) and nitrogen oxides (NOx) from the tail gas produced by nitric acid plants.

Nitric acid technology

Nearly all industrially produced nitric acid is manufactured by the high-temperature catalytic oxidation of ammonia (the Ostwald process) in two main steps:

- the oxidation of ammonia (NH_3) to form nitric oxide (NO), which is further oxidised to nitrogen dioxide (NO_2);
- the absorption of the nitrogen dioxide (NO_2) in water (H_2O) to form nitric acid (HNO_3).

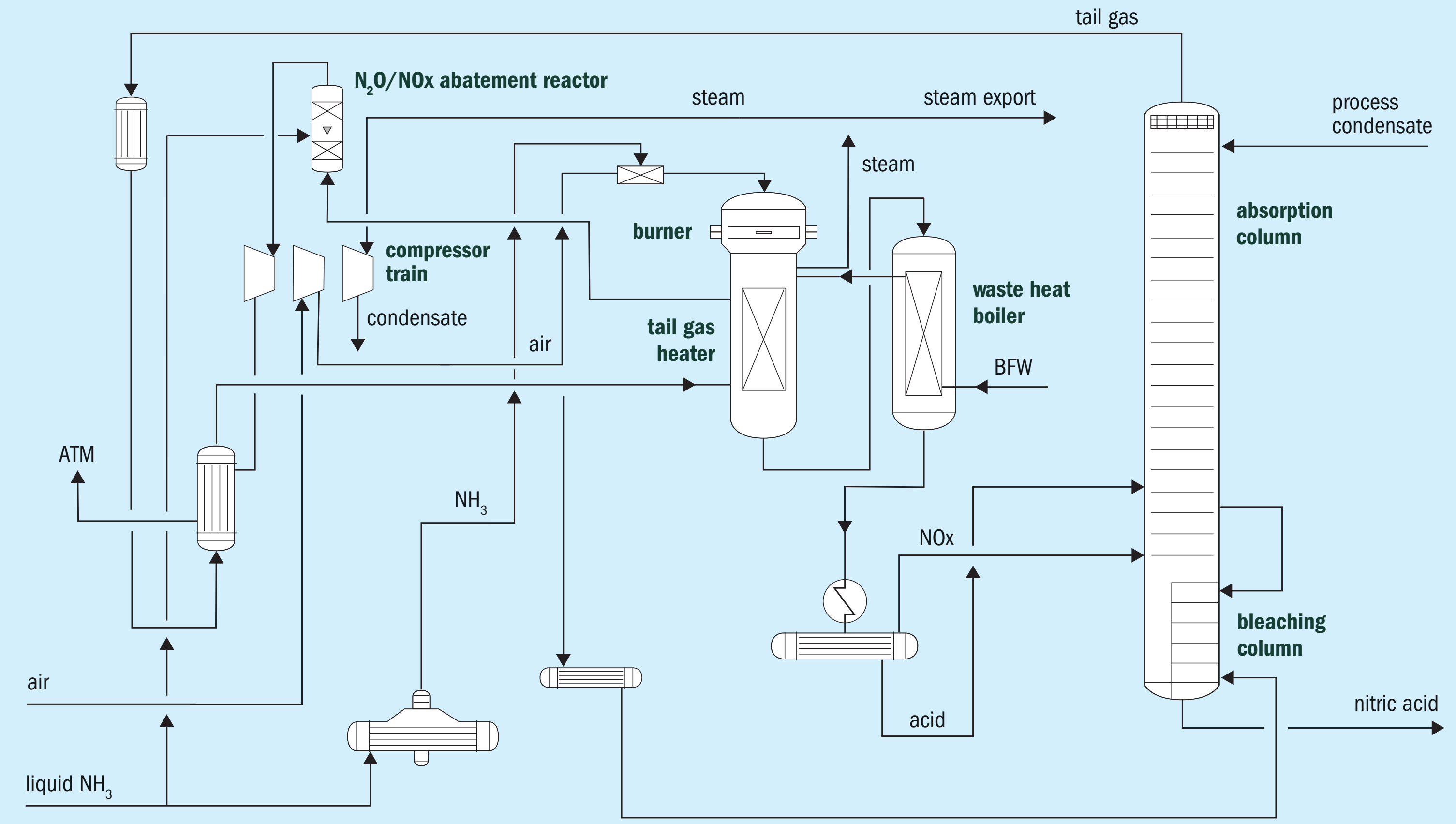
Stamicarbon, the nitrogen technology licensor of the MAIRE engineering group, offers its proven mono- or dual-pressure design. In the mono-pressure process (see Fig. 1), oxidation and absorption sections operate at the same pressure level. Different pressure levels are used for the oxidation and absorption sections in the dual-pressure process (see Fig. 2). The oxidation section is operated at pressures between 4 and 6 bar(a), while the absorption section operates between 8 and 12 bar(a), combining the advantages of medium-pressure combustion with the efficiency of high-pressure absorption.

The main characteristic of both processes is a specific heat exchanger network downstream of ammonia oxidation. This configuration has several advantages. The heat exchanging network has specific process conditions selected to prevent corrosion and ensure that no proprietary materials are required for equipment manufacturing.

In addition to using standard stainless steel in place of special materials, another key advantage of Stamicarbon's nitric acid technology is its high energy efficiency. The process is designed to minimise heat losses and maximise heat recovery from the process streams. This decreases the internal consumption of steam and lowers the operational costs.

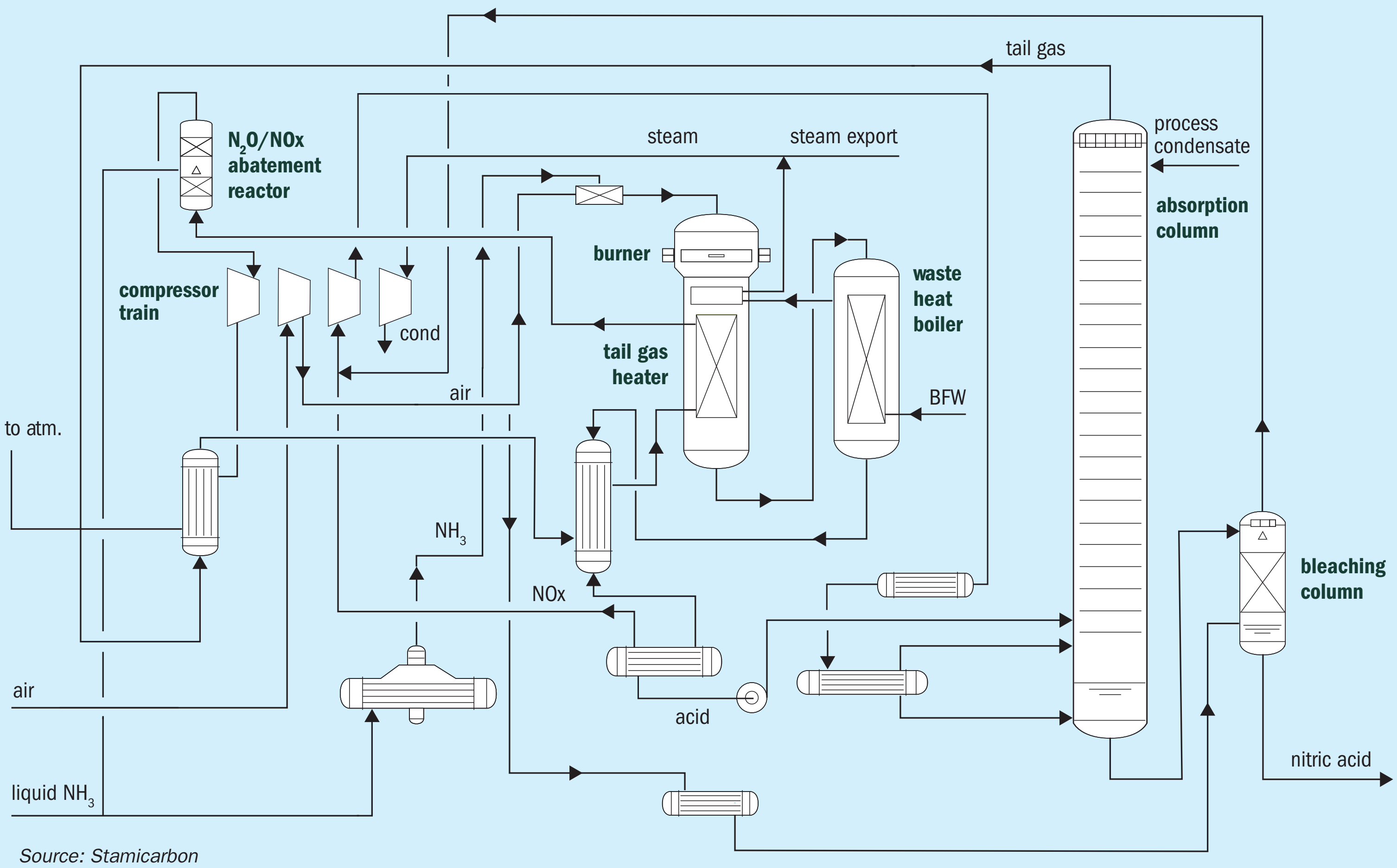
Stamicarbon's nitric acid technology is also designed with environmental concerns in mind. The technology incorporates measures to minimise emissions of greenhouse gases and other pollutants. The use of modern abatement technology allows for the reduction of nitrogen oxides and nitrous oxide, which can be reduced to almost zero, disposing of an environmentally safe tail gas.

Fig. 1: **Stamicarbon's mono-pressure nitric acid process**



Source: Stamicarbon

Fig. 2: **Stamicarbon's dual-pressure nitric acid process**



Source: Stamicarbon

Emission control in nitric acid plants

The tail gas (off-gas) from nitric acid production mainly contains nitrogen, water and impurities, such as NOx and N_2O. NOx stands for nitrogen oxide and nitrogen dioxide, gases that contribute to air pollution, smog and acid rain. N_2O – nitrous oxide, commonly known as laughing gas – is a powerful greenhouse gas, estimated to be about 300 times more powerful than CO_2.

To comply with environmental legislations, all new and most existing nitric acid plants must implement measures to reduce N_2O emissions into the atmosphere. N_2O is formed on the precious metal gauzes of the primary catalyst package in the ammonia burner as a by-product of ammonia oxidation. There are several locations in the plant where N_2O could be eliminated. However, the tertiary abatement system is the optimal solution for removing both N_2O and NOx simultaneously. The process conditions at that location are suitable for reducing both components in a single unit, offering additional savings on capex and opex.

Stamicarbon offers a unique technology that ensures significant greenhouse gas emission abatement and an adequate mixing between ammonia and tail gas, thus eliminating ammonia carryover, and minimising the pressure drop across the catalyst beds. A key safety feature is the prevention of catalyst particles from reaching the downstream tail gas expander. In addition, the system's design also allows for flexible catalyst selection based on the tail gas temperature for every nitric acid plant technology.

Tertiary abatement system for grassroots nitric acid plants

The system consists of a reactor with two packed beds holding an iron-zeolite catalyst. The first bed reduces the main part of the N_2O, while the second bed eliminates the remainder of the N_2O and the NOx. To achieve the latter, ammonia is supplied to the tail gas leaving the first catalyst bed.

$$6NO + 4NH_3 \rightarrow 6H_2O + 5N_2$$

$$6NO_2 + 8NH_3 \rightarrow 12H_2O + 7N_2$$

$$2N_2O \rightarrow 2N_2 + O_2$$

In the Stamicarbon nitric acid process, the tail gas temperature upstream of the expander is above 480°C. This temperature is reachable by a proper heat integration in the system, with the last tail gas heater placed inside the burner and close to the catalytic gauzes. Such high temperature of the tail gas maximises the energy efficiency of the process and provides several advantages to the abatement system:

- The high temperature increases the efficiency of the catalyst, reducing the catalyst volume needed.
- N_2O can be simply removed by thermal decomposition, which eliminates the use of natural gas or any other reducing agent in the first catalyst bed.
- There is no possibility of ammonia slippage, since at 480°C, ammonia is decomposed into N_2 and H_2.
- It is possible to combine NOx and N_2O removal in one bed since the temperature is suitable for both reactions.
- Standard stainless steel is used as the material of construction for the tail-gas expander.

In other words, the tail gas temperature of 480°C represents the optimal conditions in terms of capex and opex: it reduces the amount of catalyst required, allows easy combined removal of NOx and N_2O in a single device without the addition of methane and allows the use of standard stainless steel as the material of construction for the tail-gas expander.

Upstream of the abatement system, the tail gas typically has the following concentrations:

NOx: 400-600 ppmv

N_2O: about 1000 ppmv

Downstream of the tertiary abatement, these figures are reduced to levels below 10 ppmv.

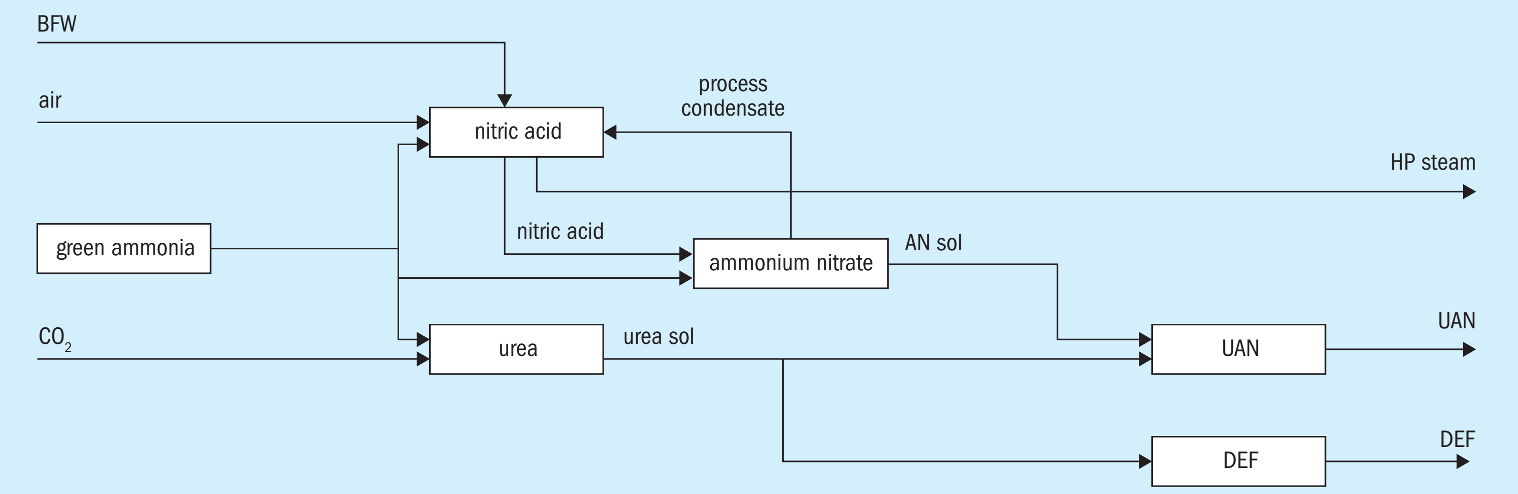
Acting as a one-stop shop for designing and delivering equipment and catalysts, Stamicarbon collaborates with leading catalyst suppliers to offer optimal and reliable tailor-made solutions, accommodating various process conditions and emission requirements.

What about non-Stamicarbon plants?

As mentioned, the Stamicarbon nitric acid process scheme is designed to have the tertiary abatement operating at favourable process conditions, which is beneficial in terms of capex and opex. However, to comply with current environmental regulations on emissions, existing plants also need to implement the removal of N_2O and NOx.

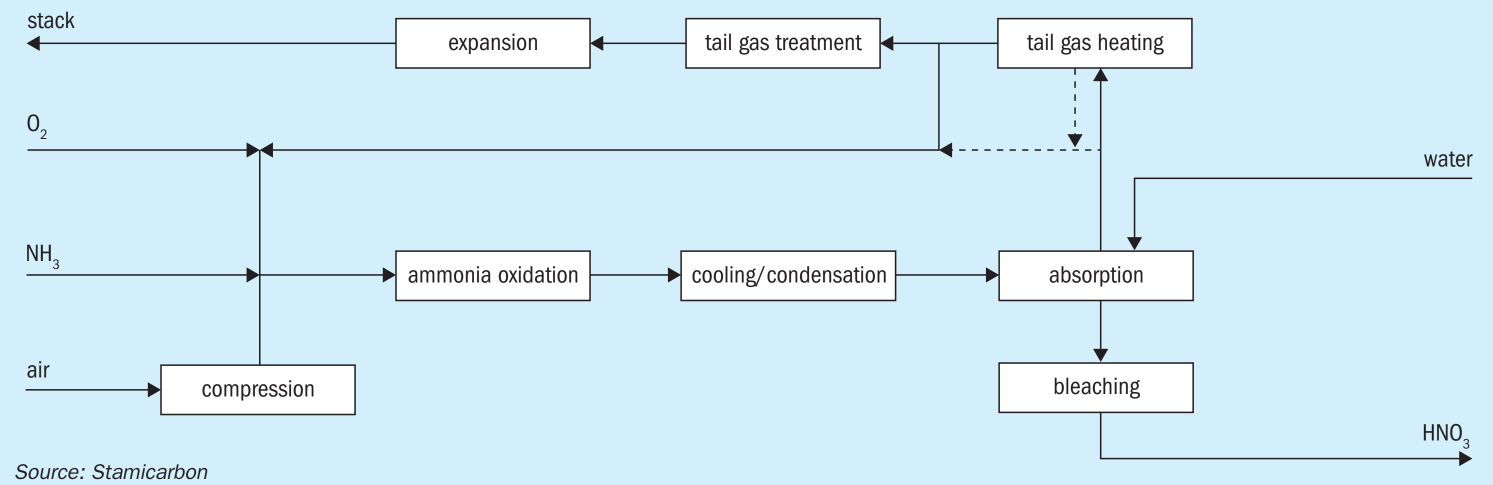
Stamicarbon can provide a tailor-made solution for any nitric acid technology, regardless of whether the tail gas operating temperature is higher or lower than that of

Fig. 3: **Integration of green ammonia and nitric acid technologies**



Source: Stamicarbon

Fig. 4: **Oxygen integration with the nitric acid technology: Recirculation of tail gas to the burner**



Source: Stamicarbon

the standard design. Through partnerships with suppliers worldwide, Stamicarbon offers advice on the type of catalyst, reactor design, and reactor location on a case-by-case basis to meet client requirements. This approach aims to minimise the impact of this new unit on the rest of the production process while considering all constraints indicated by the producer.

Integration of technologies in a green fertilizer complex

Having a comprehensive portfolio of nitrogen technologies, including nitric acid, urea, green ammonia, and other processes offered by the MAIRE Group, Stamicarbon ensures integrated plant operations that make the entire complex economically attractive and environmentally friendly.

A nitric acid plant with tertiary abatement can efficiently be combined within a larger complex (Fig. 4) that may include a green ammonia plant to produce carbon-free feedstock for the downstream units, a urea plant to produce DEF through a carbon capture technology in which CO_2 is recovered as a waste stream from an existing industrial process, and an ammonium nitrate plant to produce UAN via a mixing unit. In this case, oxygen from water electrolysis, in combination with the nitrogen from the generation unit, is effectively used in the nitric acid plant.

At the same time, to ensure that the mixture of ammonia and oxygen remains below the explosive limit upstream of the burner, additional nitrogen is required, and this can be sourced from recirculating the tail gas, as illustrated in Fig. 5.

This integration offers several advantages over conventional methods:

- There is a more positive power balance since compressor power is reduced, increasing steam production by more than 30%.
- Capex is reduced owing to the need for a smaller air compressor unit and expander.
- Conversion efficiency is increased by looping NOx gases back into the reaction (NH_3 burner, the bleacher, or both).

Additionally, the total catalyst volume, which is necessary to achieve the same level of abatement, is significantly reduced, by up to 40%, due to the recirculation of a part of the tail gas stream, which reduces the total flow of tail gas to be treated and therefore the amount of NOx and N_2O in the off-gas.

Conclusion

The industrial emission of greenhouse gases into the atmosphere is a universally recognised problem addressed by the Paris Agreement. One of the most potent greenhouse gases is N_2O, which is emitted from the tail gas of nitric acid plants. The Stamicarbon tertiary abatement technology, with its unique process scheme, enables the ideal process conditions for N_2O and NOx removal without the need to import natural gas from outside battery limits. Offering an opportunity to retrofit any type of nitric acid plant with guaranteed performance, Stamicarbon's tertiary abatement system is notable for its simple and reliable design.

> **“Offering an opportunity to retrofit any type of nitric acid plant with guaranteed performance, Stamicarbon's tertiary abatement system is notable for its simple and reliable design.”**

Tertiary abatement plays a crucial role in the design of a green fertilizer complex. When integrated with other technologies to achieve efficiency with minimal investments and operational costs, it ensures the plant achieves a minimal environmental footprint, making it an effective strategy for environmental sustainability.

To accelerate the implementation of this highly efficient technology within existing nitric acid plants, Stamicarbon actively participates in the Nitric Acid Climate Action Group (NACAG) initiatives, a global project led by the German Government. This involvement enables nitric acid plants in partner countries to receive technical and financial support for implementing N_2O abatement technology. ■

Resources

1. Statistics Netherlands, “CO_2 equivalents.” Available at: https://www.cbs.nl/en-gb/news/2022/06/urgenda-reduction-target-for-ghg-emissions-achieved-in-2020/co2-equivalents
2. Nitric Acid Climate Action Group. Available at: https://www.nitricacidaction.org/
3. Stamicarbon's nitric acid production process and plant with oxygen supply unit Patent No.: US11,772,971B2

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Ultra-HP ammonia oxidation catalysts

Catalyst development for nitric acid plants is strongly dependent on operating pressures and nitrogen loading levels. **Dr Hadi Nozari** of Johnson Matthey provides a review of some key catalyst design principles, emphasising the critical role of operating pressure in catalyst selection and highlighting the innovative contributions of Johnson Matthey in advancing catalyst technology for ultra-high-pressure ammonia oxidation in nitric acid plants.

Tailored catalyst design derived from the plant-specific operating conditions is key for ensuring optimised performance of nitric acid plants. When it comes to efficiency, platinum-based knitted gauzes have been the catalyst of choice for production of nitric oxide, a precursor in the formation of nitric acid. These catalyst gauzes benefit from extensive research into ammonia oxidation kinetics and the dynamics of metal distribution within catalyst packs. Leveraging decades of expertise in catalyst design, Johnson Matthey has been offering the HICON™ corrugated catalyst, engineered specifically for ultra-high-pressure (>10 barg) burners, to enhance catalytic performance.

Optimising ammonia oxidation

The performance of catalysts in ammonia oxidation fundamentally relies on the kinetics of the reaction. Ammonia reacts with oxygen through three main global reaction pathways, resulting in the formation of nitric oxide (NO), nitrogen (N_2), and nitrous oxide (N_2O).

$$4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O$$
$$\Delta H^o = -907.28\ kJ$$

$$4NH_3 + 4O_2 \rightarrow 2N_2O + 6H_2O$$
$$\Delta H^o = -1104.9\ kJ$$

$$4NH_3 + 3O_2 \rightarrow 2N_2 + 6H_2O$$
$$\Delta H^o = -1269.0\ kJ$$

The selectivity to each product is largely determined by the catalyst composition and pack design. Different platinum alloys and pack layouts exhibit a range of nitric oxide selectivity. Plant operating conditions such as temperature and pressure also significantly affect the selectivity. At lower temperatures, nitrogen forms as the primary product, while higher temperatures and lower pressures favour nitric oxide formation. This temperature and pressure dependency comes from the differing surface chemistries involved in the reactions. For instance, at elevated temperatures, nitric oxide is less likely to react with ammonia on the catalyst surface, leading to increased selectivity to NO.

Industrial operating conditions typically fall within a temperature range of 850 to 940°C and pressure range of atmospheric to 13 barg, achieving nitric oxide selectivity between 90 to 97%. Based on the operating pressure and nitrogen loading ranges, the majority of nitric acid plants fall into one of the four categories in a general operational spectrum, as depicted in Fig. 1.

Achieving optimal selectivity for each plant type requires careful consideration of various catalyst parameters, including wire diameter, knit density, and layering. These physical characteristics influence the diffusion of reactants to the catalyst surface and thus impact reaction kinetics. Also, the catalyst's metallurgical properties play a crucial role in determining its selectivity. Platinum, with its high selectivity to nitric oxide, is the preferred catalyst material for ammonia oxidation. Rhodium-platinum alloys, particularly those containing 3 to 5% rhodium, are commonly used due to their enhanced catalytic activity.

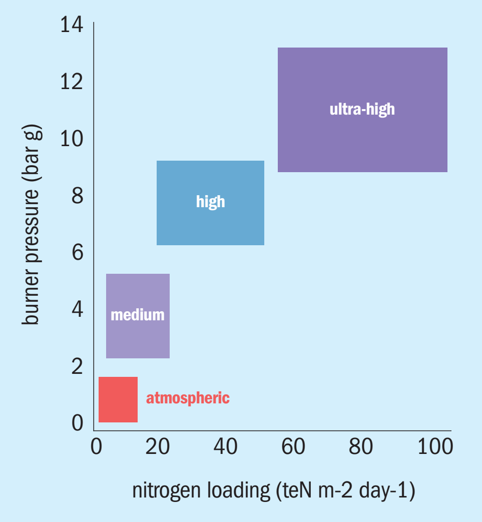
Ternary alloys of rhodium-platinum-palladium, containing high levels of palladium, demonstrate superior performance when placed in the lower half of catalyst packs in medium-pressure burners. These layers are considered more effective compared to conventional rhodium-platinum layers in this location. Leveraging these principles, Johnson Matthey's ECO-CAT™ gauzes significantly reduce the required installed weight to achieve targeted nitric acid production levels, while increasing campaign length, improving conversion efficiency, and reducing nitrous oxide formation.

In addition to the primary reactions described above, secondary reactions may take place under certain conditions, where there is more residence time in the catalyst pack for remaining ammonia to react with nitric oxide to produce additional nitrogen and nitrous oxide.

$$4NH_3 + 6NO \rightarrow 5N_2 + 6H_2O$$

$$2NH_3 + 8NO \rightarrow 5N_2O + 3H_2O$$

Fig 1: **Types of plants based on pressure and nitrogen loading**



Source: JM

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To mitigate these undesired reactions, it is important to ensure the completion of the oxidation reaction within a minimal number of catalyst layers, often achieved through use of denser knit structures, larger wire diameters or a combination of both at the top of the catalyst bed.

Understanding the intricate balance between the reaction kinetics, catalyst composition, and process conditions is critical for optimising selectivity and enhancing overall process efficiency in ammonia oxidation. Through continued research and innovation, Johnson Matthey strives to develop and optimise catalysts that meet the evolving demands of the nitric acid industry.

HICON for ultra-high-pressure oxidation

The operational features of ultra-high-pressure nitric acid plants can significantly diverge from medium and low-pressure plants. Typically, ultra-high-pressure plants feature burner diameters of approximately 2,000 mm or less, with operating pressures reaching up to 14 bar and temperatures as high as 940°C. These conditions promote high gas velocities across the catalyst gauzes, resulting in shorter campaign lengths, lower conversion efficiencies, and higher metal losses. To address these challenges, Johnson Matthey has designed and developed the HICON (corrugated knitted catalyst), tailored to optimise conversion efficiency, pressure drop, light-off characteristics, and campaign lengths. Effectiveness of HICON in ultra-high-pressure plants relies mainly on increased surface area and the capacity to reduce gauze numbers while preserving installed weight.

The following provides a summary of several advantages of the HICON catalyst, along with the underlying physics that drive the enhancements.

Increased conversion efficiency

HICON boosts conversion efficiency by increasing the rate of gas film diffusion per unit cross-sectional area of the burner. This enhancement, as a direct result of reduction in superficial gas velocity, promotes the probability of gas molecules getting into contact with the catalyst surface. It is worth noting that Johnson Matthey has successfully combined HICON and ECO-CAT technology for ultra-high-pressure plants with very high loading (>90 teN m-2 d-1), resulting in further improvements in efficiency.

Faster light-off

The increased surface area of each gauze within the HICON catalyst pack increases the probability of ammonia-air mixture reacting on the catalyst surface. Essentially, this is an effective strategy to leverage fluid dynamics for achieving a faster light-off. A faster light-off significantly reduces the time required for the plant to reach the maximum efficiency. Subsequently, ammonia slip is minimised during the plant start-up.

Additionally, in cases where light-off is a significant problem, Johnson Matthey offers alternative proven technologies. These solutions involve increasing platinum concentration on the catalyst surface, effectively facilitating faster light-off.

Reduced pressure drop

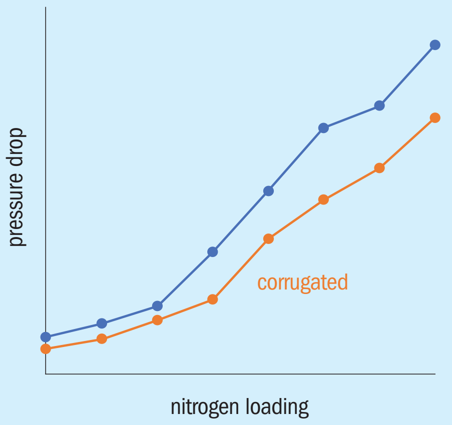
Lower superficial gas velocity through the catalyst layers translates into proportional reduction of pressure drop across the catalyst bed. The pressure drop is lowered further by the reduction in the number of gauze layers in a HICON pack, compared to a standard pack of equivalent install pgm weight. This reduction in pressure drop boosts the likelihood of either increased production throughput or reduced energy consumption.

Considering that catchment pack has the largest contribution in pressure drop across the combined catalyst-catchment layers, lowering pressure drop across the catchment is highly advantageous. To address this, Johnson Matthey offers the A1-R, reduced pressure drop catchment, for ultra-high-pressure burners. A1-R, offered either flat or corrugated, features a higher porosity minimising pressure drop during the campaign.

Fig 2: **HICON catalyst designed for ultra-high-pressure burners**

Source: JM

Fig 3: **Pressure drop advantage of HICON**



Source: JM

Extended campaign length

The rate of gross metal loss from the catalyst depends on operational parameters such as pressure, temperature, and gas stream velocity. By reducing superficial velocity, the HICON pack reduces the rate of gross burn-off, thereby prolonging catalyst life. Moreover, reduced metal loss mitigates the formation of rhodium oxide on the catalyst surface, preserving selectivity for ammonia conversion to nitric oxide while extending the catalyst life.

It is important to underline the significance of regular maintenance, particularly of air and ammonia/air filters, to sustain the maximum performance of the catalyst. Buildup of iron, silica, or aluminium will have a detrimental effect on catalyst life and operational efficiency.

Summary

This article explores some details of catalyst development, highlighting tailored solutions for ultra-high-pressure burners. In this framework JM's HICON (corrugated knitted catalyst), is engineered to address the unique challenges of high-pressure oxidation environments. With improvements ranging from increased conversion efficiency to accelerated light-off, HICON represents a significant advancement in catalyst technology for ultra-high-pressure nitric acid production. ■

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47 48 49 50 51 52 53 54 55 56

In-service monitoring of HE tube wall thickness

Aleksandra Gavrilović-Wohlmuther of Christof Group SBN presents groundbreaking sensor technology for accurate and reliable continuous monitoring of individual heat exchanger tube wall thickness in high pressure, high temperature industrial conditions.

Plants in the chemical, oil and gas, nuclear, and power generation industries, all rely to a large extent on metal structures comprising extensive metal tubes or pipework. Consequently, they all share one common issue, that is the detriment of a metal structure. Over long periods of service, corrosion and erosion of metal is inevitable, thus regular monitoring for the assessment of the structural integrity of the material and accordingly maintenance is of utmost importance to extend the lifetime and optimise the time between maintenance. The onset and propagation of corrosion is even faster in conditions of elevated temperature and pressure. Such deterioration leads to accelerated wall thickness loss, which is a threat to structural integrity and load resisting capacity of the pipes and tubes. Consequently, over time these metal components need to be repaired, replaced, or removed. Practice has shown however, that the wall thickness loss can be tolerated to some extent.

Without adequate in-operando monitoring, plant operators have little-to-no warning of developing problems. In this business, efficiency and safety are paramount. The standard approach is to schedule process unit or plant for a non-operational state, known as "shutdown". The maintenance and inspection of the heat exchanger (HE) tubes have traditionally been a time-consuming and costly process since each component shall be examined individually. The manual inspections have a limited reliability, considering the accuracy depending on the operator's skill or condition, measuring instrument and possible difference in data reading conditions. Moreover, the financial impact of the scheduled downtime on revenue is critical. Maximising the time between the shutdowns can yield substantial gains for the plant's profitability.

This article introduces a ground-breaking solution developed by Christof Group SBN, which promises to revolutionise this aspect of industrial maintenance by offering an original product that smoothly combines cutting-edge sensor technology with a real-time monitoring capability. This innovation allows for the early detection of wall thickness changes induced by corrosion and/or erosion within the heat exchanger tubes. Importantly, the new technology operates continuously, delivering in-situ monitoring, even under high-pressure and high-temperature (HPHT) conditions. Two distinct sensing systems have been harnessed for this purpose, one based on ultrasound and the other based on fibre optic interferometry. Both sensor technologies enable detection of real-time changes in wall thickness, with proven accuracy up to 0.05 mm at 220°C and 20 MPa for HE tubes made of any super-duplex steel. This innovation is however intended for any metallic HE tubes operating under HPHT.

Christof Group SBN's sensors play a crucial role in advancing the digitalisation of industrial equipment. Their recent integration into a high-pressure CO_2 stripper is a testament to their practicality and potential to enhance the efficiency of fertilizer plants while reducing the financial burden associated with scheduled maintenance shutdowns. This article delves into the technical aspects of two patented sensor systems and underscores its commercial significance in supporting customers seeking streamlined operations.

WALLMON® – fibre optic sensing system

Optical fibres, primarily made of quartz glass, have a melting point of around 1,700°C, with high compressive strength $> 1 \times 10^9$ Pa and an extraordinary chemical inertness. Due to these outstanding thermal and mechanical properties, fibre-optic sensors are resistant to the corrosive ambient and harsh industrial environments such as those encountered in critical process equipment in the fertilizer industry. A special feature of the fibre optic sensor is that it requires no electrical wiring to connect to the control system, as optical fibres themselves act as both, the sensing element (so called intrinsic sensor) and the signal propagation channel. The WALLMON® fibre-optic sensing system guaranties absolute safe in-service operation without any risk induced by sparking, short circuit, EMI, RF and HV interference, as the sensing element does not contain any electrical currents. Being made of dielectric materials, it is intrinsically an Ex-proof sensing technology.

Beside the network of optical fibres placed at the measurement points, the WALLMON® sensing system includes an optoelectronic unit (OEU), as shown in Fig. 1, responsible for interrogation of fibre-optic sensors and online signal processing. The full supervision of the heat exchanger tubes is based on the remote and safe data transmission and communication between the embedded sensors and OEU over a long distance.

During operation, vibration of the critical process equipment, thus heat exchanger tubes is an inevitable occurrence. The WALLMON® sensing system uses this unwelcome effect as an acoustic driver to

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Fig. 1: Optoelectronic unit responsible for interrogation of fibre-optic sensors and online signal processing.

monitor the frequency response and to estimate the wall thickness of the inspected tube. A wall-thinning of the heat exchanger tube is a result of a permanent loss of the material, that leads towards change of resonant frequency of the tube, shifting it towards higher values (see Fig. 2).

At the same time, the stiffness of the tube wall decreases, causing the change of strain over the tube wall. The sensing fibre is wrapped around the monitored HE tube capturing the quick varying strain signals (0 – 1,000 Hz). The optical signals are converted to the electrical one by means of an OEU. Resonant frequency is calculated out of the FFT analysis of strain signals by online processing in the OEU. To neutralise the thermal effects on the optical path length, each sensing fibre is coupled with one reference fibre.

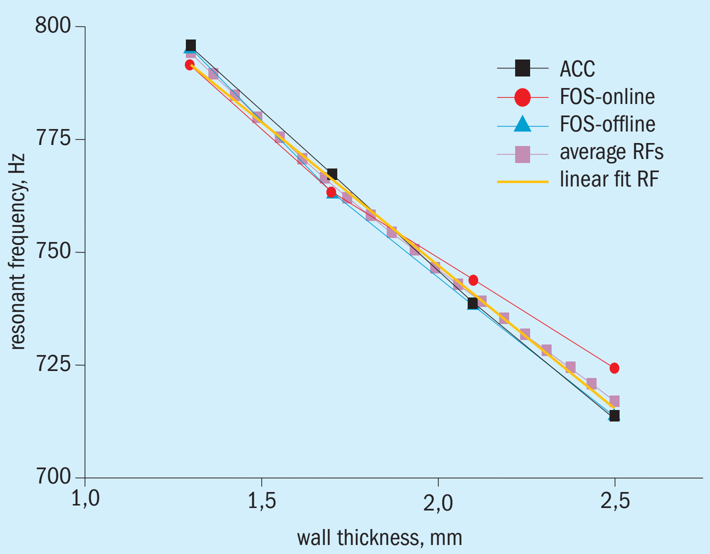
The WALLMON® remote monitoring and diagnostics service (RM&D) enables real-time data acquisition and comparison, whether conducted directly on-site, or accessed remotely through an intranet or internet connection (see Fig. 3).

MONITUBE® – ultrasonic sensing system

The time-of-flight (TOF) method in ultrasonic testing is a technique that revolves around measuring the time it takes for an ultrasonic pulse to travel through a material and return as a reflected signal. This approach is increasingly popular because it enables the measurement of wall thickness in industrial settings, specifically on parts that are only accessible from one side. Additionally, it is a quick, straightforward, and versatile technique that lends itself well to automation.

The MONITUBE® ultrasonic sensing system developed by Christof Group SBN is based on the TOF method using high temperature piezoelectric ceramics, which generate a corresponding output signal by means of high-frequency excitation. Due to the high speed, many measurements can be carried out, which, by averaging the individual values, greatly increase the measurement accuracy. In the face of harsh environmental conditions, MONITUBE® rises to the challenge, delivering impeccable measurement signals. A common issue that this sensing system has mastered successfully is the measurement accuracy over time, where no drift in the measurement signal is allowed, even over decades. In the course of development, this ruled out many commercially available sensor components

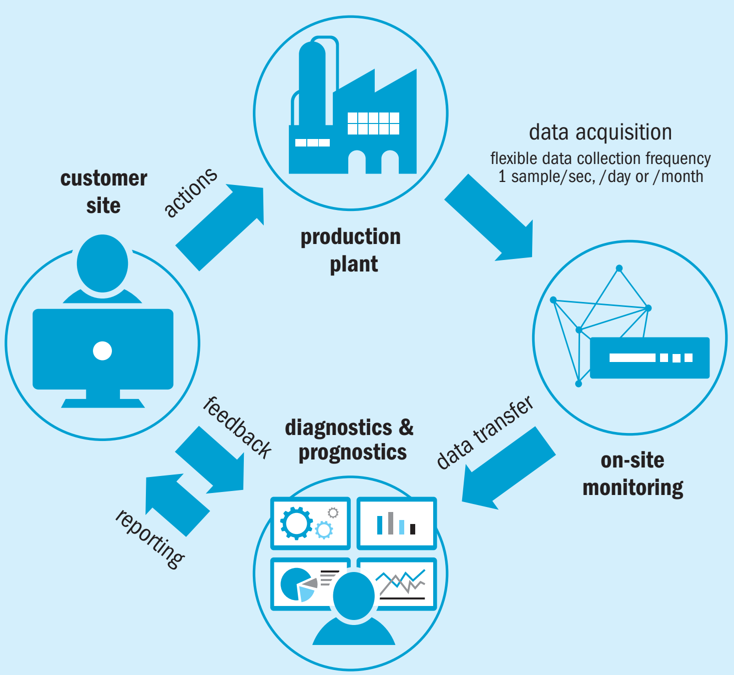
Fig 2: **Preliminary laboratory experiments at room temperature and at ambient pressure: resonant frequency vs. wall thickness of S32906 tubes, simultaneously measured by fibre-optic sensors (FOS) and accelerometers (AAC).**



Tube length: 450 mm
Outside diameter: 31 mm
Wall thickness: 1.3, 1.7, 2.1 and 2.5 mm

Source: Christof Group SBN

Fig 3: **RM&D services provide increased equipment reliability leading to a decrease in maintenance costs and lost production revenues.**



Source: Christof Group SBN

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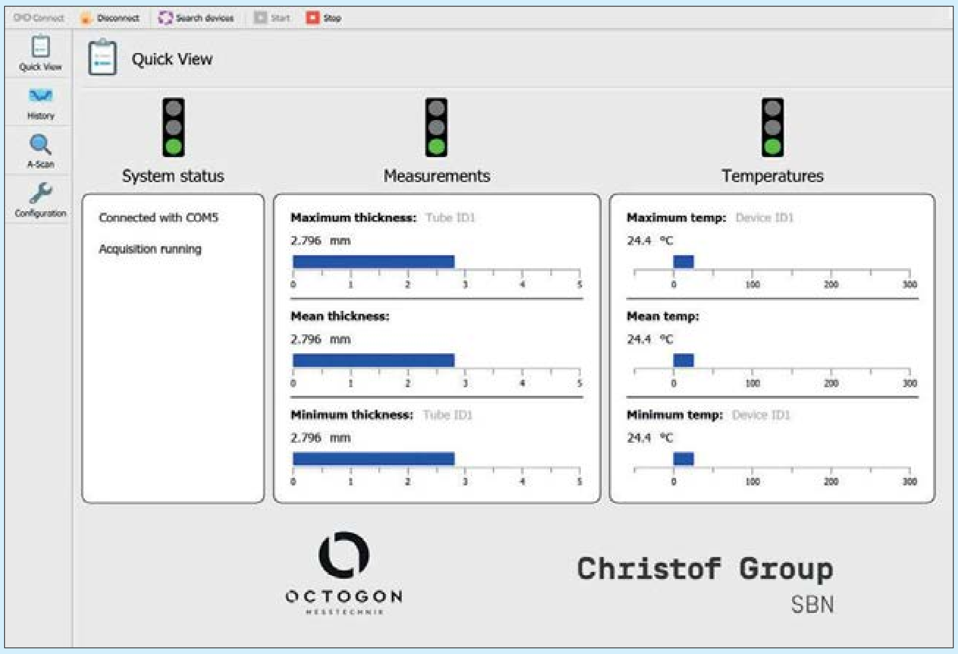
Fig 4: **Custom made graphic user interface (GUI)**



Connected with COM5

Acquisition running

Maximum thickness: Tube ID1
2.796 mm

Mean thickness:
2.796 mm

Minimum thickness: Tube ID1
2.796 mm

Maximum temp: Device ID1
24.4 °C

Mean temp:
24.4 °C

Minimum temp: Device ID1
24.4 °C

Source: Christof Group SBN

Fig. 5: Integration of ultrasound sensors into the CO_2 stripper.

that would begin to drift over time at high temperatures. Another distinctive feature of the MONITUBE® sensor system is that it does not require any coupling medium for the effective introduction of the emitted ultrasound signal into the test area. The sensing unit is carefully designed so that contact transfer losses can be reduced to a minimum.

In addition to the MONITUBE® sensing unit, which directly interacts with the HE tube, the complete ultrasound sensing setup comprises two additional elements that are placed outside the high pressure heat exchanger; an electronic hub functioning as the core of the measurement system and a user terminal for accessing measured values and adjusting settings. Employing the cutting-edge digital circuitry, the electronic hub can simultaneously assess between 8 and 16 MONITUBE® sensors. This hub is connected to the user terminal via Modbus.

For assessing measured data, an intuitive graphical user interface (GUI) is available. By using a traffic light sign, the "Quick View" interface symbolically displays the overall status, wall thickness and current ambient temperature (see Fig. 4). Additionally, the "History" interface not only allows real-time inspection of actual status but also enables users to retrieve past measurements for graphical comparisons, providing a means to evaluate visually wall thickness development over the time. The frequency of the measurements can be adjusted remotely.

Sensor placement and installation

In addition to creativity, a deep understanding of material behaviour and excessive know-how in engineering and manufacturing of critical process equipment are essential for successful sensor design, placement, and installation in an actual heat exchanger. A specific area identified as the most prone to corrosion is the most beneficial for the sensor placement. The combination of high demands on pressure resistance, heat resistance, occurring steam atmosphere, as well as the challenge of lead out of the measuring signals makes these sensing systems unique. Finally, the overall concept considers very limited installation space since the sensors are placed on and between the HE tubes, without interfering in the process (see Fig. 5). Consequently, Christof Group SBN has refined its typical production procedures, all directed toward achieving the utmost efficiency while ensuring the safe and minimally intrusive installation of sensors.

Future steps

During a month-long laboratory testing in the autoclave, both sensor technologies performed impeccably, enduring extreme conditions of up to 225°C and pressures of up to 20 MPa in water steam. This rigorous testing validated their precision to maintain a remarkable accuracy of 0.05 mm in detection of wall thickness changes, showcasing the components' resilience and suitability for harsh operational environments.

Recently, one of the sensor technologies was delivered for the first time to a valued customer of Christof Group SBN. Commissioning is set for 2024, signalling the next phase of development. This stage presents an exciting opportunity to put the sensors to the test in a real-plant scenario, uncovering insights into their long-time endurance and paving the way for potential enhancements.

Conclusion

In summary, Christof Group SBN presents ground-breaking sensor technology designed to revolutionise industrial operations. By integrating advanced sensors capable of continuous, real-time monitoring, this innovation detects early wall thickness changes due to corrosion and erosion in heat exchanger tubes. The WALLMON® fibre optic sensing system and MONITUBE® ultrasonic sensing system offer unparalleled accuracy and reliability even in extreme conditions, promising enhanced safety, efficiency, and cost savings for industries reliant on metal structures. The imminent deployment in 2024 heralds a new era in predictive maintenance and operational excellence. ■

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Towards an emerging hydrogen economy

Low carbon intensity hydrogen and ammonia production schemes from KBR, Air Liquide, Mitsubishi Heavy Industries, Casale and Johnson Matthey.

Hydrogen is one of the key solutions for addressing global warming, climate change, and energy security challenges. With current carbon-intensive hydrogen production and green hydrogen likely a longer-term solution, blue hydrogen production, with attractive levelised cost, can provide the much-needed stepping stone to an emerging hydrogen economy worldwide. In order to realise the potential benefit of low-carbon hydrogen production from fossil fuels, a reliable solution is required for a large-scale emerging market.

Ammonia as a hydrogen carrier is also a crucial enabler of the energy transition. While it will take time for renewable energy infrastructure and hydrogen production capacity to be developed at scale, low-carbon ammonia produced from natural gas with additional carbon capture supports the transition phase in the next decades.

KBR

KBR’s blue hydrogen technology: 1,000 MW clean hydrogen

Rohit Khurana

KBR has been at the forefront of SMR technology for more than 75 years. Over time, the standard size of KBR ammonia plants has doubled from 1,000 t/d ammonia (NH_3) (~300 MW H_2 equivalent) in the 1960s, to more than 2,000 t/d NH_3 (~600 MW H_2 equivalent) in the early 2000s. Since then, plant sizes have increased again, and KBR now has single-train plants in operation producing over 3,000 t/d NH_3 (~900 MW H_2 equivalent with units of 6,000 t/d NH_3 (~1,800 MW H_2 equivalent).

Leveraging on this vast experience, KBR recently developed a basic engineering design for a 1,000 MW blue hydrogen plant based on SMR with a minimally-sized post combustion capture unit (PCCU).

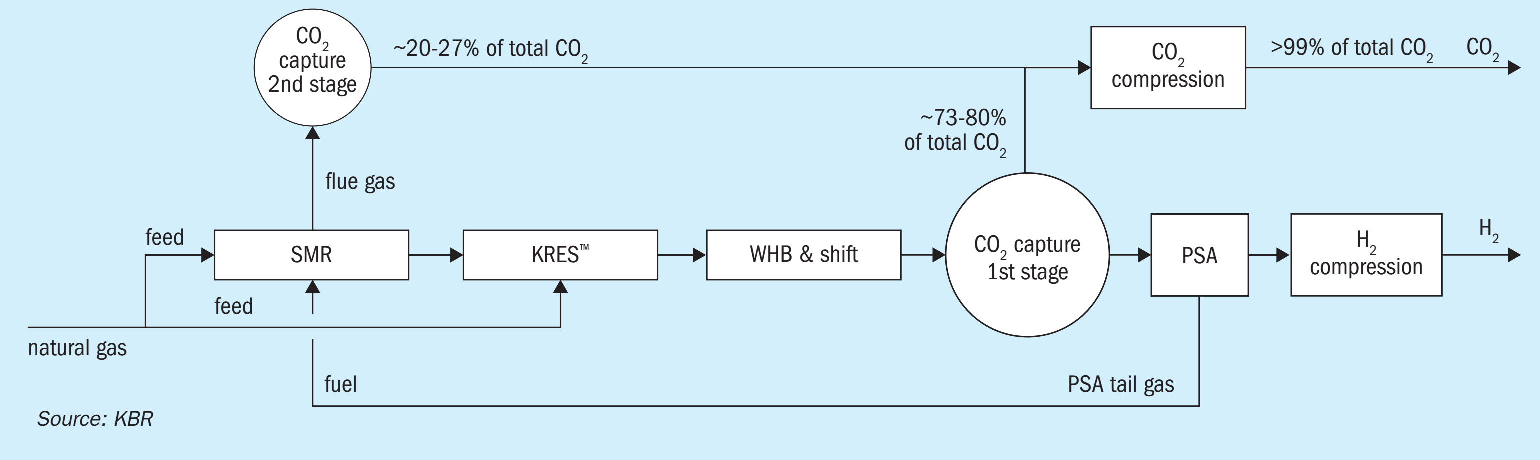
KBR’s blue hydrogen technology

KBR’s blue hydrogen process, H2KPlus^{SM}, (see Fig. 1) is based on the advanced SMR process, which utilises the proven, safe, and reliable, KRES™ technology, which helps reduce capex, opex, and importantly, carbon generation in the process. This technology has accumulated over a decade of experience and has demonstrated both operating and maintenance/reliability advantages.

The key advantages of the proven mega-scale KBR H2KPlus^{SM} process are:

- highest energy efficiency / lowest CO_2 generation;
- lowest capex;
- highest reliability / lowest downtime.

Fig 1: **KBR H2KPlus^{SM} flow scheme for mega-scale blue hydrogen**



Source: KBR

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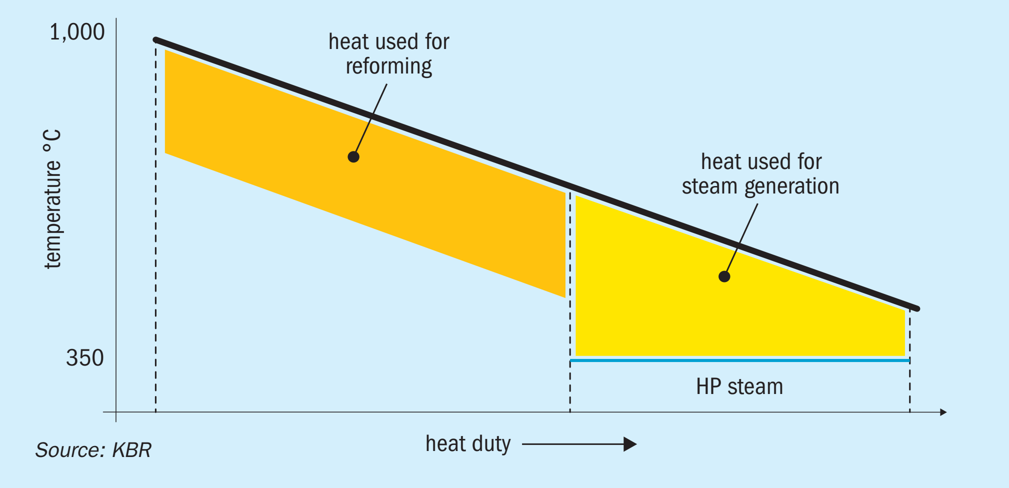
There are over 260 SMR units installed globally with the following features:

- 3 to 18 tube rows;
- furnace efficiency: 91~ 94%;
- low NOx designs, (incl. SCR);
- feed pre-heat, up to 625°C;
- flexible control options;
- optimised overall footprint.

KRES™ is the heart of KBR's blue hydrogen technology. The incorporation of KRES™ 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 steam methane reformer instead of burning fuel. In addition, KRES™ operates in parallel with the SMR, which reduces front-end pressure drop, resulting in a reduction in the power consumption of the hydrogen compressor (energy saving).

Reformed gas exiting the primary reformer at a very high temperature (~900°C) carries substantial high-grade waste heat. In the conventional reforming process, such high-grade heat contained in the reformer effluent gas is involuntarily degraded by recovering as steam, a relatively lower-grade heat carrier. KRES™ utilises this waste heat instead of consuming natural gas fuel to generate synthesis gas in the reforming exchanger. Fig. 2 illustrates the heat curve of the secondary reformer effluent with KRES™ for reforming instead of steam production.

Fig 2: **KRES™ heat curve**



Source: KBR

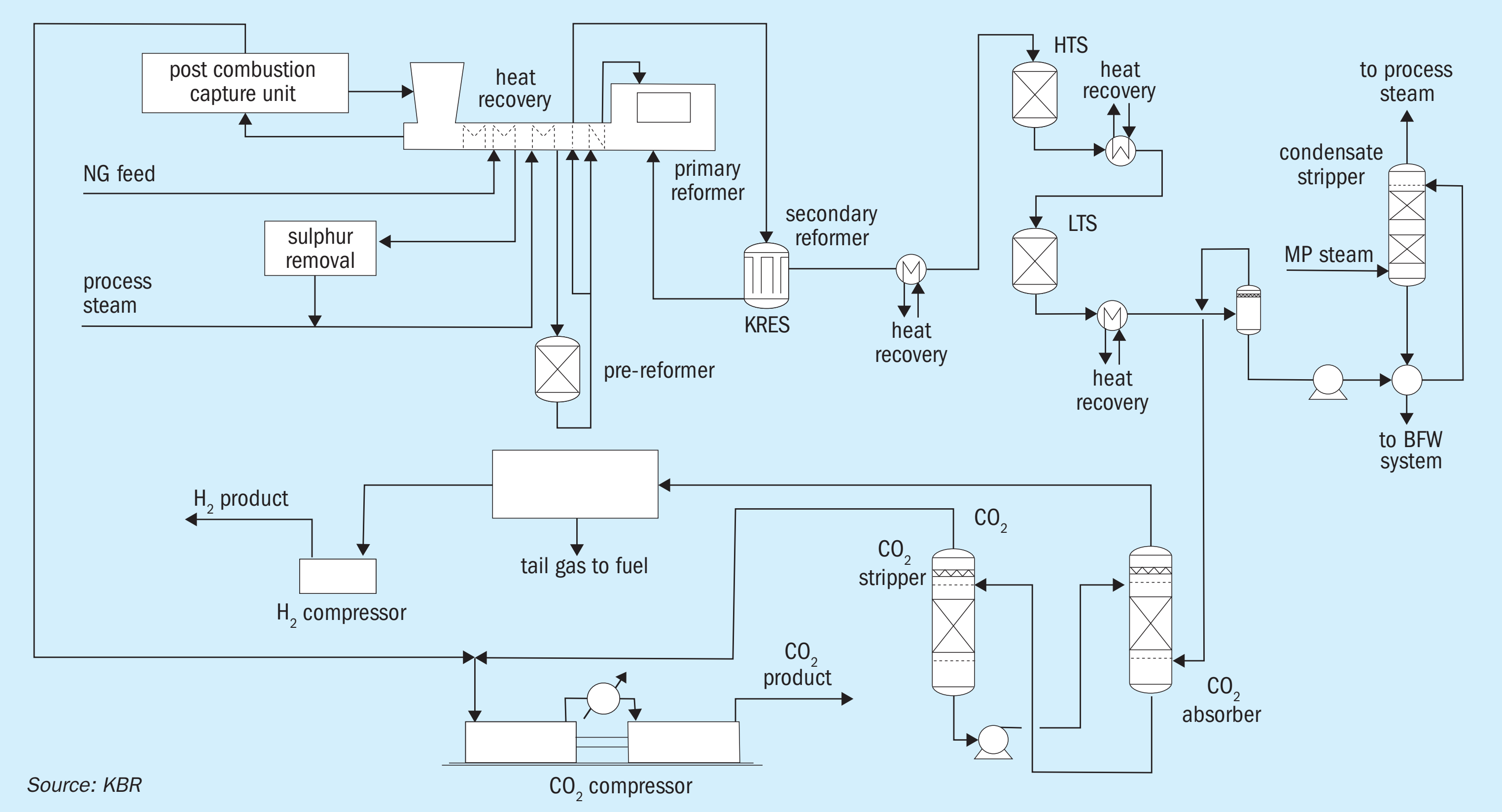
The addition of KRES™ is not only the most cost-effective route to generate hydrogen but also helps in achieving a mega capacity without a massive increase in SMR size. Being the biggest contributor to the capex in a hydrogen plant, a reduction in reformer size leads to direct capex savings.

By combining these proven technologies, the following advantages are realised in comparison to other plant designs:

- a reduction in the primary reformer size by up to 30% leading to a reduction in fuel usage and thus carbon emissions;
- significantly prolonged waste heat boiler equipment life due to lower temperatures in the inlet of the waste heat boiler (900°C versus 800°C);
- inherently safer operation with no pure oxygen in the system.

For CO_2 recovery levels up to 99%, a PCCU unit is integrated into the process flow scheme. Through the use of a PCCU, up to 98% of the CO_2 generated in the flue gases can be recovered. This supplemental CO_2 capture allows for an overall unit CO_2 recovery of up to >99%. In addition, by utilising a PCCU, the impact on the front-end equipment sizing associated with generating excess syngas for utilisation as fuel is avoided.

Fig 3: **KBR hydrogen process (H2KPlus℠) for 1,000 MW blue hydrogen**



Source: KBR

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47 48 49 50 51 52 53 54 55 56

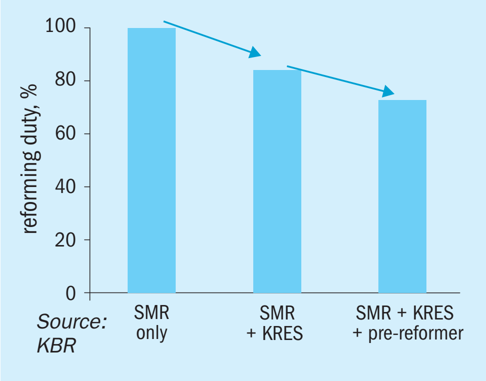
KBR's blue hydrogen process for 1,000 MW

The process flow scheme for the design of hydrogen production for a 1,000 MW plant is depicted in Fig. 3. The PCCU provides much better flexibility for a large-capacity plant without any impact on the sizing of the front-end section of the plant.

For further reduction in the opex and capex of the plant, a pre-reformer is added in a large capacity plant, which contributes roughly to a 10% reduction in the size of the reformer.

The pre-reformer, as its name suggests, is installed upstream of the SMR. It utilises the low-grade heat from the convection section of the reformer to reach the reaction temperature and reform higher hydrocarbons as well as methane to hydrogen. With the combined use of KRES™ and the pre-reformer, there is not only a significant reduction in the size of the reformer but also a reduction in the fuel consumption leading to a smaller PCCU. Fig. 4 represents the comparison of radiant duty with the addition of KRES™ and a pre-reformer.

Fig 4: **Comparison of reforming duty**



Source: KBR

Downstream of reforming, typical high temperature and low temperature shift reactors in series are used to optimally convert carbon monoxide to carbon dioxide and hydrogen via water-gas shift reactions. The carbon dioxide produced in the reforming section and shift reactors is removed using BASF's OASE White dual-stage CO_2 removal process. The system is well integrated with process waste heat used to support heating demands in both the pre-combustion and post-combustion CO_2 capture units. The hydrogen product is cleaned further to 99.9% purity by the pressure swing adsorption (PSA) process.

To increase efficiency and decrease capex at the same time, various features have been included in the system, such as:

- Pressure in the system is maximised to the allowable limits: Since the reforming reaction is favoured at lower pressure and high temperature but equipment sizing is reduced due to lower volumetric flow rate, there is a fine balance for selecting the optimum operating pressure. KBR used the unique experience of operating a primary reformer at well above 30 bar for an ammonia plant to select the optimum pressure for a 1,000 MW blue hydrogen plant.
- Use of HP flash scrubber: This enabled scrubbing of HP flash gas to remove CO_2 from HP flash gas. This CO_2, would otherwise have landed in the fuel system of the primary reformer leading to a slight increase in size of PCCU.
- Use of tail gas compressor: There is a trade-off between recovery in the PSA unit and pressure of the tail gas. By addition of a tail gas compressor, maximum recovery of hydrogen (more than 87%) even with a high purity requirement of 99.9% is ensured.

To conclude, KBR's efficient and reliable reforming technology, in combination with a small post-combustion capture unit (PCCU), leveraging economies of scale, will deliver 1,000 MW hydrogen with an unparalleled carbon capture rate of over 99% using industry-standard and well-proven equipment sizes and catalysts. ■

AIR LIQUIDE AND KBR

ATR-based low carbon ammonia

Martin Gorny, Sophia Schmidt (Air Liquide) and Bernd Haveresch, Henrik Larsen, Thor Gallardo (KBR)

Ammonia plays an essential role in the energy transition, serving existing markets and functioning as a hydrogen carrier for trans-continental shipping. To ensure economically viable and sustainable ammonia supply chains, the reduction of carbon footprints and the scale-up of production are imperative. In response to this challenge, KBR and Air Liquide have formed a collaborative alliance, bringing together their expertise in autothermal reforming (ATR), air separation, carbon capture, and ammonia production to provide customers with comprehensive and optimised solutions, serving as a one-stop shop for the industry.

KBR and Air Liquide's collaboration aims to overcome economic and environmental obstacles by jointly focusing on ATR-based low-carbon ammonia technology for the sustainable supply chains of the future.

Fig. 1: Air Liquide´s Lurgi™ ATR

PHOTO: AIR LIQUIDE

Air Liquide expertise

Air Liquide's role in the collaboration is underscored by its proven track-record as an operator and designer, particularly in low-carbon and renewable hydrogen technology

- **Oxygen-blown ATR technology**: Air Liquide has established its leadership in oxygen-based ATR technology through nearly seven decades of experience, with 33 industrial references. There are six references in operation with a production capacity corresponding to 6,000 t/d ammonia syngas each as depicted in Fig. 1.
- **Cryogenics technology**: Air Liquide has an extensive technology portfolio for cryogenic technology, serving oxygen and nitrogen production for ammonia at scale: Air Liquide designed the world's largest air separation unit (ASU) and Nitrogen Wash Unit.
- **Carbon capture**: Air Liquide's proprietary carbon capture portfolio covers cryogenic technologies (Cryocap™) and absorption technologies (Rectisol™, Recticap™). Air Liquide has delivered the only operating industrial plant that captures CO_2 from syngas utilising cryogenic technology.
- **Hydrogen and oxygen operations**: Air Liquide has more than 100 years of experience in safe oxygen production and more than 60 years of experience in the hydrogen value chain, with more than 90 plants for H_2, CO and syngas. The learnings from operations are implemented into Air Liquide's designs for safe, reliable and easy operation.

KBR expertise

KBR's contribution to the collaboration lies in its leadership in conventional, low-carbon, and renewable ammonia technology.

KBR's experience in ammonia plant design dates back to 1943. Since then, KBR's ammonia process technology has undergone a number of significant improvements which is substantiated by the fact that KBR has licensed more than 250 ammonia plants around the world, with the first KBR Purifier™ plant coming online in 1966, and the first KBR PurifierPlus™ plant coming online in 1994.

Over time, the standard plant sizes have increased from 1,000 t/d in the 1960s, to KBR now having single train plants in operation producing over 3,000 t/d. Building on this success, KBR completed the basic engineering design (BED) for a 6,000 t/d single train design in 2022.

KBR has also developed the renewable ammonia technology, K-GreeN®, which consists of a fully integrated solution, including the electrolysis.

The KBR ammonia synthesis section is a proprietary design with proven unmatched reliability, for example, using the proprietary horizontal ammonia converter, and lower energy consumption at lower capital cost, due to lower equipment count.

Common performance variables for low-carbon ammonia projects

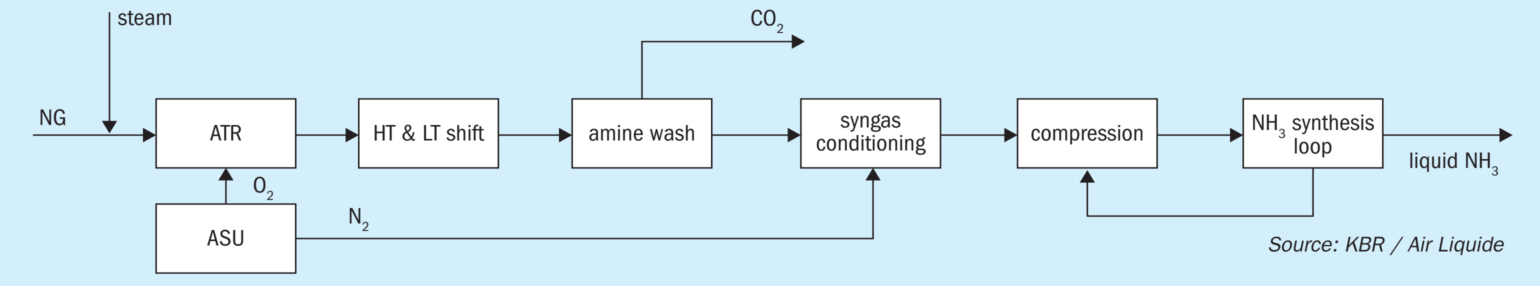
All low-carbon ammonia plants are subject to different boundary conditions and need to meet at least partially different targets. This set of key variables or conditions determines how the optimal plant is designed for such specific boundary conditions.

The main performance variables are:

- **Direct emissions**: In some instances, direct emissions must comply with a specific value to meet the requirements for subsidies. In other instances, they are only a contributing criterion to a targeted carbon intensity and need to be balanced with other performance variables. The direct emissions in a low-carbon ammonia plant are emitted by the fired heater. These adjustments in the fired duty and potentially hydrogen co-firing of hydrogen-rich streams can be used to optimise the direct emissions.
- **Electricity import**: In some cases, electricity import can be a governing boundary condition, because available electricity may be limited. But in most cases, it is a parameter that impacts carbon intensity and opex. Electricity can be used to drive machines, thus the choice of CO_2 separation technology (absorption vs. cryogenic technology) and the choice of steam level raised in the plant (high pressure vs. medium pressure) have the highest impact on electricity demand. By raising high-pressure steam (> 100 bar) instead of medium-pressure steam (approx. 50 bar) in the heat recovery downstream of the ATR, more energy to drive turbines can be provided. However, high-pressure steam needs to be superheated in a fired heater and thus increases direct emissions and natural gas demand. Electricity import is influenced as well by the oxygen demand, as typically the ASU is at least partially electricity driven. Thus, by adjusting the oxygen demand through setting the preheating temperature in the ATR the electricity import can be balanced against direct emissions from the fired heater for preheating.
- **Natural gas demand**: As natural gas consumption is typically the main opex driver, its minimisation is always the main target. However, as discussed under electricity, there is a certain potential to balance it against electricity demand by choice of machine drives and balance between recycle and purge for unconverted hydrocarbons in the syngas conditioning unit. Especially cryogenic CO_2 separation allows to maximise the conversion of unconverted methane and CO molecules back to the ATR to minimise direct emissions and natural gas consumption. In scenarios where the targeted carbon intensity includes emissions associated with the natural gas production, minimisation of natural gas consumption is especially important to limit scope 3 emissions.
- **Capex**: Plants with high carbon capture rates >95% require typically higher capex, as more equipment is required, for example, more efficient drives for minimised electricity consumption or additional equipment for the separation and recycle of unconverted hydrocarbons. Thus, capex can be balanced against the other performance parameters (e.g. compromise on carbon capture, within boundary conditions, and reduce capex by this).
- **Co-products**: Typical co-products are hydrogen and steam that can be utilised in adjacent facilities. Hydrogen co-production entails the requirement for the process to produce hydrogen at the specified quality and thus heavily influences the choice of CO_2 capture technology and hydrogen conditioning.
- Each project will have a different local climatic and utility condition and prices that influence the solution development.

The cooperation of KBR and Air Liquide is set up to develop the most advantageous solutions for any combination of the performance indicators and local conditions. Two examples of process schemes for different performance indicators and local conditions are discussed below.

Fig 2: **KBR Purifier-A℠ ammonia configuration with Air Liquide Lurgi™ ATR**



Source: KBR / Air Liquide

Stand-alone ammonia production at natural gas and CO_2 sink location

This case is a typical example of an ammonia plant location operating in island mode, requiring high overall energy efficiency, exporting low-carbon ammonia as the only product. The location provides direct supply of natural gas and offers a CO_2 sink (use or sequestration).

Fig. 2 shows the overall process scheme, combining Air Liquide's ATR and ASU with KBR's ammonia synthesis loop, producing low-carbon liquid ammonia as the sole commercial product.

The main requirements for this project, given the location, is to maximise the energy efficiency by minimising the electricity import. Due to the remote location of the plant, the electricity available from the grid would have a high carbon intensity, worsening the "carbon impact" of the plant. Thus, decreasing the electricity import enables both a higher efficiency and lower carbon intensity. This is accomplished by an optimised integration between the compressor drives of the ammonia loop, ASU and refrigeration loop with the steam generating front-end.

Air Liquide's experience in designing and operating both oxygen-blown reforming units and ASUs ensures a coherent and high level of safety and reliability. It also ensures that all operational cases are taken care of holistically.

Low-carbon ammonia production at scale is, most of the time, envisaged to make the supply chains economically viable, therefore, an additional merit of this set-up is that up to 10,000 t/d can be produced in one train of the ATR, ASU and NH_3 synthesis loop. For very large plants, Air Liquide can supply its proprietary carbon capture technology, Recticap™, which also enables the syngas treatment and carbon capture in one train.

KBR's ammonia synthesis loop, proven for world-scale ammonia production with the largest ammonia converter, does not require a purge gas recovery unit, as inert-free syngas is provided from the front-end. It is thus ideally suited to reach its full potential for energy transition, when combined with large-scale low-carbon oxygen blown syngas generation.

Energy transition project at industrial location

This case is another typical example where the ammonia plant is located in an industrial location (e.g. chemical park, integrated chemical plant), being able to utilise common services and supplies. Fig. 3 shows a configuration, where the natural gas intake can be minimised and a combined/flexible production of ammonia and hydrogen is implemented, achieving lowest carbon intensity targets with renewable electricity tie-in.

The main requirements of this set-up result from the location of the plant and the demand for minimised natural gas consumption and minimised carbon intensity. There are several process highlights of this set-up. First of all, the flexible hydrogen consumption, which can be adjusted to the customers' daily requirements. Furthermore, any CO_2 product specification can be fulfilled via Air Liquide's Cryocap™ H_2 technology: stringent CO_2 purity of more than 99.99 %, as well as pressurised or liquefied CO_2. As low-carbon electricity is available at these locations, the process integration focuses on the use of it in order to decrease the carbon intensity. This results in further reduction of the plant size and related capital expenditures.

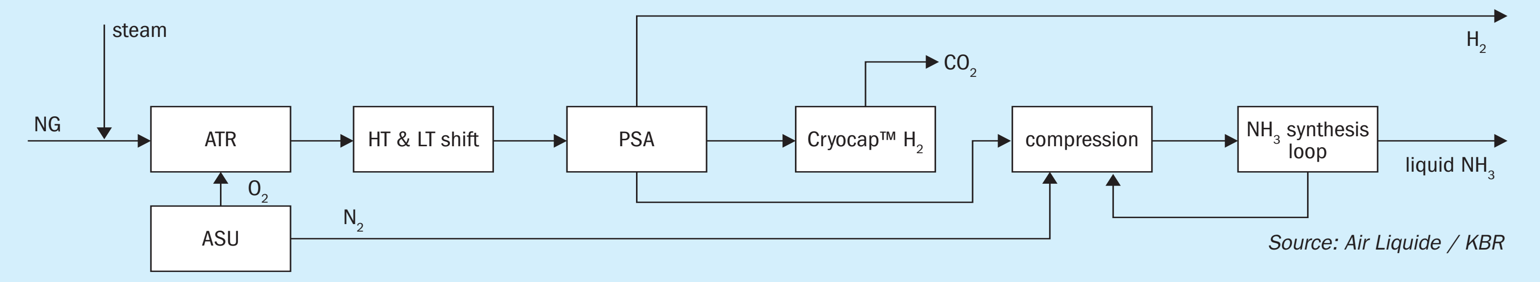
Air Liquide, as a leader in industrial gas production and operator of ASUs, can potentially also support customers' projects with the supply of oxygen and nitrogen as over-the-fence supply.

A first concrete example of the successful KBR and Air Liquide collaboration has been announced recently. Air Liquide, along with other stakeholders, have agreed to collaborate for the development of a production facility to produce more than 1.1 million tonnes per year of low-carbon ammonia in Houston, TX, USA. Air Liquide will provide technology and design for the ammonia syngas generation, including the ATR, ASU and Cryocap™ H_2, and KBR will supply their renowned ammonia synthesis loop.

Conclusion

The Air Liquide and KBR collaboration offers a true one-stop shop for the full scope of low carbon ammonia with ATR – a single point of contact, all units designed in house and an integrated set of process guarantees. ■

Fig 3: **Air Liquide's co-production configuration with KBR synthesis loop**



Source: Air Liquide / KBR

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MITSUBISHI HEAVY INDUSTRIES

Capex and opex evaluation of blue ammonia process configurations for higher CO_2 recovery

So Komada, Tsukasa Otani, Ryota Shimura

Comprehensive economic case studies have been conducted by Mitsubishi Heavy Industries, Ltd. (MHI) to compare the capex and opex of different blue ammonia process configurations for higher CO_2 recovery. At present, the hydrogen required for the commercial production of ammonia is typically derived from natural gas through steam reforming, which is highly energy intensive, requiring approximately 30 GJ of energy and around 2.4 tonne of CO_2 is emitted per tonne of product ammonia.

In the ammonia process, the CO_2 produced in the process stream is recovered by the CO_2 removal section before the ammonia synthesis loop, therefore the main focus to reduce the carbon footprint is how to reduce the CO_2 emission from flue gas in the reforming section.

In this article three different configurations of the blue ammonia process with significant high CO_2 recovery (99% in ammonia plant ISBL) are discussed and compared:

- Conventional SMR + post combustion capture (Fig. 1)
- ATR + post combustion capture (Fig. 2)
- ATR + H_2 fuel combustion (Fig. 3)

The ATR process was evaluated using the TOPSOE SynCOR Ammonia™ process and the post combustion capture was evaluated using MHI's novel Advanced KM CDR Process™

Conventional SMR process and ATR process

Reforming of natural gas in an ammonia plant can be carried out in two ways:

- conventional two-step steam-methane reforming (SMR) or
- single autothermal reforming (ATR)

In the conventional SMR process, approx. 30% of CO_2 is produced by primary reformer burners to provide endothermic reforming reaction heat by fuel combustion. Therefore, base carbon capture rate by the CO_2 removal section in the process stream will be approx. 70%. In recent years, modified versions of the SMR process with improved plant capacity, energy efficiency and CO_2 emissions have also been applied.

In ATR, the steam reforming reaction and partial oxidation occurs simultaneously in a reactor wherein pure oxygen is fed to combust internally a fraction of the methane feed. The exothermic combustion of methane provides the heat required for the steam-methane reforming reaction. Therefore, the external heat input required for preheating the feed in the ATR process is lower than that of a conventional SMR process. As a result, approx. 85 to 88% of the CO_2 generated in the ammonia process is directly captured from the process CO_2 section without any special efforts.

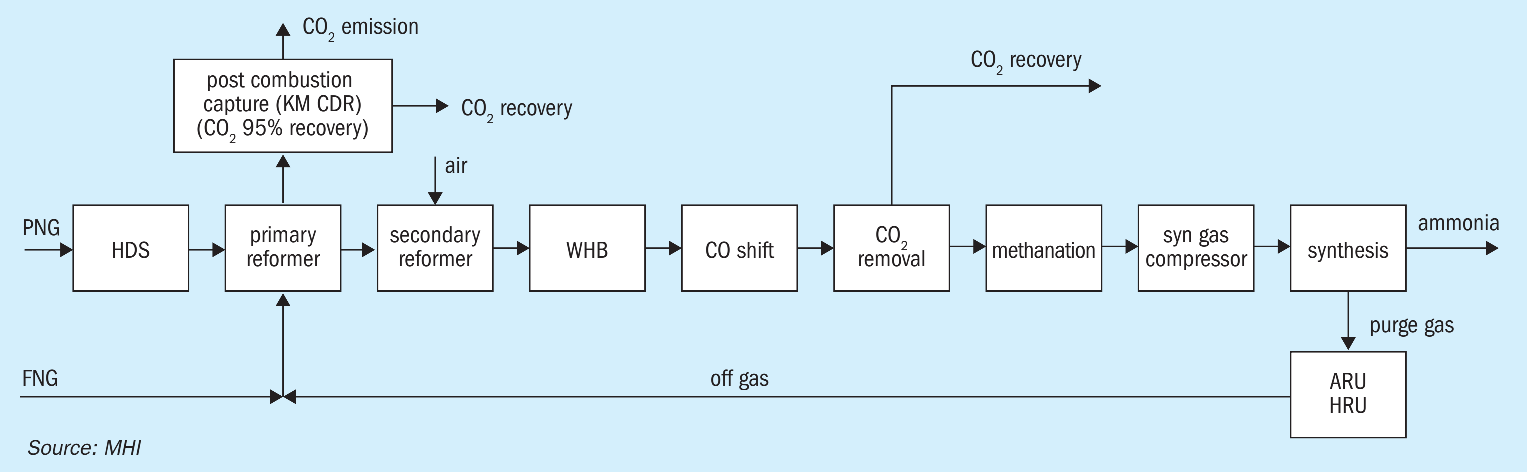
In addition to carbon footprint, ATR has other advantages over conventional SMR in terms of plant capacity, smaller footprint and energy consumption. ATR designs such as TOPSOE's SynCOR™ technology has been developed especially for large capacity plants e.g., with ammonia production up to 7,000 t/d NH_3. Since ATR does not require a tubular reformer, smaller plot area is possible. Moreover, the SynCOR™ reactor can operate with a lower steam-to-carbon ratio (S/C) below 1.0, typically at 0.6, compared to 2.8 to 3.0 in the conventional SMR process. Hence, energy consumption in the form of the required steam is reduced.

To further improve the CO_2 recovery rate, the hydrogen fuel combustion process and post-combustion CO_2 capture process can also be considered.

Hydrogen fuel combustion and post-combustion CO_2 capture

In recent blue ammonia projects, the hydrogen fuel combustion process is generally considered. In the hydrogen combustion process (Fig. 3), hydrogen produced in excess of the amount required for ammonia synthesis is used as a fuel for reforming section, thereby bringing CO_2 emissions from the process closer to zero. In the conventional ATR

Fig 1: **Case 1 SMR + post combustion process scheme**



Source: MHI

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process, CH_4 and CO as off-gas removed by the nitrogen wash unit are used as the main fuel source of the fired heater, while in the hydrogen combustion process, hydrogen production is increased by recycling the off-gas to the ATR inlet to realise a hydrogen fired heater. The hydrogen combustion process can achieve significant low CO_2 emissions without post combustion technology. The unconverted carbon continues to circulate through the front end until it is converted to CO_2 and recovered in the CO_2 removal section, thereby making it possible to achieve a CO_2 recovery rate of more than 99% from the ammonia process.

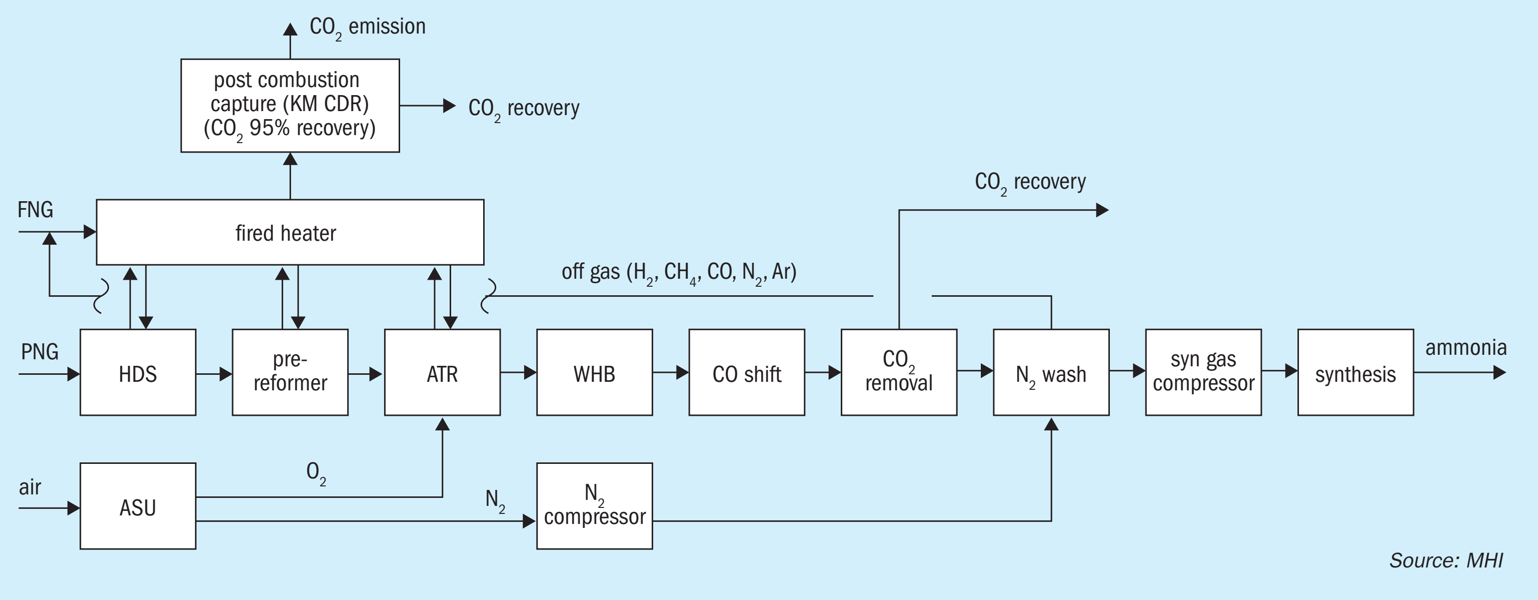
In the hydrogen combustion process, the flow rate through the entire front-end section is increased compared to a conventional ATR process. The higher the recovery rate required, the higher the off-gas recycle rate, thus having an impact on the opex and capex. As larger scale capacity is required for blue ammonia production as a clean fuel, the hydrogen combustion process may also be problematic in terms of equipment size in the front-end section such as the CO_2 removal unit.

Instead of producing hydrogen fuel, another option to reduce the plant overall CO_2 emission is to recover the CO_2 from the flue gas of natural gas-fired heaters. In the post-combustion CO_2 capture scheme (see Fig. 1 for SMR, Fig. 2 for ATR), the flue gas is treated to recover the CO_2 using a post-combustion technology with high carbon capture rate such as MHI's KM CDR™. In this configuration, excess hydrogen production and off-gas recycle is not necessary. Although additional investment for the carbon dioxide recovery facility is imperative, flue gases from other emission sources such as the auxiliary boiler and gas turbine can also be treated using the same facility.

KM CDR technology

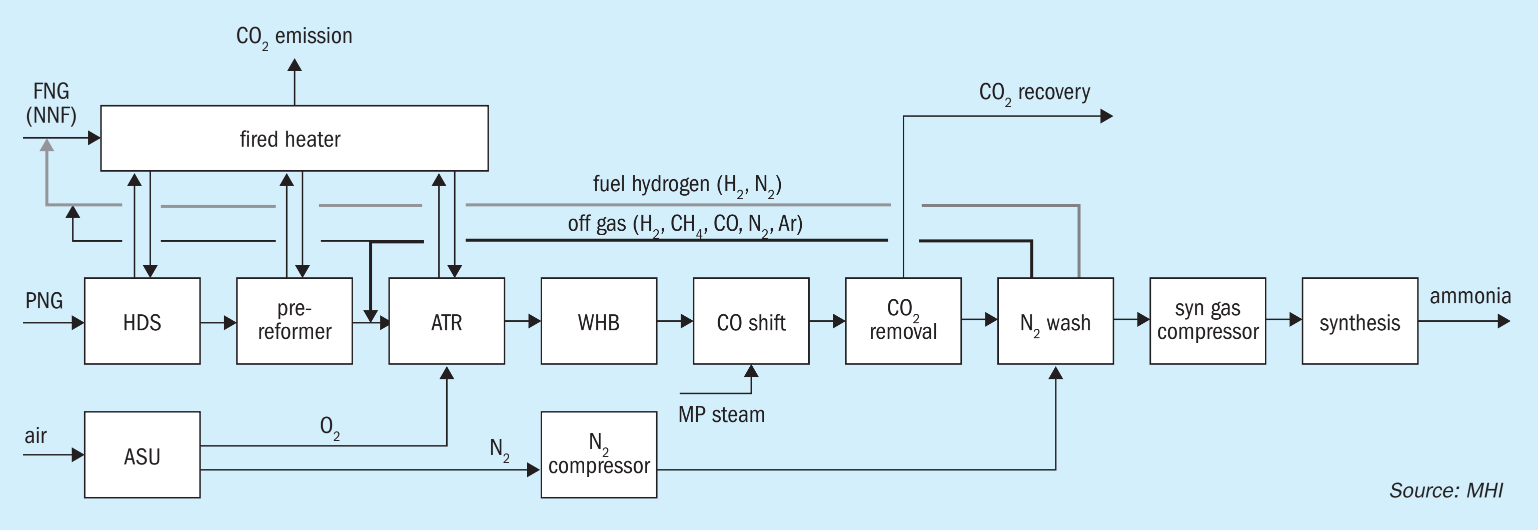
MHI's high efficiency chemical solvent post combustion process, the KM CDR Process™, has a proven record and knowledge based on 30+ years in-house research and development and experience. R&D started in 1990 in collaboration with Kansai Electric Power Co., Inc. (KEPCO), and in 1999 MHI delivered the first commercial plant using an advanced sterically-hindered amine-based solvent, KS-1™ in Malaysia. Since then, it has been delivered in 18 commercial plants (three under construction) including the world's largest post combustion CO_2 capture commercial plant (2016, Petra Nova, 4,776 t/d CO_2 capture). Most of

Fig 2: **Case 2 ATR + post combustion process scheme**



Source: MHI

Fig 3: **Case 3 ATR + hydrogen combustion process scheme**



Source: MHI

Table 1: **Major conditions and results of TCM demonstration test**

CO_2 Source	CCGT*, RFCC** flue gas
Solvent	KS-21™ solvent
Flue gas flow rate, Sm³/h	30,400 – 55,000
Flue gas CO_2 content, vol-%	4 – 4.3 (CCGT flue gas)
Regenerator pressure, barg	0.30 – 1.58
CO_2 capture rate, %	95 – 99.8

**CCGT: Combined Cycle Gas Turbine   **RFCC: Residual Fluid Catalytic Cracker*

these commercial references are aimed at CO_2 recovery from the ammonia plant reformer for enhanced urea production.

The KM CDR Process™ consists of three main sections:

- the flue gas cooler,
- the absorber (for CO_2 recovery)
- the stripper (for solvent regeneration).

Key technical feature of the technology are listed below:

- flexible CO_2 capture rate (90% to 98% or higher depending on the carbon intensity requirement);
- compatible with multiple flue gas sources;
- good dispatchability including emergency scenario based on dynamic simulation (no impact on the reformer operation by unexpected trip of CO_2 capture plant;
- flexible CO_2 product pressure from regenerator;
- various options for amine emission recovery system to meet specific project requirement, e.g., multiple washing stage, acid washing, and others;
- Applicable to existing facilities as a retrofit to enhance urea production or to reduce the CO_2 emission from the existing facility for blue ammonia.

Recent update – Advanced KM CDR Process™

With the need for CO_2 capture growing around the world, MHI has developed the Advanced KM CDR Process™, which uses a new solvent KS-21™, a technologically improved version of the former KS-1™ solvent.

A demonstration test of the new process has been completed at the Technology Center Mongstad (TCM) in Norway using exhaust gas from gas turbine as a CO_2 source. KS-21™ offers superior regeneration efficiency compared to the conventional solvent. In addition, the economic efficiency is further improved by reducing operating costs due to its low volatility and high stability against deterioration. The solvent consumption is more than 20% lower than that of KS-1™, depending on the conditions due to the suppression of thermal degradation of the solvent. It is also possible to increase the operating pressure of the regenerator, which can reduce the power of the CO_2 compressor by 10~15%, since the solvent can withstand higher temperature.

In the demonstration test at TCM, the new solvent greatly outperformed the conventional amine solvent (MEA) and also outperformed MHI's existing KS-1™ solvent. Major conditions and results of the TCM demonstration test are summarised in Table 1.

Economic case studies

Comprehensive economic case studies were conducted for a low carbon blue ammonia plant with natural gas as a feedstock. In this study, more than 95% of the CO_2 recovery rate in the ammonia plant inside battery limit (ISBL) is considered in all cases. For post combustion recovery, the Advanced KM CDR Process™ is applied as ISBL. For all cases, the required utilities and offsite facilities (such as the air separation unit, power generation, CO_2 compression / dehydration, auxiliary boiler, cooling water, etc.) are taken into consideration in the evaluation.

Electric power for normal operation is fully generated by the steam turbine generator in the plant, allowing the cost and/or carbon intensity of the import power to be ignored, to compare each case by minimum variables. River water is assumed as a water source and is treated by the water treatment unit to fulfil the quality requirement in each service. The ammonia storage tank and ammonia ship loading facility is also considered in the plant. Recovered CO_2 is compressed and dehydrated to fulfil the CO_2 pipeline requirement.

Case studies

The three cases considered were:

- Case 1: 3,000 t/d of ammonia, conventional SMR + Advanced KM CDR Process™ (post combustion capture from primary reformer flue gas).
- Case 2: 3,500 t/d of ammonia, ATR + Advanced KM CDR Process™(post combustion capture from fired heater flue gas).
- Case 3: 3,500 t/d of ammonia, ATR + hydrogen combustion (internal off-gas recycle to improve the CO_2 recovery).

In Case 1, the conventional two-step reforming process (SMR + air fired ATR) is applied in combination with the Advanced KM CDR Process™ (see Fig. 1). 95% of the CO_2 in the primary reformer flue gas is recovered by the KM CDR unit. The overall CO_2 recovery rate in the ammonia plant ISBL is more than 95% in consideration of process CO_2 removal unit.

In Case 2, the Topsoe SynCOR Ammonia™ process is applied in combination with the Advanced KM CDR Process™ (see Fig. 2). 95% of the CO_2 in the fired heater flue gas is recovered by the KM CDR unit. The overall CO_2 recovery rate in the ammonia plant ISBL is more than 99% in consideration of process CO_2 removal unit.

In Case 3, the Topsoe SynCOR Ammonia™ process is applied (see Fig. 3). The produced hydrogen (and nitrogen) is extracted from the nitrogen wash unit and used as a fuel for the fired heater. The nitrogen wash unit off-gas is recycled to the ATR to avoid CO_2 emissions due to carbon (CH_4 and CO) combustion. The overall CO_2 recovery rate inside battery limits is more than 99% which is achieved by pre-combustion capture only. Part of the nitrogen wash unit off-gas is used as fired heater fuel to avoid the accumulation of inerts. Due to the off-gas recycle, the front-end capacity is larger than Case 2 to produce hydrogen fuel.

A summary of the case comparison is shown in Table 2 and the summary of CO_2 recovery rate is summarised in Table 3.

In this study, carbon recovery is discussed for Scope 1, however, it is also possible to achieve more than 95% CO_2 recovery for Scope 1+2 using KM CDR technology to treat flue gas from the auxiliary boiler and/or gas turbine generators without renewable energy. In such case, further capex benefit is expected since the KM CDR unit can treat several flue gases in one unit.

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Results and discussion

Table 4 compares the operating and capital expenses based on the defined cases. The results show that Case 2 (ATR + post combustion capture) can achieve the lowest opex and capex. For smaller ammonia plant capacity, Case 1 (SMR + post combustion capture) will have the lowest capex. For Case 3 (ATR + H_2 fuel), both opex and capex is slightly higher than Case 2. Although Case 2 requires a post combustion capture plant to recover the CO_2 from the fired heater flue gas, Case 3 requires larger front-end equipment and more feedstock due to the production of fuel hydrogen. The power consumption for the ATR process is higher due to the heavy duty equipment such as the air separation unit, but total opex is lower than the SMR process. The results are based on 99% CO_2 capture in an ammonia plant ISBL, the optimal process configuration in terms of opex and capex will vary depending on the required CO_2 recovery and plant capacity. If the required CO_2 recovery rate is 85~90%, the hydrogen fired process would be competitive compared to the ATR + post combustion capture configuration since the impact on front-end capacity is small.

Table 5 shows a qualitative evaluation for each case. Case 3 has an advantage in terms of plant operability since it has no KM CDR unit. On the other hand, Case 1 and Case 2 have the advantage of a common post combustion CO_2 capture unit for not only reformer flue gas but also boiler and GTCC flue gas.

ATR with hydrogen recycle (Case 3) is often selected for new blue ammonia studies to reduce CO_2 emissions for reasons such as operability, but the above results shows that ATR + a post combustion scheme (Case 2) also has a competitive edge in terms of both of opex and capex for blue ammonia. The post combustion plant will be more competitive in cases where the boiler or power-generating plant is constructed together with the ammonia plant, since the post combustion capture plant (e.g., the KM CDR Process™) can treat all flue gases from the ammonia plant, boiler, and power generation plant in one unit. The post combustion capture unit can be individually operated with the ammonia plant easily and is also suitable for revamp projects. ■

Table 2: **Case summary**

	Case 1	Case 2	Case 3
Ammonia production, t/d	3,000	3,500	3,500
Ammonia process	SMR	ATR	ATR
Post-combustion capture	Yes (95% capture)	Yes (95% capture)	No
Reformer, fired heater fuel	NG + off-gas	NG + off-gas	Hydrogen + (off-gas)*

** Most of the off-gas from nitrogen wash unit is recycled to the reformer to minimise the CO_2 emissions.*

Source: MHI

Table 3: **CO_2 recovery rate (ISBL)**

CO_2 generation	Case 1	Case 2	Case 3
Process, %	72	85	> 99
Flue gas, %	28	15	< 1
Total, %	100	100	100
CO_2 recovery – Scope 1	**Case 1**	**Case 2**	**Case 3**
from process*, %	100	100	100
from flue gas, %	95	95	-
Overall CO_2 recovery, %	> 98.5	> 99	> 99

**In case of no upset of CO_2 removal unit such as natural gas composition change, sudden climate change and foaming.*

Source: MHI

Table 4: **Operating and capital expenses (per tonne NH_3)**

	Case 1	Case 2	Case 3
Ammonia production, t/d	3,000	3,500	3,500
NG consumption, %	100	95.2	98.6
Power consumption*, %	100	105	112
Opex, %	100	95	98
Capex, %**	100	97	99

**The power is fully generated with a steam turbine generator in the plant.*

Source: MHI

Table 5: **Qualitative evaluation**

	Case 1	Case 2	Case 3
Plant operability	KM CDR unit operation	KM CDR unit operation	-
Plot area	KM CDR unit	KM CDR unit Air separation unit No primary reformer	Larger front-end size Air Separation Unit No Primary Reformer
Additional CO_2 capture from boiler / GTCC to improve carbon footprint	Treated by existing KM CDR unit	Treated by existing KM CDR unit	Additional post combustion capture unit

Source: MHI

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CASALE

Casale blue ammonia processes

Casale has embraced the energy transition challenge focusing on developing sustainable technologies for the production of various base chemicals, including blue ammonia from natural gas resources.

Casale's technology portfolio for blue ammonia production includes:

- HyPURE-N
- N-ELEVA BLUE

HyPURE-N

Hypure-N is a blue ammonia process designed for large scale production (from 3,500 t/d and above in a single train) with very low carbon intensity. Virtually all of the CO_2 generated in the front-end is captured and compressed, up to e.g., 200 bar g, for sequestration or other utilisation purposes, e.g., for enhanced oil recovery. CO_2 recovery as high as 99% can be achieved.

High level of decarbonisation is achieved through the adoption of a pre-reformer and pure O_2-blown auto-thermal reforming (ATR) front-end, operated at high pressure and with a low steam to carbon ratio.

This patented reforming scheme is key to obtaining large capacities and high energy efficiency, whilst reducing the generation of high temperature heat (limited only to preheating purpose), which is the main cause of the high carbon emissions through the stack in traditional "grey" processes.

The syngas generated in the reforming section is processed in a CO shift unit, made up of Casale Axial-Radial® high temperature shift (HTS) and low temperature shift (LTS) converters, and then purified in two steps: first in an amine-based CO_2 removal section and then in a liquid nitrogen wash section (see Fig. 1).

The inert-free make-up gas so obtained is compressed before being sent to a Haber-Bosh based ammonia synthesis loop where low-carbon, cold ammonia is produced.

With the exception of the syngas and the refrigeration compressors, which are driven by steam turbines, all other movers utilise electrical power generated within the plant. The process is based on a specific pre-combustion philosophy whereby all fuel requirements are met by utilising part of the carbon-free syngas generated plus other off-gases. As a result, the natural gas requirement is reduced along with the associated CO_2 emissions generated from the burning of natural gas, which is central to meet the low environmental impact target.

The process is extremely flexible and may be tailored to specific needs in terms of carbon capture requirements and energy consumption.

Key benefits include:

- low energy consumption – as low as 7.4-7.6 Gcal/tonne LHV basis, including utilities and final CO_2 compression at battery limits;
- reduced levelised cost of ammonia (LCOA);
- potentially no steam/power import or export required;
- total CO_2 emissions per tonne of ammonia produced – from 0.08 to 0.02 t.

N-ELEVA BLUE

Casale also offers another process, named N-ELEVA BLUE, for the production of blue ammonia, best suited for capacities ranging from 1,000 t/d to 3,500 t/d. The N-ELEVA BLUE process is based on a conventional SMR ammonia plant with fuel gas supplied from the low carbon syngas available downstream of the CO_2 removal section.

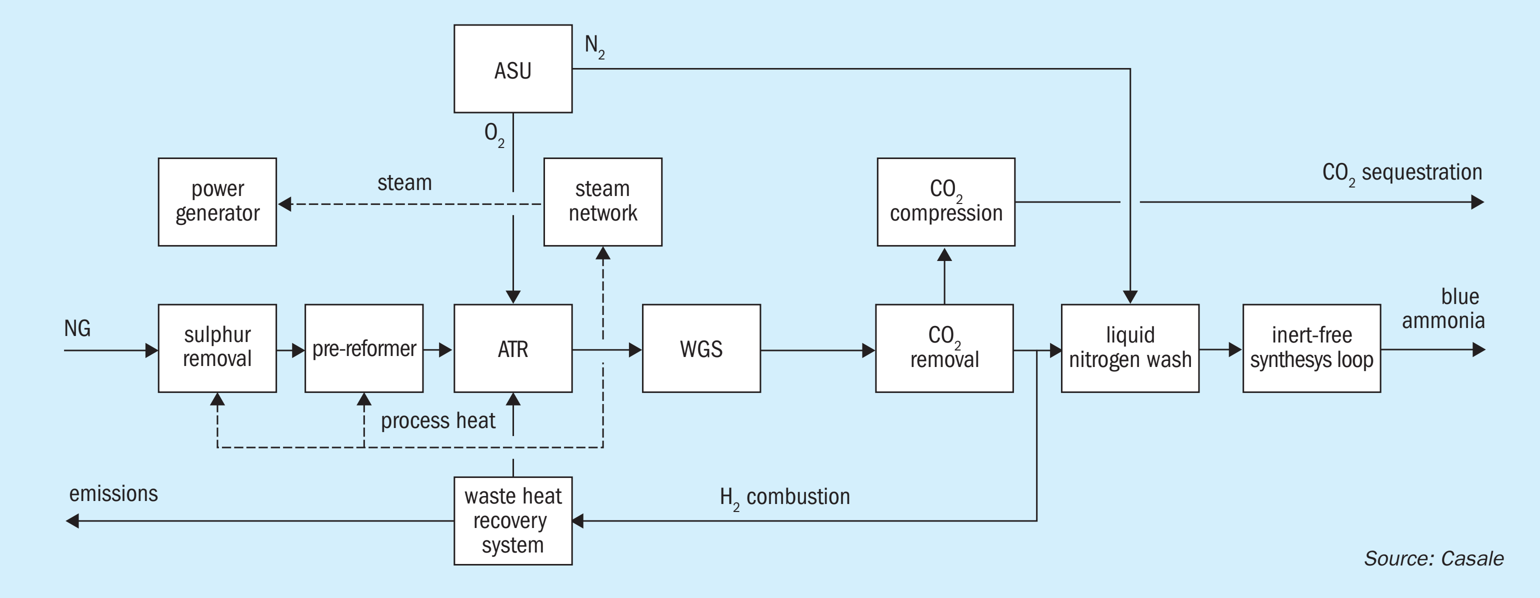
A block flow diagram of the N-ELEVA BLUE process is shown in Fig. 2.

Synthesis gas preparation

Desulphurisation: The natural gas is first desulphurised over a conventional cobalt-molybdenum based catalyst followed by absorption over a ZnO bed.

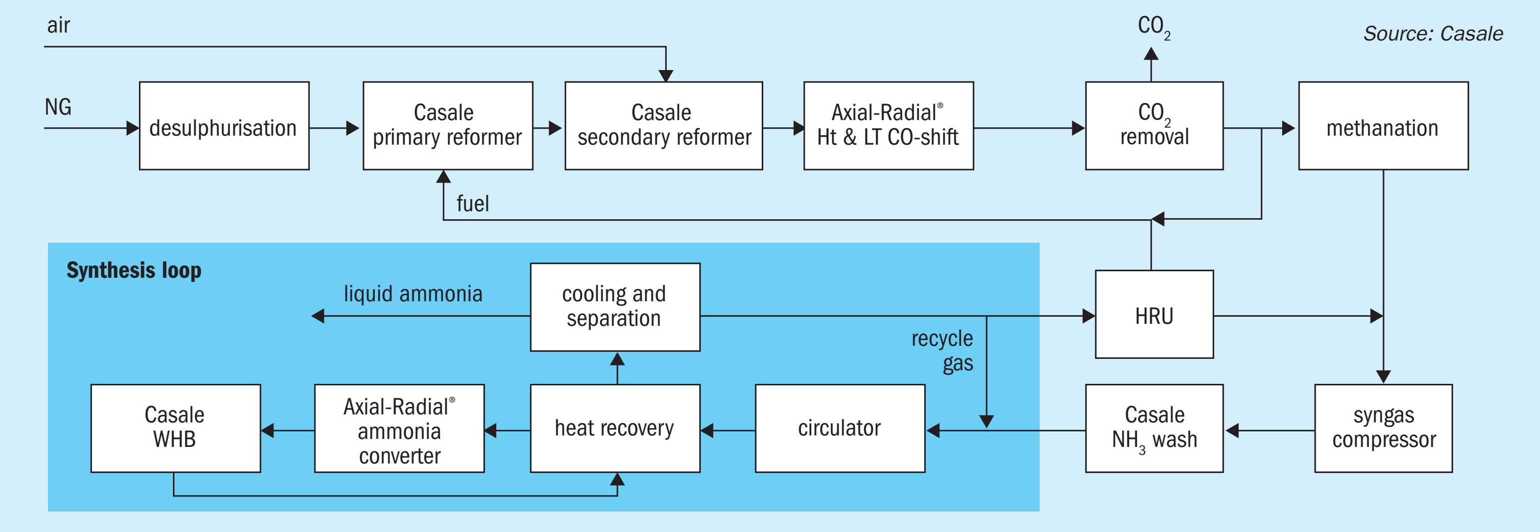
Steam reforming: After mixing with steam and being preheated, the desulphurised gas passes through the catalyst tubes of the primary reformer furnace, where

Fig 1: **Block flow diagram of HyPURE-N blue ammonia process**



Source: Casale

Fig 2: **Block flow diagram of N-ELEVA BLUE ammonia process**



Source: Casale

it reacts to form hydrogen and carbon oxides. The fuel for the reforming furnace is mainly natural gas; the combustion air is preheated in the reformer flue gas heat recovery train (convection section).

Secondary reforming: The reforming process is completed in a catalytic reactor using the heat generated by the partial combustion of the incompletely reformed process gas from the primary reformer, using process air introduced through a special patented Casale burner. The air flow rate is adjusted to obtain the correct amount of nitrogen to achieve a 3:1 H_2/N_2 ratio in the final synthesis gas mixture, before it is admitted to the ammonia synthesis section.

CO shift section: After cooling to an appropriate temperature in a waste heat boiler generating high-pressure steam, the bulk of the carbon monoxide (CO) content of the raw synthesis gas is converted to CO_2 and H_2 by reaction with steam in a two-stage process (high temperature and low temperature shift). Casale Axial-Radial® flow internals are used in both shift reactors. A VPSA can be optionally used to enrich the air going to the secondary reformer.

CO_2 removal: After cooling and condensation of the surplus steam, the gas next passes into the absorption column of a high efficiency regenerative CO_2 removal system (third-party solution technology), leaving with a CO_2 content of <1,000 ppmv. The CO_2 is recovered from the rich solution in the regenerator of the CO_2 removal system and made available for other uses. For special applications Casale can supply proprietary hardware for this section.

Methanation: Downstream of the CO_2 removal section, part of the syngas (CO_2 depleted) is routed to the primary reformer fuel gas system. The process gas is then reheated before undergoing a final purification stage (catalytic methanation) where any remaining carbon oxides are converted back to methane by reaction with hydrogen. The final synthesis gas is cooled and fed to the ammonia synthesis section.

Ammonia synthesis and separation

Compression: The fresh make up gas (MUG) is compressed in a centrifugal compressor up to the required pressure for ammonia synthesis. The compressor has a low pressure (LP) casing and a high pressure (HP) casing. Upon leaving the LP casing the gas is dried by washing with liquid ammonia using a Casale proprietary ammonia scrubber. This removes the last few traces of oxygenates (mainly CO_2 and H_2O), which are a poison for the synthesis catalyst.

Part of the hydrogen recovered in the loop purge gas hydrogen recovery unit (HRU) is added to the MUG at this stage, whilst the remainder is added at the suction of the compressor. The dry synthesis gas flows directly to the suction of the HP casing and is compressed to the synthesis loop pressure.

Ammonia synthesis: Before entering the ammonia converter, the combined make-up gas and recycle gas stream from the circulator is fed to the hot gas-gas heat exchangers, in which it is heated by hotter gas returning from the converter. The preheated gas then enters the ammonia converter, where it reacts over an iron-based ammonia synthesis catalyst.

The ammonia converter is the well proven Casale Axial-Radial® design incorporating three adiabatic, beds, with intermediate cooling by two inter-bed heat exchangers. At the converter outlet, the product gas is cooled, first in a waste heat boiler and then in the hot gas-gas heat exchangers, before condensing the ammonia produced, first in a water cooler, then in the "cold" gas-gas exchanger and lastly in the ammonia chillers.

Ammonia refrigeration: The ammonia refrigeration section mainly consists of a multi-stage compressor. The ammonia vapours leaving the last stage discharge is condensed by cooling and expansion and is collected in the refrigerant receiver.

Purge gas treatment

Ammonia recovery: To prevent excessive build-up of inerts in the synloop, a portion of the recycle gas is continuously withdrawn as "purge gas". Along with other inert gas from the refrigerant ammonia receiver, this gas is washed with water in two separate packed columns to absorb its residual ammonia content.

Hydrogen recovery: The washed purge gas is processed in a hydrogen recovery (HRU) unit, which removes most of the hydrogen it contains for it to be returned to the synthesis loop.

Process benefits

Key benefits include:

- low energy consumption (from 7.9 Gcal/tonne LHV basis);
- reduced capex;
- the steam export can be adjust according to specific needs, from nil export to maximum export;
- compact and simple lay-out, with all sections arranged in a way to minimise the overall footprint and optimise the connections across the different sections of the plant.

The total CO_2 emissions to the atmosphere per tonne of ammonia produced are up to 0.1-0.15 t.

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JOHNSON MATTHEY

Low carbon intensity ammonia using JM's LCH technology to deliver net zero targets

Matt Cousins

Ammonia production is a highly energy-intensive process, which currently accounts for about 2% of global energy consumption with commensurate CO_2 emissions. The challenge facing the ammonia industry is twofold - how to increase overall ammonia production without increasing overall CO_2 emissions; and how to decrease the CO_2 intensity of existing ammonia manufacturing assets.

Johnson Matthey's (JM's) LCH technology is an effective way of decarbonising an ammonia flowsheet which offers:

- high feedstock efficiency;
- enables use of power from renewable sources;
- higher CO_2 capture rate;
- proven, reliable and safe technology;
- enhanced feedstock flexibility.

In conceptual terms, an ammonia manufacturing process consists of a hydrogen production step followed by a synthesis step in which hydrogen reacts with nitrogen to make ammonia.

As most CO_2 emissions are associated with the hydrogen production step, decarbonised hydrogen production is a prerequisite to decarbonised ammonia production.

When low carbon hydrogen is produced more CO_2 is captured as there is far less atmospheric combustion.

Many ammonia projects are in areas with increasingly abundant renewable energy resources. Consequently, it is no longer necessary to constrain the design of an ammonia plant to generate sufficient steam to provide all the motive power required to drive the main compressors. Instead, ammonia plants can be designed and optimised around renewable power import, as illustrated in Fig. 1.

The benefits from this approach include:

- lower carbon intensity;
- lower specific gas consumption;
- lower capital cost.

Johnson Matthey LCH technology

Advanced gas reforming is the principal technology used for blue hydrogen production. It consists of either an autothermal reformer (ATR) or an ATR coupled with a gas heated reformer (GHR).

LCH technology with ATR

The ATR combines two processes that take place in a primary reformer:

- heating of the process gas (on the air side of the tubes in a SMR);
- reforming of the feedstock (on the process side of the tube in a SMR).

The ATR carries out both these functions on the process side of the flowsheet. It does this by introducing oxygen through a burner, which entrains the oxygen flow with the process gas flow. This happens in the area below the burner. Simultaneously the gas stream ignites due to the flammability of the gas mixture, and it is partially oxidised (burnt) creating heat, resulting in the formation of CO and H_2O. These processes take place in the neck of the JM ATR design.

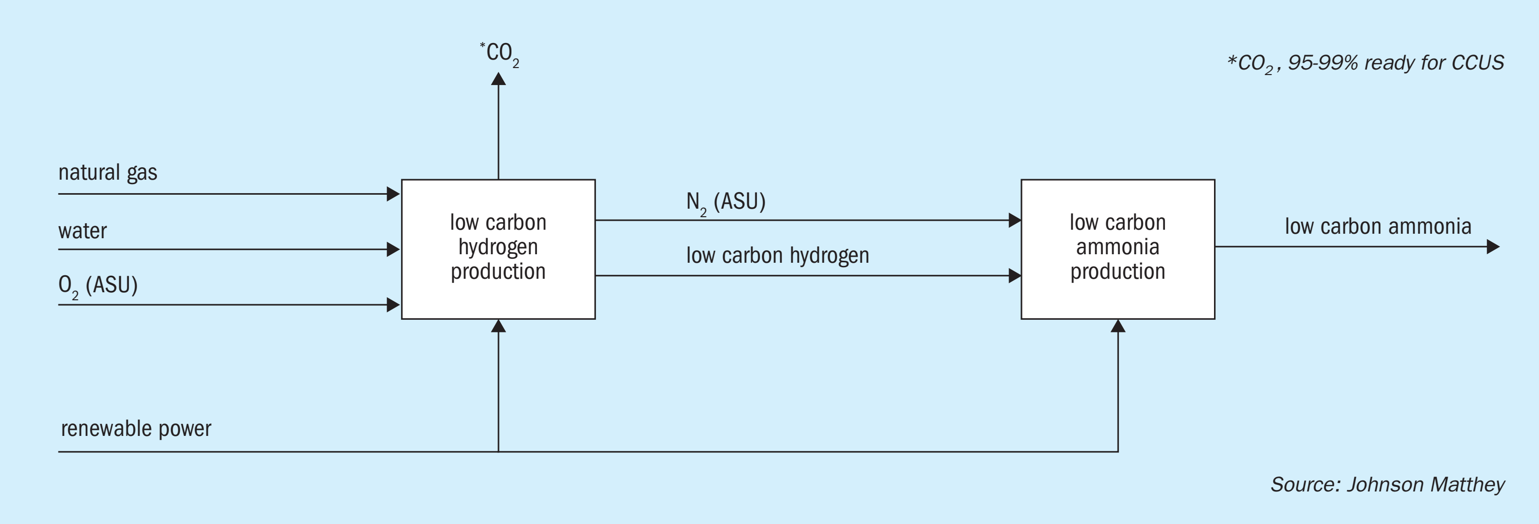
The hot, well mixed gas stream then passes through a catalyst bed, where the reforming reactions take place, producing hydrogen by reacting process gas with steam as shown by the general reaction equation below:

$$CH_4 + H_2O \rightleftharpoons CO + 3H_2$$

CO also reacts with H_2O in the process, to produce H_2, and CO_2 via the water gas shift process.

Due to the elevated temperature (typically 950 to 1,050°C exit the ATR), the equilibrium position favours high methane conversion, and the kinetics to reach the equilibrium point are elevated. Therefore, when using an active catalyst with properties that protect it from the

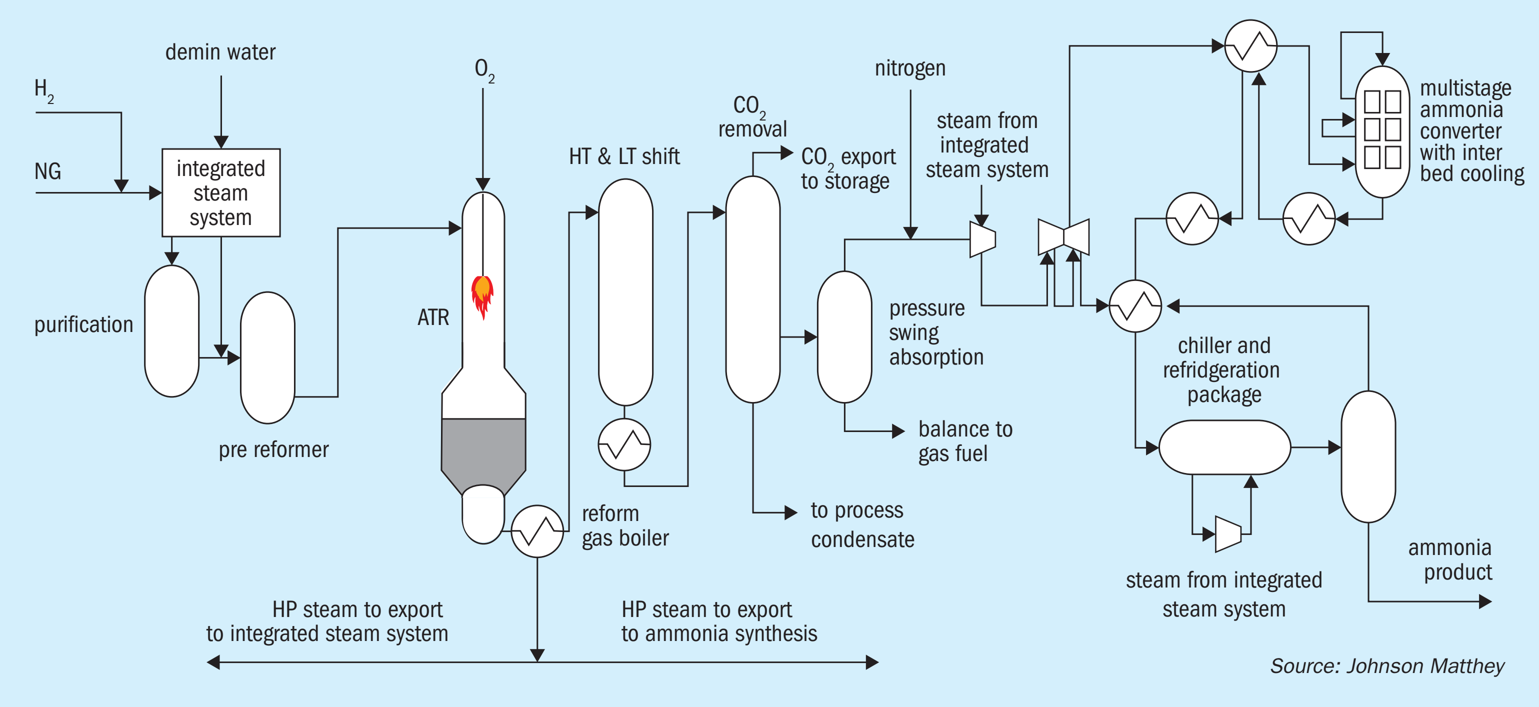
Fig 1: **Basic flow diagram of LCH technology based production integrated with renewable power network**



*CO_2, 95-99% ready for CCUS

Source: Johnson Matthey

Fig 2: **LCH technology with ATR flowsheet integrated with an ammonia loop to provide low carbon ammonia**



Source: Johnson Matthey

harsh process conditions, long lives and high effectiveness can be gained from relatively small volumes of catalyst.

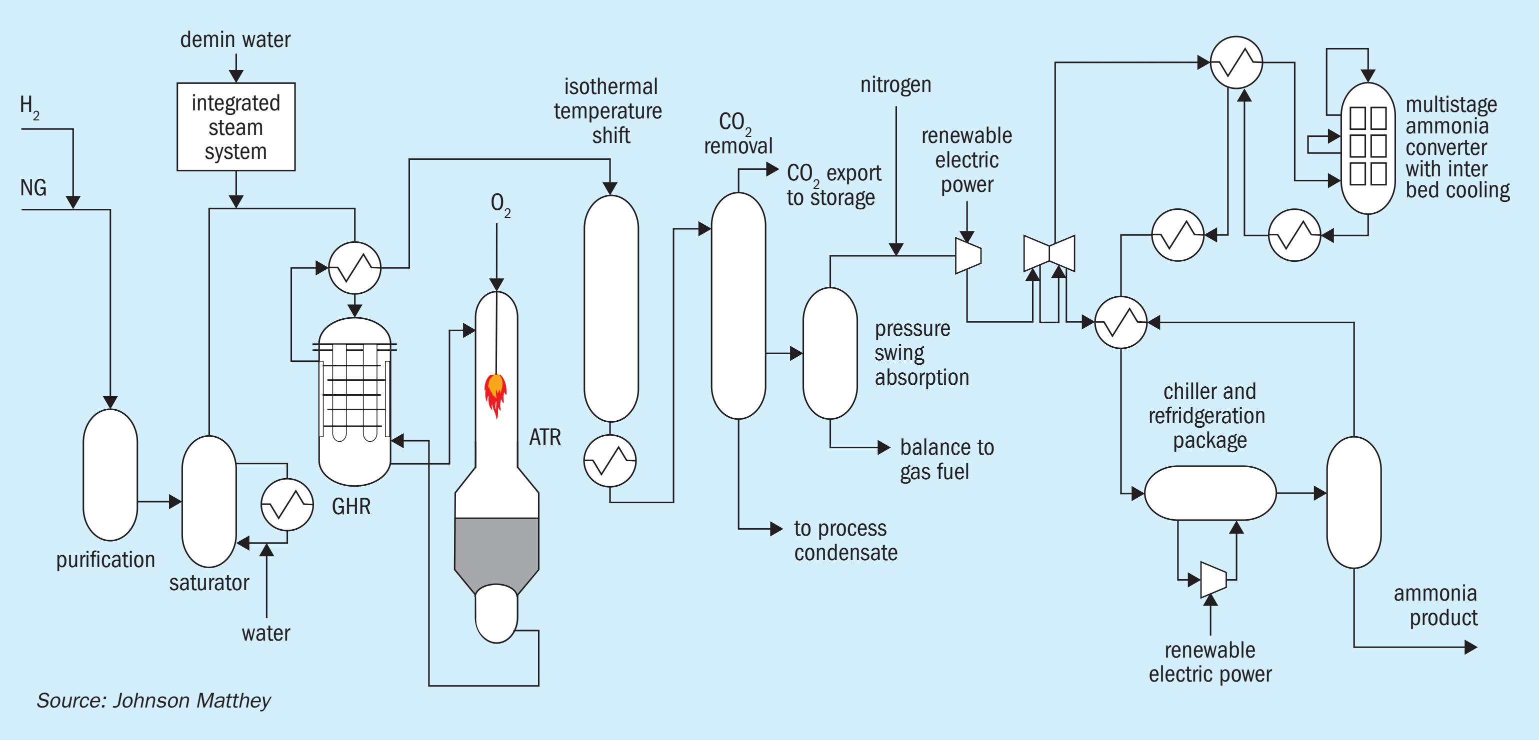
The JM LCH technology with ATR flowsheet (Fig. 2) may be integrated with an ammonia synthesis loop in an analogous way to what we know today, that uses high grade steam exit the secondary reformer. The ATR flowsheet uses the involuntary steam raised from the reform gas boiler(s), exit the ATR, to provide motive steam.

The LCH technology flowsheet provides a low level of methane slip exit the ATR and uses a PSA to remove trace CO slip from the WGS section. The hydrogen product has a low inert level and the nitrogen also has high purity because it is a product of the air separation unit (ASU), not an air intake as is typically used today. This means there are less inert gases built up in the loop, lowering the purge, so elevating the effectiveness of the loop. This has operational cost benefits and means the capex is lower for a given production capacity because equipment is smaller.

LCH technology with GHR / ATR:

Having just described a LCH technology with an ATR that provides involuntary steam raising, we now review a flowsheet that can be integrated to provide low steam export from the hydrogen production process. This enables the use of external renewable electrical power. This can lower the carbon intensity of the product an lower the cost of the production as less natural gas is needed per unit of ammonia production.

Fig 3: **LCH technology with GHR/ATR flowsheet integrated with an ammonia loop to provide low carbon ammonia**



Source: Johnson Matthey

This configuration uses the heat exit the ATR to directly drive the reforming reaction in a GHR (see Fig. 3), where the GHR replaces the reformed gas boiler in the ATR flowsheet, using the high-grade heat on the shell side of the GHR, to drive approximately 30% of the total hydrocarbon reforming reaction, on the tube side, before the gas enters the ATR. This JM technology is recognised for leading the way in making best use of the available sensible heat.

The ATR then completes the remaining 70% of the reforming reaction, through the processes already described. In this case the size of the ATR, for the same hydrogen production, can be smaller. It follows that the ASU can also be smaller, as less oxygen is required. This has two effects:

- it lowers operational costs, as less power is needed for the ASU. Instead, there is direct use of the high-grade heat from the ATR;
- it is capex neutral, as the GHR adds a unit operation, while the ASU is smaller and lower in cost.

Other benefits of an GHR/ATR flowsheet are:

- the natural gas requirement per unit of hydrogen (and so ammonia) is reduced by typically 15%, as no gas is used to raise steam;
- it follows the CO_2 production is also reduced proportionally by the same amount;
- as future import power decarbonises, the LCH flowsheet is future proofed in that it will immediately be able to take advantage of green power while making hydrogen with maximum feed gas efficiency.

The benefits from the high purity gases supplied to the ammonia loop are still provided. These advantages are fundamental traits of LCH technology flowsheets.

Two cases have been descibed – one where a LCH technology flowsheet provides of the steam requirement by integrating LCH technology with an ATR flowsheet with an ammonia loop; the other where the steam demand is substituted with electrical power, and there is minimal steam generation from the hydrogen section of the LCH flowsheet with GHR/ATR. This small amount of steam is combined with steam raised from the ammonia loop and can be used to offset the import of OSBL (outside battery limits) power through driving a turbine. It follows optimisation to import renewable power and does not necessitate elimination of all steam turbines. JM's LCH technology is flexible so can be optimised on a project specific basis according to metrics such as:

- gas availability and cost;
- electrical power availability, cost and CO_2 credentials;
- carbon intensity requirement of product ammonia.

References for LCH technology

The LCH technology is a combination of mature, well proven unit operations which are already utilised in other JM technologies and when effectively integrated can produce low carbon hydrogen and ammonia at a large scale.

Examples from integrating LCH technology with an ammonia loop

JM have modelled the LCH technology schemes shown in Figure 2 and 3.

The scenario illustrated in Fig. 2 shows the ATR flowsheet, integrating the high pressure (HP) steam raised in the reformed gas boiler, downstream of the ATR, and that from the heat recovery in the ammonia loop to provide the motive power to the loop.

The scenario illustrated in Fig. 3 shows the GHR/ATR flowsheet, this generates electric power from the steam raised which is predominately from the ammonia loop. This is combined with outside battery limits (OSBL) power to meet the motive power demands of the loop. This electric scheme means there is no shared HP steam system, so should be considered where flexibility is required between hydrogen:ammonia production, as it does not necessitate ammonia production to close the energy balance. It is also the flowsheet most advantaged to benefit from increasingly available renewable power.

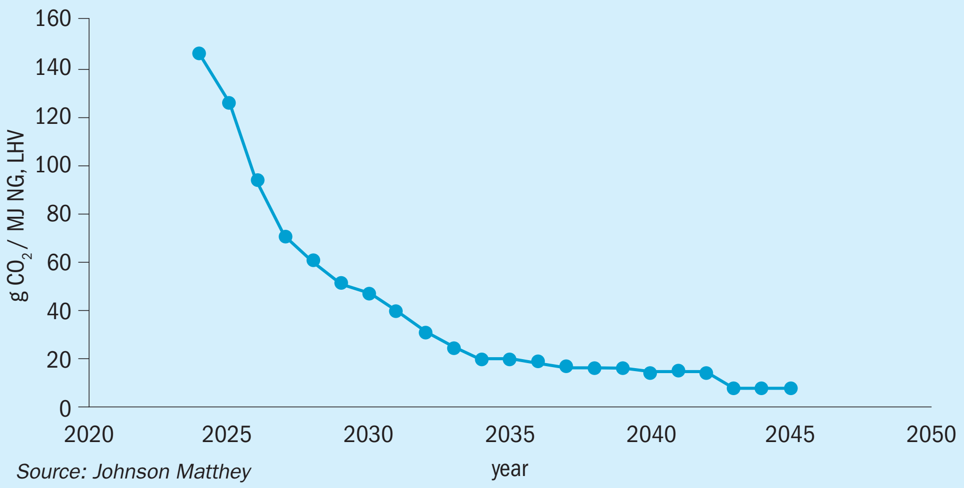
The ASU and CO_2 removal may be steam or electrically driven and is a flexibility in either design. In each case the designs have been developed to provide the same ammonia capacity and carbon capture rate, in this case 97%. It is important to note that the carbon capture rate can be tuned, if a higher (or indeed a lower) value is needed.

The efficiency of the power plant increasing and how this would favourably affect the overall energy efficiency of the blue ammonia process was also considered.

Differences to be considered when making comparisons between low carbon ammonia flowsheets (making "blue" ammonia) and current non-decarbonised SMR flowsheets (making "grey" ammonia) are:

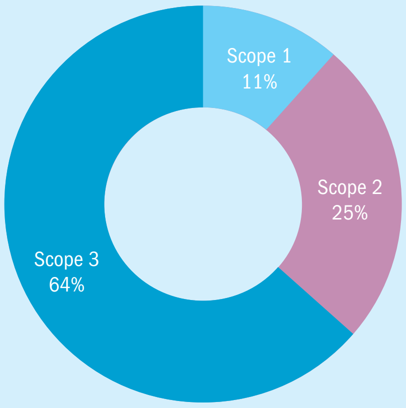
- Low carbon technology captures more CO_2, so energy demands on the CO_2 capture system are higher than an SMR flowsheet, where about 70% of the CO_2 reaches the CO_2 removal system. This adds to the energy demand, as >95% of the CO_2 reaches the CO_2 removal system and is captured.
- CO_2 compression also adds to the energy demand of low carbon technology to facilitate storage.

Fig 4: **Reducing scope two emissions projected by the UK standard for electrical power feed into the grid**



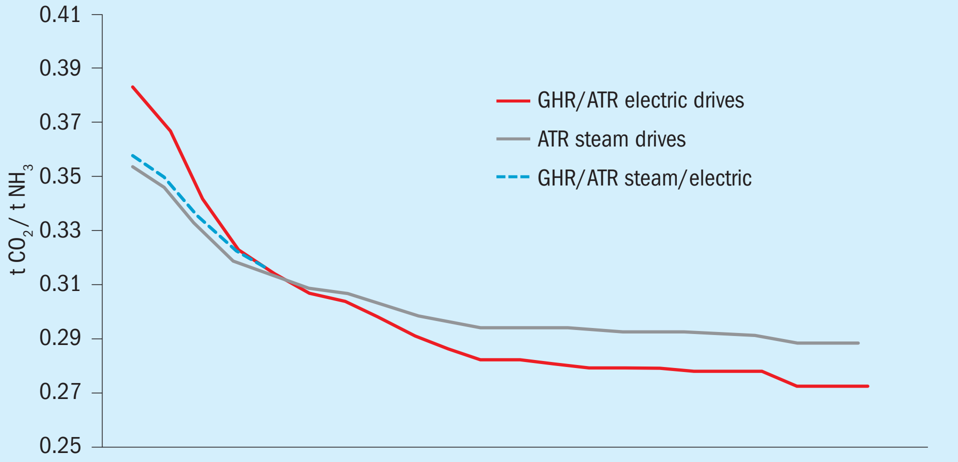
Source: Johnson Matthey

Fig 5: **% Impact of scope 1, 2 and 3 emissions for a typical blue ammonia flowsheet***



Basis: from NG with low OSBL power import
Source: Johnson Matthey

Fig 6: **Total carbon Intensity of LCH flowsheets integrated using electric or steam motive power**



Source: Johnson Matthey

Therefore, it is to be expected that the energy demand per tonne of low carbon ammonia is higher than that of grey ammonia. Assessments of this energy penalty are of the order of 10%.

Considering the impact of electrical power plant efficiency, both LCH technology flowsheets see some benefit from this change, as both flowsheets use some electric drives, for example the ASU package. Nevertheless, as the grid changes, flowsheets that make least steam and use electric power instead would be most advantaged, as power plant efficiency increases.

Improvements in power generation efficiency leads to improvements in the efficiency of plants which consume electric power. This improvement can offset the blue ammonia energy penalty referred to above.

The wider energy ecosystem will change over the depreciation period for plants built today.

The carbon intensity of the electricity will reduce, as renewable power becomes increasingly available. This will reduce the carbon intensity of the ammonia product.

Fig. 4 shows the reduction of scope 2 emissions projected by the UK for electical power feed into the grid.

Traditionally ammonia plant efficiencies have been calculated using the assumption that electrical energy consumed is produced from marginal natural gas. A conversion factor of 40% is often used for this conversion efficiency. As power grids become increasingly based on renewables, this dependency is less relevant; for example, a fully renewable grid offers an efficiency loss that approaches zero.

Considering the total carbon intensity, not just direct emission from production, is part of most standards being put in place, this means everything within the emissions system boundary must be considered, including the gas, electric and water supply.

Analysis of the total carbon intensity of the flowsheets based on 2024 carbon intensity data shows how scope 1 emission values (i.e. direct emissions, a company causes by operating the things it owns or controls) are the smallest factor, and the dominate factors are from the import of the gas and electricity (see Fig. 5).

The UK low carbon hydrogen standard is <2.4 kg CO_2 per kg H_2. This, the most stringent global standard today, can be translated to a value for NH_3, based on the weight percentage H_2 in NH_3. This results in a value of <0.42 kg CO_2 per kg NH_3.

Considering the total CO_2 emitted from the natural gas processed and the electrical power, both LCH flowsheets offer a carbon intensity below the translated total value of 0.42 kg CO_2 per kg NH_3. However, over time the flowsheet with the lowest carbon intensity will change as the relative carbon intensity of gas and electric power change.

The data in Fig. 6 shows the decreasing carbon intensity trends for both flowsheets.

Today a flowsheet utilising steam raised from natural gas has the lowest carbon intensity value, so the focus would currently be to consume as little gas as possible to achieve this. Over time, electrical drives offer the lowest carbon intensity option. This should not be surprising as this flowsheet allows the operator to access increasingly low carbon intensity OSBL power.

The dotted line illustrates that although two extremes have been selected, dominated by steam or electric, there is the option to design a flowsheet to use a mix of steam and electricity and create an optimum for an individual project. Either flowsheet can the optimised to maximise the value based on the cost and availability of gas and electricity and the overall carbon intensity to provide the optimal solution.

Conclusion

LCH technology (both with ATR or GHR/ATR) meets low carbon hydrogen criteria. It de-risks the transition to low carbon ammonia production as each unit operation is industrially proven. Which LCH technology flowsheet offers the best solution largely depends on the energy situation, and the availability of low carbon intensity electrical power.

In the near term the lowest carbon intensity flowsheet might be steam driven but in the medium to long term the GHR/ATR flowsheet is the lowest carbon intensity solution as it:

- maximises the use of high-grade heat
- reduces the amount of gas needed to produce ammonia;
- allows operators to access renewable power to further lower the carbon intensity of their product.

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