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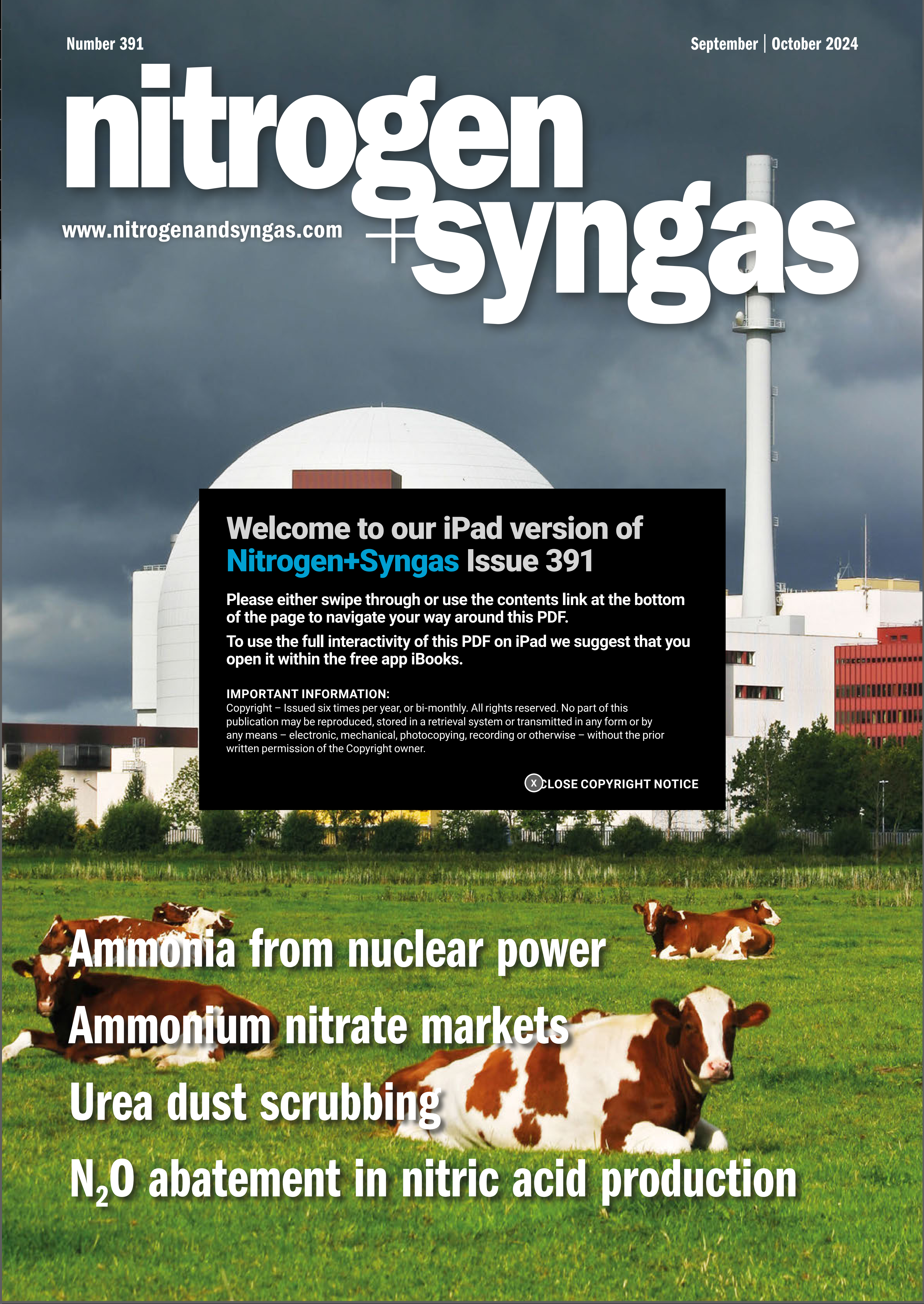

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Ammonia from nuclear power

Ammonium nitrate markets

Urea dust scrubbing

N_2O abatement in nitric acid production

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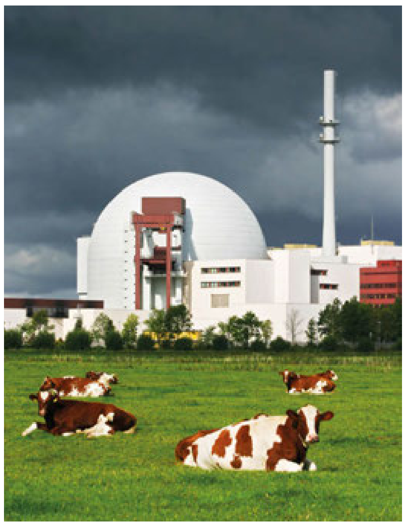

Cover: Brokdorf Nuclear Power Plant, Schleswig-Holstein, Germany
Istockphoto.com/Jan-Otto

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A sea change?

> **"Maersk commented that it was 'hedging its bets' on future fuel technology..."**

In our May/June issue I discussed the race to be the next major green shipping fuel, in which methanol and ammonia both remain significant contenders, but which methanol appeared to be pulling ahead in. But more recently, a few stories from the past few weeks have left me not quite as sure as I was about that. Firstly, there's the news in our Syngas News section this issue that the FlagshipONE green methanol project in Sweden is being delayed and possibly abandoned, because demand for green methanol for shipping has not actually materialised as fast as was anticipated.

Secondly, Maersk, who have been one of green methanol's greatest evangelists, and who have ordered 18 very large container ships (VLCCs) capable of running on methanol as a fuel, have now ordered another 50-60 ships… which will run on LNG. The fleet renewal plan will commission 800,000 TEU of vessel capacity, with deliveries expected between 2026 and 2030. In the press release accompanying the announcement, Maersk commented that it was "hedging its bets" on future fuel technology. It did still say that "green methanol is likely to become the most competitive and scalable pathway to decarbonisation in the short term", but Maersk also foresees "a multi-fuel future for the industry which includes liquified bio-methane." It was about that time that people started noticing that the methanol vessels Maersk has ordered are dual fuel capable, and can also run on conventional shipping fuels. Indeed, as per the FlagshipONE announcement, many presumably are.

In May I also noted that orders for ammonia powered ships seem to be picking up, and a trawl of recent announcements noted that Japanese classification society ClassNK has awarded what it claims is the world's first accreditation for machinery room safety for ammonia to the ammonia-fuelled medium gas carrier currently under development by a consortium that includes NYK, Nihon Shipyard, Japan Engine Corporation, and IHI Power Systems. The 40,000 m^3 vessel is scheduled for delivery in November 2026. Elsewhere, Wärtsilä has signed a contract with Norwegian shipowner Eidesvik to supply the equipment for the conversion of an offshore platform supply vessel (PSV) to operate with ammonia fuel. The vessel, 'Viking Energy', which is on contract to energy major Equinor, is scheduled for conversion in early 2026 and is expected to start operating on ammonia in the first half of 2026, becoming the world's first ammonia-fuelled in-service ship. And Swiss shipping company Gearbulk has ordered two additional ammonia/methanol conversion ready 82,300 dwt ships in China. The units will be sister vessels to four Pulpmax open hatch vessels ordered earlier this year, and will be built at the same shipyard, CSSC Huangpu Wenchong Longxue in Guangzhou, China, with delivery between October 2028 and January 2029. Gearbulk's partner company Grieg Maritime Group has already ordered four ammonia-ready vessels to its fleet, to be completed in 2026.

Personally, I still see methanol as a much easier fuel to handle than ammonia, or indeed LNG, and a more likely candidate, even if only, as Maersk puts it, "in the short term". But with the potential of tens of million tonnes per year of demand at stake, the future is still looking very uncertain for all of the candidate fuels, and hence the plants being developed predicated on that demand. ■

Richard Hands, Editor

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Price Trends

Ammonia benchmarks west of Suez remain supported by limited availability at key regional export hubs amid increased potential for cargoes to arrive from the East, where availability is far healthier, and prices appear under pressure. The disparity in prices was illustrated towards the end of August, when Nutrien sold 25,000 tonnes to multiple buyers in NW Europe for 1H September delivery at $550-555/t c.fr. When netted back to Trinidad, the price marks a sizeable premium on the $375/t f.o.b. last achieved by Nutrien back in late June, although given that last business in Algeria was fixed at $520/t f.o.b., it appears there is room for delivered sales into Europe to move up further. Regional availability is still limited, with extreme weather conditions in the US Gulf and North Africa potentially impacting supply further over the coming weeks.

East of Suez, all eyes were on India, where FACT was tentatively suggested to have awarded its latest purchase tender at $415/t c.fr, amid healthy demand from downstream Indian phosphate fertilizer producers ahead of the forthcoming Kharif season. That demand should be satisfied in large part by the Middle East, where Ma'aden again expects to export 175,000 tonnes in September. Demand elsewhere in the region remains subdued, with spot interest from South Korea and Taiwan.

In Malaysia, Petronas may have some spot availability moving into the latter half of August and early September, amid a healthy production outlook. Talk has again emerged of some minor output issues in Indonesia, though these are unlikely to pose a major impact to overall supply or indeed prices.

In urea markets, India's latest import tender was confirmed for 29 August closing, but with a long shipment window, with NFL seeking to secure tonnage through to end October. This was viewed as a bearish signal as it should increase dramatically the volume offered to NFL. The tender could still exclude any significant volume from China. While exports are expected to emerge in October, there may be no clarity from the Chinese government by the closing date of the Indian tender and with no certainty that exports will be allowed, traders will not want to risk any short sales. Supply could then be focused on the Middle East and Russia and, with no certainty of Indian's next move after this tender, could look to secure sales to provide a solid platform of exports for the start of Q4.

Other markets are still slow to come forward. Brazil saw offers pushed to $360-365/t c.fr on news from India but buyers have yet to respond. They may step up fearing India will take out all the excess tonnes from Russia and the Middle East for September and October – months when Brazil usually has a very heavy line up to meet forward demand. Europe is still slow to step up. Sales that are being seen are some way below Egyptian aspirations of $360/t f.o.b. The UK and Italy has taken product that looks to reflect closer to $330-340/t f.o.b.

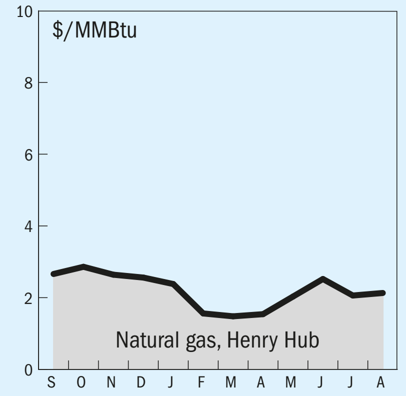
Table 1: **Price indications**

Cash equivalent	mid-Aug	mid-Jun	mid-Apr	mid-Feb
Ammonia ($/t)				
f.o.b. Black Sea	n.m.	n.m.	n.m.	n.m.
f.o.b. Caribbean	440-500	360	435	395
f.o.b. Arab Gulf	320-350	320-330	270-300	270-350
c.fr N.W. Europe	550-575	450-460	460-470	470-480
Urea ($/t)				
f.o.b. bulk Black Sea	305-325	340-350	250-260	300-320
f.o.b. bulk Arab Gulf*	290-335	280-350	275-290	345-352
f.o.b. NOLA barge (metric tonnes)	305-316	300	285-305	355-360
f.o.b. bagged China	n.m.	n.m.	300-310	330-335
DAP ($/t)				
f.o.b. bulk US Gulf	550-570	550-570	550-570	550-570
UAN (€/tonne)				
f.o.t. ex-tank Rouen, 30%N	240-245	260-265	230-240	255-260

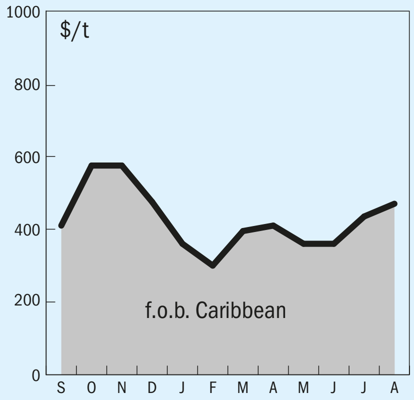
*Notes: n.a. price not available at time of going to press. n.m. no market. * high-end granular.*

END OF MONTH SPOT PRICES

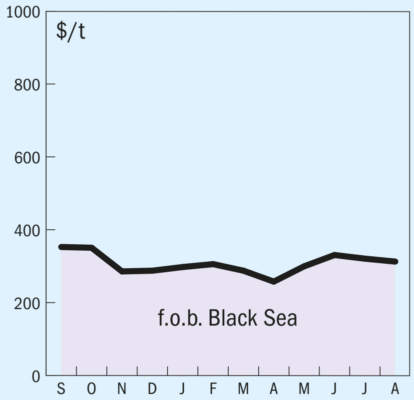
natural gas



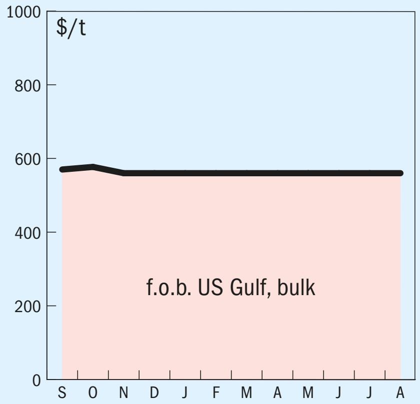
ammonia



urea



diammonium phosphate



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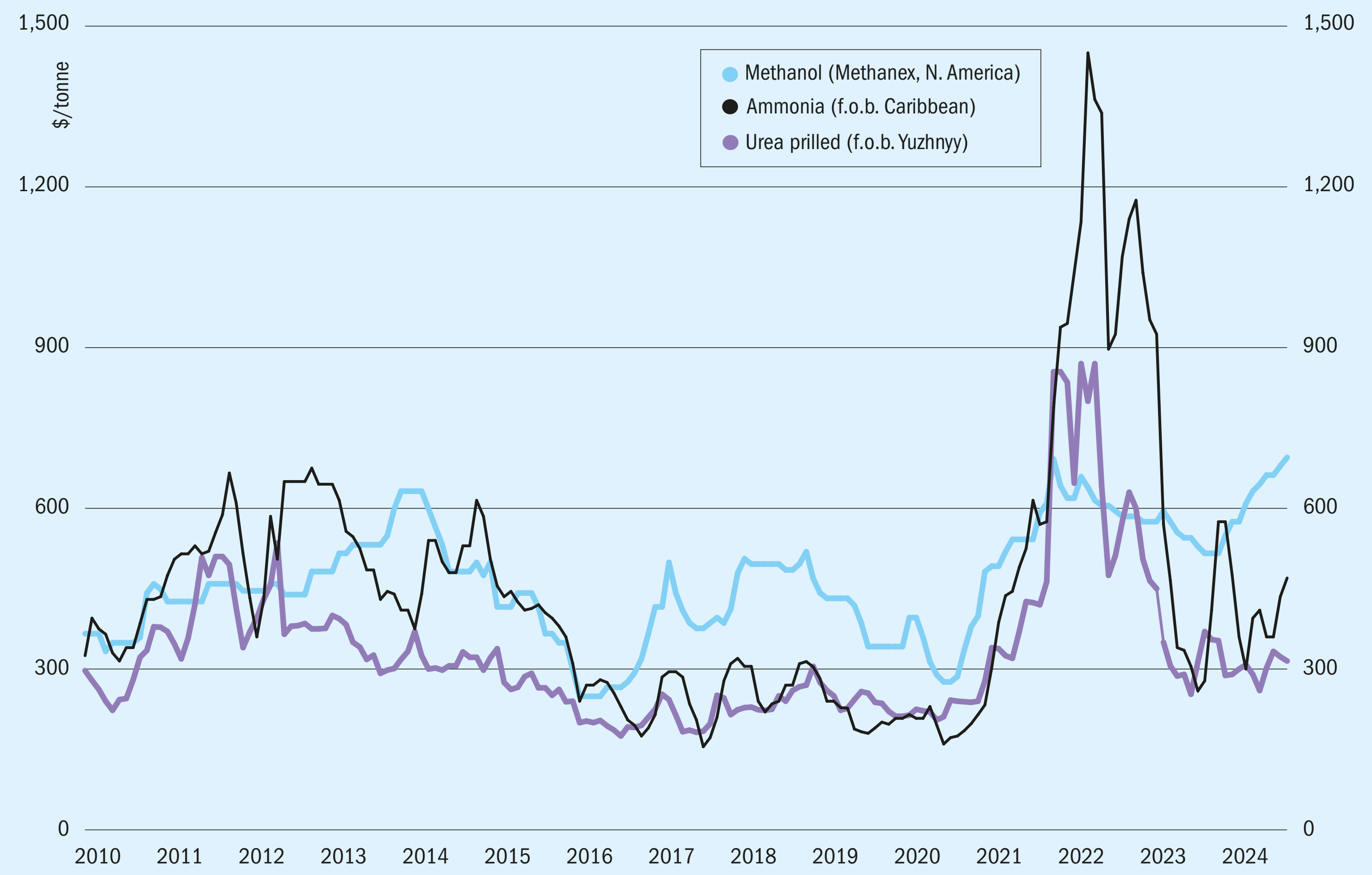
Market Outlook

Historical price trends $/tonne



Source: BCInsight

AMMONIA

- In China, domestic prices are expected to come under significant downward pressure, with seaborne indications already following suit, with buyers said to have rejected offers around the $375/t c.fr mark.
- Ukraine's Odessa Port Plant is in the market for natural gas to restart ammonia and urea production, local reports suggest. One of the tenders to secure gas is for the supply of 251,800 cubic meters which would be sufficient to restart one ammonia unit and operate it to full capacity until the end of the year.
- Ammonia prices are likely to remain relatively flat as curtailments tighten product availability. Postponement of new US capacity and Russian exports should delay any oversupply in the market, with downstream fertilizer capacity expansions not outpacing ammonia supply additions until 2026.

UREA

- There is still no sign China will ease urea export restrictions in the short term. Most market players are bearish on the volume of urea that will be exported in the balance of 2024. Only a marginal improvement is expected in September. With prices weakening, there has been some interest from NPK producers to cover for the autumn application which has encouraged a small increase in price.
- Indian buying continues to set the tone for the market. Production increases outpaced demand increase in 1H 2024, with a shortfall of 546,000 tonnes, and while imports have been down 30% for the year to end July, at just under 2 million tonnes they suggest comfortable inventories in India.
- Egypt has faced significant production disruption due to natural gas supply interruptions, with production running at around 80% of capacity, offering a potential bullish factor.

METHANOL

- Methanol markets have been tight in 3Q 2024, with increased demand outpacing supply, leading to a significant global inventory drawdown and increasing methanol prices. The tightness looks set to remain to the end of 3Q 2024, in spite of some improvements in methanol supply and inventories globally. Increased supply from the Geismar 3 plant in Louisiana will be offset to some extent when Methanex shuts down its Atlas plant on Trinidad and restarts Titan, removing 1 million t/a of capacity.
- Methanex reported healthy demand growth across all traditional and energy-related downstream sectors, with (methanol-to-olefins) MTO operating rates influenced by the availability of supply.
- Longer term, the startup of the new 1.8 million t/a Petronas methanol plant on Sarawak, Malaysia will help to ease market tightness towards the end of 2024 and start of 2025. ■

Nitrogen Industry News

UNITED STATES

Woodside to buy OCI clean ammonia plant

OCI Global says that it has reached an agreement for the sale of 100% of its equity interests in its Clean Ammonia project currently under construction in Beaumont, Texas for $2.35 billion on a cash and debt free basis. The buyer is Australian LNG and energy company Woodside Energy Group Ltd. Woodside will pay 80% of the purchase price to OCI at closing of the transaction, with the balance payable at project completion, according to agreed terms and conditions. OCI will continue to manage the construction, commissioning and startup of the facility and will continue to direct the contractors until the project is fully staffed and operational, at which point it will hand it over to Woodside. The transaction is expected to close in H2 2024, subject to shareholder approval.


PHOTO: WOODSIDE ENERGY

The OCI Clean Ammonia Project under construction.

The clean ammonia project began engineering work in late 2021 and construction in December 2022m and is expected to produce first ammonia in 2025. It uses Linde's low CI hydrogen production and carbon capture technology with OCI's ammonia production, storage and transportation infrastructure. In addition, Linde has contracted with ExxonMobil for the CO_2 transportation and sequestration infrastructure. The project in its first phase will result in the capture and sequestration of 1.7 million t/a of CO_2, and will be capable of producing 1.1 million t/a of blue ammonia in its first phase, with the necessary infrastructure and utilities in place to double that capacity in its existing plot plan. Permitting for the second line has been submitted and is expected to be received by year-end.

Nassef Sawiris, Executive Chairman of OCI commented: "We are exceptionally proud to have put in motion on a global scale the first blue ammonia project, with first production expected in less than a year from now. This pioneering investment will contribute to the global availability of low-carbon intensity ammonia, with significant potential to reduce carbon emissions in hard-to-abate sectors, including existing markets in fertilizer and industrial sectors, as well as in new applications in power and shipping. We are confident that in Woodside we have found the rightful custodian for this landmark asset and its talented employees. Under Woodside's leadership, OCI Clean Ammonia will play a vital role in the global energy transition, delivering new energy products and lower carbon services to reduce Woodside's customers' emissions globally." ■

Wabash Valley selects Baker Hughes for CO_2 sequestration

Energy technology company Baker Hughes has signed a long-term agreement with Wabash Valley Resources (WVR) to supply advanced technology services and solutions to support WVR's ammonia production with compression systems, injection well construction and perform testing and monitoring services for the geological sequestration of carbon dioxide.

Wabash Valley Resources' low carbon ammonia fertilizer project will relocate an existing gasification-based ammonia plant to become Indiana's first ammonia fertilizer plant. It will serve the US Corn Belt by creating a reliable supply of domestic, lower cost fertilizer produced through a zero-carbon-capable process while capturing 1.65 million t/a of CO_2. In January 2024, WVR received two Class VI permits from the US EPA to construct CO_2 injection wells in Indiana, the first such permits issued by the EPA since 2014 and the first in a new wave of over 100 well applications pending.

"We are excited for this milestone with Wabash Valley Resources to advance geological carbon capture and storage technology in the United States," said Judit Prieto, senior vice president for Enterprise Customer Solutions at Baker Hughes. "This agreement underscores Baker Hughes' strategic commitment to new energy ventures that leverage our technical excellence and safety standards through decades of experience."

Agreement on carbon capture

ExxonMobil has signed an agreement with CF Industries to capture and store up to 500,000 t/a of carbon dioxide from CF's facilities in Yazoo City, Mississippi. Dan Ammann, president of ExxonMobil Low Carbon Solutions, said, "We're serious about expanding carbon capture – a safe, proven solution for hard-to-decarbonize industries. Our agreement with CF Industries is the latest example of how we can help industrial customers make significant progress, quickly and economically."

The project will capture up to 50% of the site's carbon emissions and is expected to begin operations in 2028. "We've set ambitious goals to reduce our emissions from our operations, and CCS will play a key role in getting us there. We are really pleased to expand our relationship with ExxonMobil for our second CCS project together as their leading expertise helps accelerate our decarbonization journey," said Tony Will, president and CEO of CF Industries.

CF Industries will be investing $100 million in the project and expects it will be able to qualify for up to $85/t of captured CO_2 under the US IRA's 45Q tax credit mechanism.

Low carbon nitrogen plant seeking Federal funding

The city of Richland in Washington state has requested $5 million in Federal funding for engineering work needed to connect its new Northwest Advanced Clean Energy Park and the Bonneville Power Administration grid. The city is the site for a green ammonia development by Atlas Agro, which hopes to build an ammonia and downstream nitrogen fertilizer plant

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using low carbon energy from nuclear power. Atlas has put the size of the projected plant at 700,000 t/a, with an investment cost of $1 billion.

MEXICO

Feasibility study for new urea plant

Portuguese civil construction group Mota-Engil has signed an agreement with state run Mexican national oil company, Petróleos Mexicanos (Pemex), for the construction of an ammonia-urea and downstream urea solutions plant at Escolin, in Vera Cruz state. The agreement covers the engineering, construction, financing and operation of a complex producing ammonia, urea and DEF urea solutions, with an annual production equivalent to 700,000 tonnes ammonia. It is hoped that the plant will decrease Mexico's imports of fertilizers.

The contract uses a 'tolling' model, whereby Pemex delivers the main raw materials (gas and water) to the operator, who will be the only responsible for their transformation and for the delivery of the final product, without price change risk of the raw materials and/or any responsibility in the sale of the final product. The project will be developed in three phases, beginning with engineering feasibility studies lasting 4-6 months. The second phase, construction, is expected to last 42 months and have an investment cost of US$1.2 billion. The final, operation phase is expected to last for 20 years.

Mota-Engil says that it will work with Spanish group Duro Felguera on the project.

AUSTRALIA

Incitec Pivot ends fertilizer sales talks

Incitec Pivot Ltd says that it has ceased negotiations with PT Pupuk Kalimantan Timur for the sale of its fertilisers business, Incitec Pivot Fertilisers (IPF). The company says that the decision "follows careful consideration of how to maximise value for shareholders while balancing the risks of completing the transaction in a reasonable timeframe."

IPL will continue to manage its Dyno Nobel explosives business and IPF fertilizer business separately. Dyno Nobel will focus on delivering its strategy to expand its position as a leading global, premium explosives business that provides its customers with safe and cutting-edge technology, solutions and services. IPF will continue to deliver on its strategy of providing value-add fertilisers and soil health services that increase productivity for agricultural customers.

EGYPT

Agreement on green ammonia

TAQA Arabia and Voltalia have signed a framework agreement with the Egyptian government for the production of green ammonia, with a total investment that could reach up to $3.40 billion. The project is intended to be carried out in two identical phases, each featuring a 500 MW electrolyser powered by over 1.30 GW of solar and wind energy, according to a press release. Located at a greenfield site near Ain Sokhna port in the Suez Canal Economic Zone, the facility will have an annual production capacity exceeding 350,000 t/a of hydrogen per phase.

CHINA

Stamicarbon to revamp urea plant

Maire subsidiary NextChem says that its Stamicarbon nitrogen technology licensing group has been selected by Linggu Chemical Co. Ltd to provide the licensing and process design package to improve the energy efficiency of an existing urea plant in China with an overall capacity of 3,100 t/d. The upgrade will include Stamicarbon's Advanced MP Flash design technology, a key component of the EVOLVE Energy™ series, which enhances plant efficiency by reducing steam usage and optimising feedstock utilisation. It can lower overall energy consumption by up to 20%, enabling the plant to achieve substantial energy savings without the need for additional high-pressure equipment. Alessandro Bernini, CEO of Maire noted that the project significantly strengthens the company's technological presence in China, a key market for advanced industrial solutions.

Construction begins on large scale green ammonia project

Jizhong New Energy has begun construction on the Siziwang Banner green ammonia demonstration project in Inner Mongolia, close to the city of Ulanqab. As reported in China Daily, 1.25 GW of wind and 1.15 GW of solar generating capacity will power "160 sets of 1200 Nm^3/h [alkaline] electrolysers", ultimately producing 500,000 t/a of renewable ammonia. The $2.6 billion project will be located at the existing Duerbot Chemical Park, and be built over three phases. Jizhong New Energy is a subsidiary of state-owned coal company Jizhong Energy Group. The project will also feature thirty six 2,000-m^3 spherical ammonia and hydrogen storage tanks, and some of the wind and solar power generated by the project will be supplied to the local electricity grid.

China may use ammonia co-firing at coal based power plants

China's central planning National Development and Reform Commission (NDRC) has launched an Action Plan for Low-Carbon Transformation and Construction of Coal Power Plants (2024-27) which aims to reduce carbon emissions from China's large coal fired power sector. All coal-fired power plants in China will have to begin their "initial low-carbon transformation" in 2025 as part of plans to reduce their CO_2 emissions by 50% by 2027, according to the Action Plan. The plan offers coal-plant owners three methods to reduce emissions: by co-firing either biomass or green ammonia produced from renewable hydrogen; or by using carbon capture, utilisation and storage (CCUS).

OMAN

Shell selects KBR technology for Blue Horizons Project

KBR says that its blue ammonia technology has been chosen by Shell for the Blue Horizons low-carbon hydrogen and ammonia project in Duqm, Oman. This facility will use KBR's advanced ammonia synthesis loop technology to produce ammonia with lower carbon intensity and at a competitive cost. Under the terms of the contract, KBR will deliver a proprietary engineering design for the 3,000 t/d ammonia plant, which will use hydrogen generated by Shell's Blue Hydrogen technology. Jay Ibrahim, president of KBR Sustainable Technology Solutions, noted that the project aligns with Oman's Vision 2040 targets. The blue hydrogen and ammonia are expected to be used in local industries in the Duqm Special Economic Zone and exported to international markets.

Shell has also contracted Wood plc to deliver pre-front-end engineering design (FEED) services. Wood will design the integrated blue hydrogen and ammonia production plant, marine facilities including ammonia storage, 200-km pipeline and CO_2 injection plant.

RUSSIA

Plans for additional nitrogen production

In its most recent annual report, TogliattiAzot (TOAZ) says that it plans to significantly increase ammonia and urea production by 2035. The company says that it intends to ramp up ammonia output to 4 million t/a, an increase of around 500,000 t/a on current production, and more than double urea production from 1.76 million t/a to 3.9 million t/a, with the addition of two new urea plants, each with a capacity of around 850,000 t/a. The company is also targeting an additional 690,000 t/a of nitric acid, 786,000 t/a of ammonium nitrate, 500,000 t/a of UAN, 200,000 t/a of melamine and 100,000 t/a of NPK fertilizer production.

This year TOAZ expects to expand its ammonia loading system into railway tanks, a potentially important factor in moving anhydrous material from the firm's production facility in the Russian interior to its yet-to-commission ammonia transhipment terminal at Taman on the Black Sea coast in the absence of the trans-Ukraine ammonia pipeline.

Elsewhere, construction is reportedly nearing completion at Shchekinoazot's new ammonia-urea unit in Tula province. The facility will have capacity to produce 525,000 t/a of ammonia and up to 700,000 t/a of urea, with design capacity expected to be reached by 2025 Q1, according to a company statement.

BRAZIL

Site reserved for green ammonia project

Porto do Açu, a subsidiary of economic group Prumo Logística, and Norwegian developer of green hydrogen and ammonia plants Fuella have signed a contract reserving 1.0 million m^2 of land for a new low-carbon hydrogen hub at the port complex in the north of the state of Rio de Janeiro. The project includes green hydrogen production by 520 MW of electrolysis with downstream ammonia and methanol production. The facility is projected to produce 400,000 t/a of green ammonia, which could be shipped through the port's liquids terminal, for export or domestic uses. A final investment decision is expected by 2028, and first production by 2030.

"This is a landmark agreement for us, in expanding our portfolio of projects internationally, to highly competitive and attractive regions. We believe that Porto do Açu is a fantastic location and partner for us. The winning factors for us were not only the site and the infrastructure in place, but also the dedication, competence and support of the team," said Thorsten Helms, Managing Director Business & Corporate Development at Fuella.

Tender to restart urea plant

State oil company Petrobras has invited tenders to reactivate its Araucária Nitrogenados SA (ANSA) fertilizer plant in Paraná state. The tender includes inspection and maintenance services for storage and tanks, including boiler-making and complementary equipment. Located adjacent to the Presidente Getúlio Vargas refinery (REPAR), ANSA has production capacity for 720,000 t/a of urea and 475,000 t/a of ammonia, as well as 450,000 m^3/year of automotive urea solutions. Petrobras approved the restart of operations at the plant, which has been idled since 2020, in June, aiming to restart operations by the end of 2024. Petrobras is also looking at completing construction at the UFN-III ammonia-urea plant in Mato Grosso do Sul state and is preparing the respective bidding process.

ARGENTINA

Feasibility study for nano urea plant

The Indian Farmers Fertiliser Cooperative (Iffco) says that it will set up a 'Nano Urea Liquid' manufacturing plant in Argentina in partnership with the Cooperative Confederation of Argentina (Cooperar) and Instituto Nacional de Asociativismo y Economia Social (INAES). The three companies have signed a memorandum of understanding to analyse the feasibility of setting up the plant, as well as exploring cooperation in trade and investment in areas of mutual interest, including agrochemicals and agricultural inputs to achieve sustainable development.

CHILE

Environmental review for green ammonia project

Austrian developer AustriaEnergy says it has submitted its \$11 billion green ammonia project for environmental review. HNH Energy, to be based in the windswept Magallanes region, will involve a wind park with 194 turbines generating 1.4 GW of energy, and hydrogen electrolysis and ammonia production at San Gregorio, 120 km northeast of Punta Arenas. Construction, tentatively scheduled to begin in July 2026, is expected to take six years. Planned green ammonia production capacity in the final phase is estimated at 6,600 t/d.


PHOTO: CASALE

Togliatti's newest urea unit, commissioned in 2022.

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KUWAIT

KBR to advise on renewables and hydrogen project

KBR has been awarded an advisory consulting contract by Kuwait Oil Company for the development of a country-wide 'master plan' for the production of 17 GW of renewables and 25 GW of green hydrogen by 2050. Under the terms of the contract, KBR will provide advisory consulting services to develop a phased strategy for the deployment of wind and solar power, combined with power storage capability. The renewable power capability will be linked to the production of green hydrogen for internal industrial use, as well as for export purposes. The work is expected to be performed over the next 18 months, with KBR developing a market analysis, techno-commercial feasibility studies, as well training of Kuwaiti nationals.

Jay Ibrahim, President of KBR Sustainable Technology Solutions, said: "We are excited to be a part of this significant national level strategy in Kuwait, as we continue to grow our presence in country. This win highlights our advisory capabilities in the development of major energy transition investments at a national level, supported by decades of successful project delivery and technology deployment in the GCC region. It is indicative of KBR's strategic commitment to Kuwait, sustainability and the energy transition."

GERMANY

Clariant and KBR expand strategic collaboration in low-carbon ammonia

Clariant Catalysts has announced the expansion of its strategic cooperation with KBR in the field of ammonia production. The partners will continue collaborating on traditional ammonia projects while significantly increasing their focus on low-carbon and carbon-free "green ammonia" applications. The solutions will combine Clariant's AmoMax ammonia synthesis catalysts with KBR's K-GreeN® ammonia technologies to maximise the economics and energy efficiency of ammonia production.

Georg Anfang, Vice President Syngas and Fuels at Clariant Catalysts, said, "We are proud of our long and successful history as partners and are delighted to strengthen our cooperation with KBR. By extending our collaboration towards sustainable ammonia solutions, we generate synergies for innovations supporting fertilizer production and the energy transition. Our state-of-the-art catalysts optimally complement KBR's advanced process technologies to enable economical and reliable large-scale production of low-carbon and green ammonia."

Green ammonia from Norway

German energy company EnBW says that it is starting to market 100,000 tonnes of green ammonia from the Skipavika Green Ammonia (SkiGA) project in Norway. The volumes are planned to be available from 2027, and according to EnBW, can be transported to various delivery locations, such as the port of Skipavika in Norway, to selected terminals in Western Europe or to industrial sites, including in Germany. Interested companies should register online to bid for the corresponding capacity, and the process starts on July 26, 2024. SkiGA is based on 130 MW of electrolyser capacity, and aims to cut carbon emissions by around 240,000 t/a compared to the use of 'grey' ammonia.

CANADA

Green ammonia project may be abandoned

Fortescue Future Industries appears to be scaling back its ambitious plans for green hydrogen and ammonia development, and is pushing back the timescale for its proposed $2 billion, 700,000 t/a plant at Prince George, British Columbia, and may abandon it altogether. The plant had anticipated taking green energy from wind and hydroelectric power, but the 1 GW of power required appeared to be beyond what could be supplied locally. Fortescue has said that it will focus on projects where the economics are better, with four projects currently under development in Australia, the US, Norway and Brazil.

ANGOLA

Cash boost for urea development

The African Export-Import Bank has announced its financial support for an ammonia-urea plant at Soyo. Afreximbank will loan $1.4 billion, and will act as the lead arranger and financial advisor for the project, with Angolan conglomerate OPAIA Group and state-owned Sonangol P&P Natural Gas (Sonagas) serving as sponsors. Currently, Angola imports over $120 million worth of fertilizers annually to meet local consumption demands. The completion of the new plant, which will have a capacity of 3,870 t/d of urea, is expected to dramatically reduce these imports. Production is currently expected to start in 2027.

IRAN

Ammonia output to reach 5 million t/a

The Iranian National Petrochemical Company says that ammonia production in Iran is expected to rise to 5 million t/a this year, with the launch of the 450,000 t/a Persian Gulf Star Oil Company (PGSOC)'s ammonia plant at the port of Bandar Abbas.

TANZANIA

New urea plant

The Tanzania Investment Center (TIC), the Tanzania Fertilizer Regulatory Authority (TFRA) and the Petroleum Development Corporation (TPDC) have signed a memorandum of understanding (MoU) with ESSA in Indonesia to develop a new gas-based ammonia-urea plant in the Mtwara region. The agreement was signed on 31 July in Dar es Salaam. Construction of the plant is expected to be completed by 2027 and production will begin two years later, in 2029. Speaking at the signing, Tanzanian Minister of Planning and Investment, Professor Kitila Mkumbo, said the construction of the factory will make Tanzania completely independent. Tanzanian fertilizer consumption has risen to 800,000 t/a in 2023-24, according to the Tanzania Fertilizer Regulatory Authority (TFRA).

PARAGUAY

Yara signs CAN sales agreement

Yara International has entered into a strategic heads of terms agreement with ATOME PLC to purchase the entire output of ATOME's forthcoming renewable calcium ammonium nitrate (CAN) production facility, sited in Villeta, Paraguay. Under this agreement, Yara will market and sell the fertilizer under its YaraBela product line. The project, set to commence in 2027, will use 145 MW of baseload renewable power to produce green ammonia and export downstream fertilizers. ATOME has successfully concluded the front-end engineering and design (FEED) phase for its project during the first half of 2024, positioning the company to make a final investment decision later this year. Upon completion, the Villeta facility is set to produce up to 264,000 t/a of calcium ammonium nitrate fertilizer. ■

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SWEDEN

Green methanol project abandoned

In its most recent interim report, published on August 15, renewable energy developer Ørsted said that it was abandoning the FlagshipONE renewable methanol project because the anticipated market for green methanol as a marine fuel had not materialised as quickly as expected. The strategic decision comes nearly two years after final investment decision (FID) on the project.

In the company's report, Mads Nipper, Group President and CEO of Ørsted, commented: "The liquid e-fuel market in Europe is developing slower than expected, and we have taken the strategic decision to de-prioritise our efforts within the market and cease the development of FlagshipONE. We will continue our focus and development efforts within renewable hydrogen, which is essential for decarbonising key industries in Europe and closer to our core business. We maintain a strong focus on de-risking project execution and prioritising growth options with the highest potential for value creation."

The FlagshipONE project, to have been sited in the Swedish town of Örnsköldsvik, was to produce 55,000 t/a of methanol a year, enough for one large container vessel, making it a large-scale pilot project. Its targeted on-stream date was 2025. The company is also delaying a US renewables project. Mr Nipper said: "Despite encouraging progress on our US offshore wind project, Revolution Wind, the construction of the onshore substation for the project has been delayed. This means that we have pushed the commercial operation date from 2025 into 2026, which led to an impairment."

Ørsted has taken an impairment of 1.5 billion Danish krone related to the FlagshipONE project, equivalent to $221 million, and almost half of its total impairment losses for the first half of the year. ■

AUSTRALIA

Feasibility study for green methanol bunkering

A Memorandum of Understanding (MoU) has been signed between HAMR Energy, the Port of Melbourne, Maersk, ANL, Svitzer, Stolthaven Terminals, and ABEL Energy to explore the commercial feasibility of establishing a green methanol bunkering hub at the Port of Melbourne. The collaboration will examine a potential project involving the transportation of green methanol from HAMR Energy's flagship project in Portland, Victoria to the port of Melbourne for storage and bunkering services.

Commenting at the signing of the MoU, the state of Victoria's Minister for Energy and Resources Lily D'Ambrosio said: "Victoria has the most ambitious decarbonisation agenda in the country, and this announcement is another example of how we're leading the development of renewable and alternative fuels." HAMR Energy Director and Company Secretary, David Stribley added: "HAMR Energy is developing a world-class green methanol facility in Portland, Victoria to accelerate shipping industry decarbonisation which will rely entirely on natural and renewable resources available in Australia."

CANADA

Blue methanol project launched for Medicine Hat

Methanol has contracted carbon capture and storage specialist Entropy to evaluate the integration of carbon capture, utilisation, and sequestration technology at Methanex's Medicine Hat methanol production site in Alberta. A preliminary front-end engineering and design study will look at the feasibility of leveraging Entropy's modular post-combustion carbon capture technology at the site. It is hoped the project will support the sequestration of CO_2 in addition to utilisation. The partnership wants to capture 400 t/d of CO_2. A portion of the captured CO_2 will be fed back into the methanol process as feedstock to produce around and additional 50,000 t/a of methanol.

Mark Allard, Senior Vice-President of Low Carbon Solutions at Methanex, said the project exemplifies Methanex's commitment to reducing its greenhouse gas emission intensity by 10% by 2030 and advancing at least one low carbon solutions project into pre-FEED in 2024. The project is expected to be an approximately C$100 million (US$75 million) investment, with the largest portion of the funding set to come from Entropy. Upon a final investment decision, Entropy will construct and own the capture equipment adjacent to Methanex's facility. Methanex will supply the utilities, build the tie-ins to its facility, and operate the capture equipment once it is commissioned.

UNITED ARAB EMIRATES

Masdar and Total to examine methanol to aviation fuel project

UAE-based clean energy developer Masdar has agreed with TotalEnergies to assess the development of a commercial green hydrogen to methanol to Sustainable Aviation Fuel (SAF) project in Abu Dhabi. According to Masdar, the focus of the new project will be to help decarbonise hard-to-abate sectors, such as the aviation and maritime industries. The project will take green hydrogen from renewable energy powered electrolysis, in addition to capturing and utilising CO_2 from industrial sources as a feedstock for the production of green methanol and SAF.

Founded in 2006, Abu Dhabi-based Masdar develops utility scale renewable energy and green hydrogen projects around the world. The company has goals to scale its global renewable energy capacity to 100 GW, and production of green hydrogen to 1 million t/a by 2030. The company recently raised $1 billion in a green bond offering aimed at supporting investments in new greenfield renewable energy projects.

CHINA

Honeywell selected for methanol-to-SAF project

Honeywell International says it has been contracted by Inner Mongolia Jiutai Group to deliver its technology for a project to produce sustainable aviation fuel (SAF) from e-methanol in China. Honeywell's UOP eFining™ is a methanol-to-jet fuel processing technology that turns methanol produced from carbon dioxide and green hydrogen into aviation fuel. The company claims that the use of this technology can lower greenhouse gas emissions by 88% compared to conventional jet fuel. Inner Mongolia Jiutai will use eFining to convert its methanol-to-olefins facility into a SAF plant. The process will incorporate using wind resources in northwest China and will result in the production of 100,000 t/a of SAF from green methanol.

"Honeywell's extensive technical expertise and practical experience in SAF have enabled us to identify innovative ways in which flexible feedstocks can be used to support aviation's energy transition," said William Yu, President of Honeywell China.

MALAYSIA

Opening ceremony for new methanol plant

In July an official opening ceremony was held for the Sarawak Methanol Complex at Tanjung Kidurong in Bintulu (the Malaysian side of the island of Borneo). Speaking at the ceremony, the premier of Sarawak province Datuk Patinggi Tan Sri Abang Johari Tun Openg said that it marked Sarawak's entry into the petrochemical industry and the state's emergence as a significant player in the global methanol market. The world scale plant has the capacity to produce up to 1.75 million t/a of methanol, and is the first mega methanol plant to be developed and built by state-owned Sarawak Petchem Sdn Bhd.

The Premier said Sarawak Petchem is currently exploring other opportunities as part of a strategy to diversify their portfolio and make green energy adoption a reality, as outlined in the National Energy Transition Roadmap (NETR). "With various multi-billion dollar flagship projects in Bintulu, Sarawak is well-positioned to be a regional green energy hub. This will spur rapid economic activities that would open up more profitable ventures," he said. Besides the current allocated gas supply for the Sarawak methanol plant project, Petroleum Sarawak Berhad (Petros) will also supply another new 160 million standard cubic feet per day of natural gas to Sarawak Petchem for a new low carbon ammonia and urea plant project.

TRINIDAD & TOBAGO

Methanex to switch from Atlas to Titan

Methanex is planning to idle its 1.85 million t/a Atlas methanol plant on Trinidad in September this year and simultaneously restart its neighbouring idled 875,000 t/a Titan methanol plant in what president and CEO of Methanex Rich Sumner described as a "seamless transition" in a recent investor call. Titan has been idle since 2020, but will be restarted following the recent signing of a two-year natural gas supply agreement with the National Gas Company of Trinidad and Tobago (NGC). The short duration of the contract reflects the "challenging near-term gas supply and demand situation in the country," according to Sumner. Likewise the shutdown of the Atlas plant, which Methanex owns the controlling 63% stake in, is due to the expiration of its legacy 20-year natural gas agreement in September 2024.

INDIA

TOYO in feasibility study on green methanol production

TOYO Engineering Corp says that it has been selected by Japan's Ministry of Economy, Trade, and Industry's survey on overseas green projects. The survey aims to investigate the feasibility of constructing a value chain for the production of green methanol using TOYO's proprietary g-Methanol® technology, which utilises green hydrogen) and biogenic CO_2 to make methanol. The CO_2 would be sourced form NTPC Ltd in Southern India, and the green methanol would be exported to Japan to be used as a bunker fuel and also as a raw material for low-carbon synthetic fuels. The study is expected to last approximately one year, with ENEOS Corporation being the prospective off-taker in Japan for the methanol produced by this project.

CIL and GAIL to build synthetic natural gas plant

Coal India Ltd (CIL) has signed a joint venture agreement with the Gas Authority of India Ltd (GAIL) for the development of a coal to synthetic natural gas plant. The gasification based unit forms part of India's National Coal Gasification Mission, launched in January this year, which aims to better utilise coal as a feedstock for chemical production. The plant is to be located in the Raniganj area of Coal India's subsidiary, Eastern Coalfields Ltd, and will produce 80000 Nm^3/hr of synthetic natural gas (SNG). Annual production is slated at 633.6 million Nm^3, requiring 1.9 million t/a of coal, to be supplied by Eastern Coalfields. After gasification, the syngas will be reformed into methane. India continues face shortages of natural gas in spite of major expansions in LNG import capacity. This will be CIL's second coal gasification project; the company is also collaborating with Bharat Heavy Electricals Limited (BHEL) to set up India's first commercial ammonium nitrate plant at Lakhanpur in Odisha state. That project is looking to produce 660,000 t/a of ammonium nitrate with an investment cost of $1.4 billion, with commissioning expected in financial year 2029-30.

SOUTH AFRICA

Total pulls out of gas project

TotalEnergies has decided to exit a gas-rich block offshore South Africa after it found developing the new Brulpadda and Luiperd fields would be "too challenging". TotalEnergies has a 45% interest in the block. Canadian Natural Resources Ltd (CNRL), which holds another 20% stake, has also said that it would not be proceeding with development. Qatar Energies seems likely to follow suit. Total's development plan was to pipe gas from the two deep water finds to the Mossel Bay gas-to-liquids (GTL) plant, operated by state oil company PetroSA, which has been idle for several years due to a lack of gas feedstock. However, wrangling over gas prices with government and PetroSA's decision to engage with Russia's sanctioned Gazprombank to revitalise the GTL plant, are understood to have been key factors behind the departure of CNRL and TotalEnergies.

GERMANY

Shell to build green hydrogen plant for refinery

Shell Deutschland has taken a final investment decision (FID) to progress REFHYNE II, a 100 MW renewable proton-exchange membrane (PEM) hydrogen electrolyser at the Shell Energy and Chemicals Park Rheinland in Germany. Using renewable electricity, REFHYNE II is expected to produce up to 44 t/d of renewable hydrogen to partially decarbonise site operations. The electrolyser is scheduled to begin operating in 2027. Renewable hydrogen from REFHYNE II will be used at the Shell Energy and Chemicals Park to produce energy products such as transport fuels with a lower carbon intensity. Using renewable hydrogen at Shell Rheinland will help to further reduce Scope 1 and 2 emissions at the facility. In the longer term, renewable hydrogen from REFHYNE II could be directly supplied to help lower industrial emissions in the region as customer demand evolves. ■

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People

Nutrien has announced the appointment of **Mark Thompson** as executive vice president and chief financial officer, effective from 26 August 2024. Thompson succeeds Pedro Farah, who will remain with Nutrien in an advisory capacity until his departure on 31 December 2024.

Ken Seitz, Nutrien's president and CEO said: "Mark's impressive track record of execution, along with his proven financial and strategic acumen provides the unique ability to succeed in this position on day one. He brings in-depth knowledge of our business that will support the advancement of our strategic actions to enhance quality of earnings and cash flow. On behalf of the Nutrien team, I would also like to thank Pedro for his service and commitment to Nutrien over the last five years."

"I've had the privilege to serve in leadership roles across the company and firmly believe in the opportunities afforded by Nutrien's strong competitive advantages and world-class asset base to deliver long-term shareholder value," said Thompson. "I look forward to continuing to partner with Ken and our executive leadership team on the disciplined execution of our strategy and drive a focused approach to capital allocation."

Thompson has been with the company since 2011, currently serving as executive vice president and chief commercial officer. Prior to his current position he held numerous executive and senior leadership roles across the company, including chief strategy & sustainability officer, chief corporate development & strategy officer, and vice president of business development for Nutrien's Retail business. He earned his Bachelor of Commerce (Finance) and Bachelor of Arts degrees from the University of Saskatchewan is a Chartered Financial Analyst (CFA).

Seifi Ghasemi, the chairman, president, and CEO of Air Products, has announced the formation of a new senior management board to execute the industrial gas giant's two-pillar growth strategy. In July 2024, Air Products confirmed its two-pillar strategy: to grow its industrial gas business, including related technology and equipment, and to be a first mover in clean hydrogen, when it signed a deal to see its LNG business.

The new management board is made up of the following 11 individuals in the following roles, each of which will report directly to Ghasemi: **Ivo Bols**, President of Europe and Africa; **Wolfgang Brand**, Senior Vice-President of Project Delivery and Technology; **Victoria Brifo**, Senior Vice-President and Chief Human Resources Officer, and Corporate Communications and Corporate Relations; **Brian Galovich**, Senior Vice-President and Chief Information Officer; **Ahmed Hababou**, President of the Middle East and India; **Kurt Lefevere**, President of Asia; **Francesco Maione**, President of the Americas; **Sean Major**, Executive Vice-President, General Counsel and Secretary, Mergers, Acquisitions, and Sustainability; **Wilbur Mok**, Senior Vice-President of the Equipment Businesses; **Wally Nelson**, Vice-President of Global Helium; and **Melissa Schaeffer**, Senior Vice-President and Chief Financial Officer.

Ghasemi said that the formation of the new management board will further streamline and optimise Air Products' global organisation to ensure it maintains its position in the market. He added, "It further enhances our ability to execute our full portfolio of projects. I am focused on our company strategy, project execution, and the development of our senior leaders. I remain highly enthusiastic about the future of Air Products and am proud to lead this company and work alongside our talented and dedicated team."

Sasol has announced the appointment of **Walt Bruns** as chief financial officer (CFO) and executive director of Sasol Limited, effective 1 September 2024. Walt, a certified chartered accountant in South Africa, is currently CFO of Sasol Southern Africa including Energy and Chemicals.

Calendar 2024/2025

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

16-18

World Fertilizer Conference,
WASHINGTON DC, USA
Contact: The Fertilizer Institute
Tel: +1 202 962 0490
Email: info@tfi.org

29 – OCTOBER 4

Ammonium Nitrate/Nitric Acid
Conference, MONTREAL, Canada
Contact: Sam Correnti, DynoNobel,
Karl Hohenwarter, LAT Nitrogen,
Michael Gill, Orica
Email: sam.correnti@am.dynonobel.com,
karl.hohenwarter@lat-nitrogen.com,
michael.gill@orica.com,
annaconferencehelp@gmail.com
Web: annawebsite.squarespace.com/

OCTOBER

7-9

Global Syngas Technologies Conference,
SAN DIEGO, California, USA
Contact: Global Syngas Technologies Council
PO Box 18456, Sugar Land, TX 77496 USA
Tel: +1 713 703 8196
Email: info@globalsyngas.org

22-24

World Methanol Conference 2024,
COPENHAGEN, Denmark
Contact: Mike Nash, Chemical Market
Analytics
Tel: +44 20 8544 7860
Email: events@chemicalmarketanalytics.com

NOVEMBER

11-13

Ammonia Energy Association Annual
Conference, NEW ORLEANS,
Louisiana, USA
Contact: Ammonia Energy Association
Email: meetings@ammoniaenergy.org
Web: https://ammoniaenergy.org/
conferences-events/2024-annual-
conference/

JANUARY 2025

26-29

Fertilizer Latino Americano, RIO DE
JANEIRO, Brazil
Contact: CRU Events
Tel: +44 (0) 20 7903 2444
Email: conferences@crugroup.com

FEBRUARY

10-12

Nitrogen+Syngas Conference 2025,
BARCELONA, Spain
Contact: CRU Events
Tel: +44 (0) 20 7903 2444
Email: conferences@crugroup.com

Plant Manager+

How to solve stripper efficiency issues (part 2)

Part 1 of this series on stripper efficiency issues provided a brief history of the CO_2 stripping process and discussed how the invention of the HP CO_2 scrubber back in the 1960s revolutionised urea technology. In part 2 we take a look at how high liquid load can affect stripper efficiency.

A high stripper efficiency is most critical in urea plants with a CO_2 high pressure stripper and no medium pressure recirculation section, like in most Stamicarbon stripping plants. In those plants, a lower stripper efficiency has an immediate impact on the pressure in the low pressure recirculation section.

Recently, Stamicarbon introduced its LAUNCH MELT Flash technology, featuring a medium pressure vessel between the CO_2 high pressure stripper and the low pressure recirculation section (see Fig. 1). With this configuration one can accept a lower stripper efficiency (for example, 70% instead of 80%) taking advantage of the lower steam consumption of the stripper (some 100 kg/tonne) and more operating flexibility for the load to the recirculation section.

With this configuration one can accept a lower stripper efficiency of 80% which can be realised with an effective tube length of 6 m. Chiyoda, one of Stamicarbon's approved EPC contractors chose an effective tube length of 8 m, which resulted in a design stripper efficiency of 82%.

Fig. 2 shows the general scheme of a CO_2 stripper. In a CO_2 high pressure stripper, the liquid from the urea reactor flows as a falling film inside the tube from the top of the tubes to the bottom, while CO_2 enters the bottom of the stripper and flows upwards. At the same time medium pressure steam (20-23 bars) heats the tubes from the shell side.

Fig. 3 shows the temperature profile of a CO_2 stripper and a NH_3 stripper.

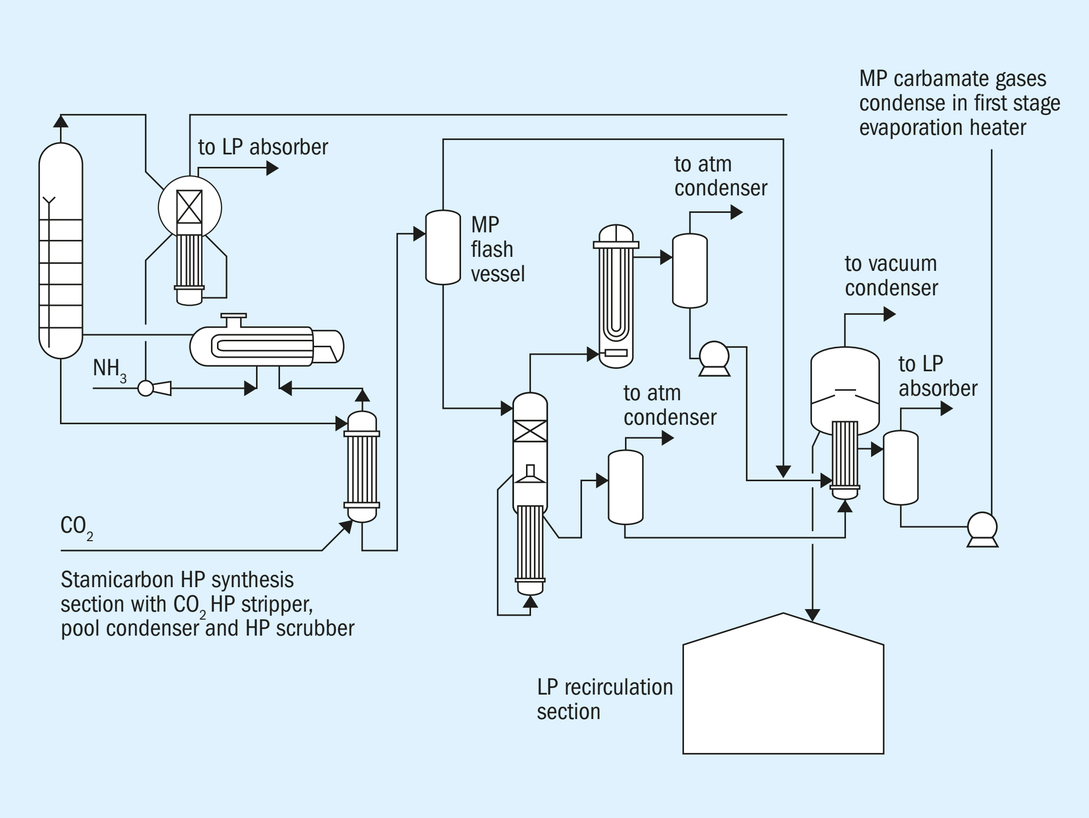
One can see that in a CO_2 stripper the maximum temperatures exist in the top three meters of the tubes. This is the reason that Stamicarbon advises the measurement of corrosion rates only in this part of the tubes as the corrosion rates are highest here. One can also see that in an NH_3 stripper the temperatures are highest in the bottom of the tubes and that the temperatures here are higher than in a CO_2 stripper resulting in the use of titanium and zirconium in NH_3 strippers.

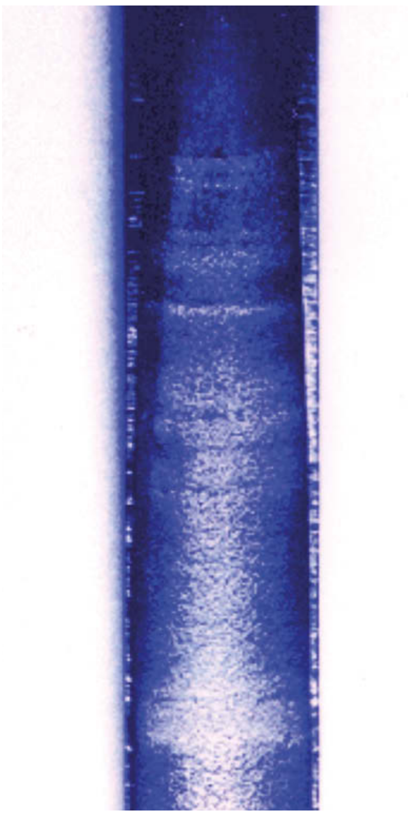
As indicated in Part 1, there are several causes for actual stripper efficiency being lower than design. Here we discuss high liquid load.

High liquid load

As previously mentioned, in a CO_2 stripper, the reactor outlet solution flows as a falling film inside the tubes from the top to the bottom. The falling film facilitates the dissociation of liquid ammonium carbamate into its two gaseous components, carbon dioxide and ammonia, and leads to the benefit of a low residence time, which minimises the formation of unwanted biuret and urea hydrolysis reactions.

Fig. 1: **LAUNCH® MELT™ Flash technology**





Thinning of tube wall thickness (top of picture) due to corrosion.

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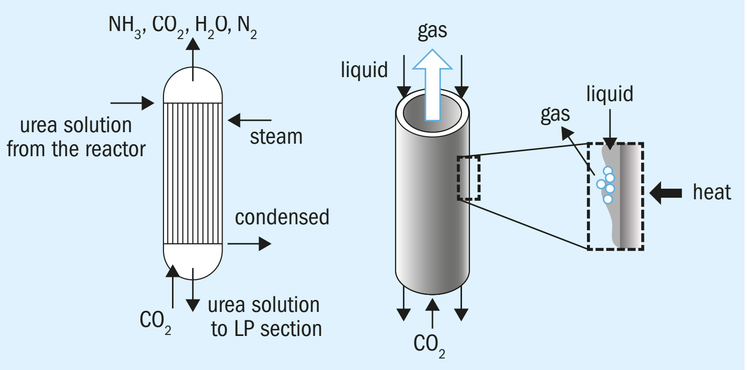
Fig. 2: **Schematic of a CO_2 stripper**



Schematic of a CO_2 high pressure stripper and how it functions

The CO_2 feed flowing from the bottom to the top plus the heat from the shell side facilitates the dissociation of the ammonium carbamate still present in the solution leaving the reactor into carbon dioxide and ammonia gas. Note that hardly any water, which is also present in the reactor outlet solution, will evaporate. In the actual stripper tubes, almost half of the liquid introduced in the top is evaporated, the gas and liquid loads are much greater at the top than at the bottom. This means that flooding will occur first in the top of the tubes. At a reactor outlet solution temperature of 183°C and a pressure of 140 bar, the flooding limit in a 1-inch tube is found to be 145 kg of solution per hour. In practice, an upper limit of 70% of this value is applied. [Source: IFS Proceedings no. 166]

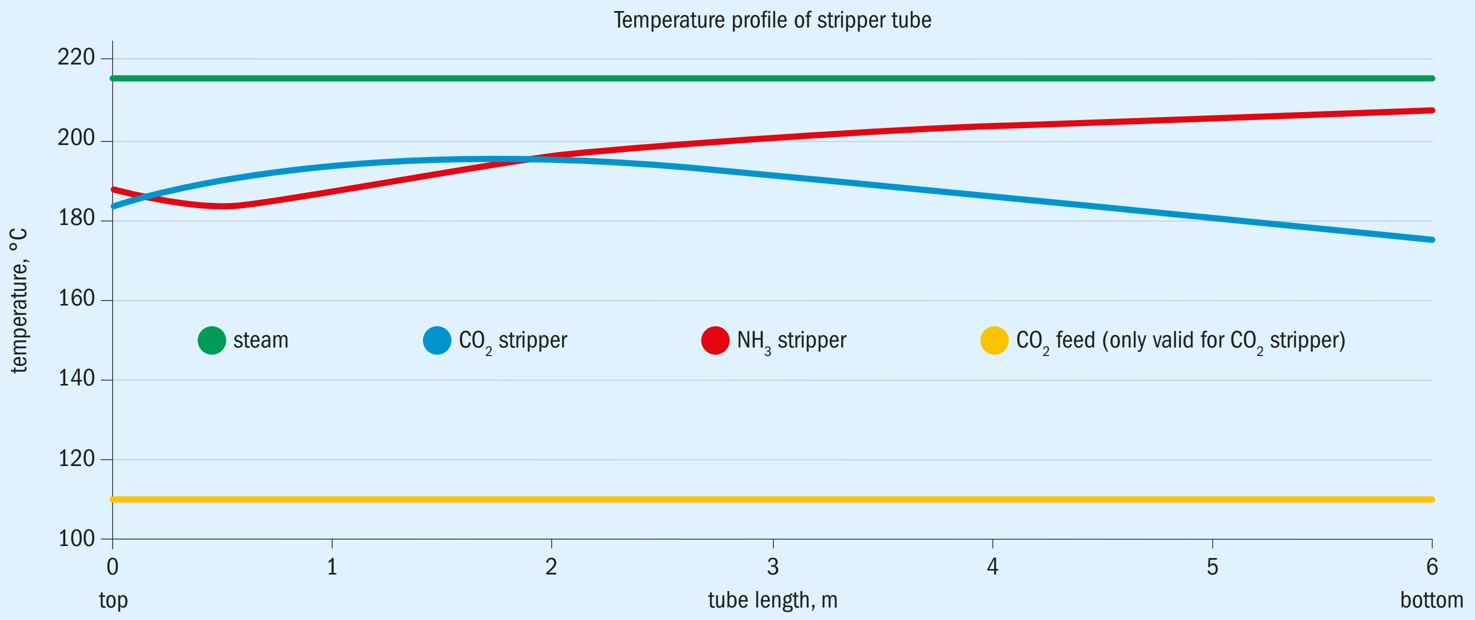
At a certain load the falling film will break off the tube wall and flooding will start. It is important for every urea plant to know at which plant load the stripper shows flooding because above that plant load the stripper efficiency will be lower, leading to more ammonia in the stripper bottom outlet, leading to higher temperatures of that stream and more gas to the low pressure recirculation section. The pressure in the recirculation section will increase and more carbamate needs to be recycled, leading to an overall lower performance of the urea plant. A sudden temperature increase of the stripper bottom temperature, e.g. 3-4°C in 15 minutes, is a clear indication that the flooding limit of the stripper has been reached.

Even more critical when reaching the flooding limit is the maldistribution of the liquid from the urea reactor over all the tubes. A stripper tube which receives too much liquid and shows flooding behaviour can experience active corrosion with significant high corrosion rates and a possible tube rupture in case the applied material of construction is an austenitic stainless steel. Liquid containing ammonium carbamate should and normally does contain sufficient oxygen to assure passive corrosion (max 0.1 mm/year corrosion rate) and not active corrosion (20-30 mm/year corrosion rates). But a stripper tube under flooding condition may contain liquid which has a long residence time in the tube and due to the passive corrosion rates the available oxygen may get depleted leading to active corrosion with significant higher corrosion rates, resulting finally in a tube rupture as shown in the picture on page 16. One can see the thinning of the tube wall thickness at the top compared to the bottom of the picture which results from the higher active corrosion rates.

A tube rupture is troublesome for the urea plant operators as the entire solution present in the high pressure synthesis section will flow through the ruptured tube. Thus it is very important that flooding of a stripper with 25-22-2 austenitic stainless steel tubes should be avoided. A stripper with Safurex super-duplex tubes has a significant benefit as active corrosion has never been seen with this material.

It is interesting to note that the internal surface of the tube is related to the flooding limit in a linear way. And as the internal diameter and thus also the internal surface increases in time due to the unavoidable passive corrosion rates, during its lifetime, a CO_2 high pressure stripper will show an increasing flooding limit. For example, a stripper may reach its flooding limit at 110% plant load when it is new and 120% plant load at its end of lifetime conditions. As the CO_2 high pressure stripper is typically one of the major bottlenecks in a urea plant, it is recommended to always replace the stripper by a larger one with more tubes when it reaches end of lifetime. ■

Fig. 3: **Temperature profile of a CO_2 stripper and a NH_3 stripper**



Nuclear powered ammonia

With green ammonia from renewable energy facing cost hurdles to adoption, thoughts have turned to using nuclear energy as a carbon free alternative.

Many low carbon projects for producing ammonia have focused on two essential alternatives; conventional ammonia production using fossil fuels, particularly natural gas, followed by carbon capture and storage/utilisation ('blue' ammonia), or use of hydrogen generated via water electrolysis using renewable energy – wind, solar or hydroelectric ('green' ammonia). However, an alternative zero carbon source of power is already widely available and adopted worldwide; nuclear energy. While it 'burns' uranium fuel (although this can be reprocessed where such technology is available), and hence is not strictly renewable, other nuclear fuels are available, and while it generates radioactive waste which must be safely stored and disposed of, it is nevertheless a zero carbon energy source. The scalability of blue ammonia remains an open question at present, as outside of enhanced oil recovery, carbon dioxide has not been permanently sequestered on the kind of scale that would be needed to convert much of the world's ammonia production, while green ammonia, although costs of electrolysis are falling, remains expensive compared to conventional 'grey' ammonia production. The use of nuclear power to generate hydrogen for ammonia production – sometimes called 'pink' or 'yellow' ammonia - is consequently receiving serious consideration.

Increasing nuclear use

Nuclear power continues to see an increase in use. According to the World Nuclear Association, global nuclear electricity generation rose to 2,600 TWh in 2023, up from 2,540 TWh in 2022, providing 9% of the world's electricity—second only to hydropower among clean energy sources. WNA argues that this meant that nuclear reactors currently help avoid 2.1 billion t/a of carbon dioxide emissions from equivalent coal generation, and at COP28, twenty-five countries signed a declaration to triple nuclear capacity by 2050. There are currently 64 reactors under construction in 15 countries, two thirds of these in Asia, and almost half in China alone. Eastern Europe and Russia are also seeing major expansions.

In the European Union, while nuclear energy use has been reduced due to concerns over waste disposal, and in Germany has virtually ended due to environmental concerns, there remain major proponents of nuclear power, particularly France, which uses nuclear power to generate over 60% of all of its electricity. French pressure helped include nuclear energy use as part of EU renewable energy usage targets in a deal agreed at the end of 2023. Nuclear power plants in Europe can now produce and market hydrogen that may be used by industry as a replacement for fossil fuels, and contribute to the region's goals of sharply reducing fossil fuel use while boosting supplies of clean fuels. Nuclear power has seen something of a re-evaluation in Europe since Russia cut supplies of natural gas to the continent, sending natural gas prices spiking to unheard of levels, and outside of France it remains a major source of energy in several other countries, including Sweden, Spain, Switzerland, Finland, Belgium and Bulgaria.

Indeed, it can be argued that the Borealis project to instal 30 MW of electrolysers at its Ottmarsheim production site in France running off electricity from the French electricity grid will in effect be producing a proportion of nuclear ammonia. The demonstration project is aiming to deliver 24,000 t/a of low carbon ammonia by 2025-26 and it can be argued that 60% of this is effectively nuclear based ammonia capacity. However, nuclear power plants mainly generate base load electricity, more useful to power companies than solar or wind power as it does not have slack periods, while integrating nuclear heat as well as power generation into ammonia production is more efficient, and so it is likely that for large scale ammonia production, dedicated nuclear plants might be required.

Benefits for hydrogen

Nuclear power can operate at very high capacity, for long periods without upset, making it ideally suited to large scale provision with a dedicated end use such as chemical production, as it eliminates supply uncertainties and interruptions which are problematic for fossil fuel based ammonia plants given the several days required for start-up and shutdown. It also means that production is not subject to the volatility of fossil fuel prices, again particularly natural gas prices, making operating costs far more predictable. Finally, eliminating gas or solid fuel reforming as a source simplifies the process, with the hydrogen feed needing far less treatment before it is used in ammonia production.

Methods of hydrogen generation

As Figure 1 shows, there are several ways that nuclear energy can be used to produce hydrogen for ammonia production. Firstly, it can be used for simple 'cold' electrolysis of water in the same way that renewable power is used, as per the Borealis project mentioned above. However, the heat generated by nuclear reactors means that this can also be incorporated into the process, as low- or high-temperature steam electrolysis. This increases the efficiency of the electrolysis from around 25% using

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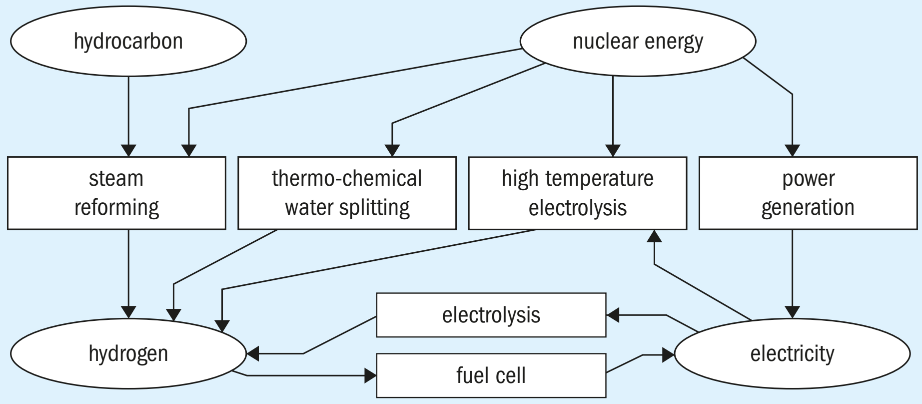
Fig. 1: **Routes from nuclear energy to hydrogen**



Source: IAEA[1]

cold electrolysis (ca 33% for the reactor x 75% for the cell) to up to 45% for high temperature steam electrolysis. It is even possible to use nuclear heat to thermochemically break down water into its component molecules, by using sulphur and/or iodine intermediates, raising efficiency to around 50%. In additional to all of these, it is possible to use nuclear heat to heat the reformer of a conventional ammonia plant. Steam reforming requires temperatures of over 700°C, easily generated by a nuclear reactor, and allowing around one third of gas consumption (i.e. all reformer heating gas) to be eliminated, along with flue gas CO_2 emissions.

There have been studies of all of these routes recently, in both the US and Russia. Perhaps predictably, however, there remain some technical issues which need to be overcome. High-temperature (550-750C) steam electrolysis in solid oxide electrolysis cells requires about one-third less energy than low-temperature electrolysis, but commercialisation has remained elusive due to the poor durability of components in a hot hydrogen environment. High temperature hydrogen attack, also known as 'metal dusting', remains a serious problem for steels, and even the ceramics used in the research projects suffered considerable degradation.

Thermochemical processes

Several direct thermochemical processes are being developed for producing hydrogen from water. For economic production, high temperatures are required to ensure rapid throughput and high conversion efficiencies. An intermediate heat carrier is usually used for safety reasons, generally a helium or molten fluoride salt loop. In each of the leading thermochemical processes the high-temperature (800-1000 °C), low-pressure endothermic (heat absorbing) decomposition of sulphuric acid produces oxygen and sulphur dioxide:

$$2H_2SO_4 \rightarrow 2H_2O + 2SO_2 + O_2$$

Subsequent reactions can involve iodine, such as the General Atomics process, which combines the iodine with the sulphur dioxide in the exothermic Bunsen reaction:

$$I_2 + SO_2 + 2H_2O \rightleftharpoons 2HI + H_2SO4$$

The HI then dissociates to hydrogen and iodine at about 350-450°C, endothermically:

$$2HI \rightleftharpoons H_2 + I_2$$

This can deliver hydrogen at high pressure. Overall this is effectively reduction of water to hydrogen and oxygen; all of the reagents other than water are recycled, and there are no effluents, hence it may be called the sulphur-iodine cycle, with zero-carbon hydrogen and oxygen byproducts. Japan and South Korea are both conducting research to use this to generate low cost hydrogen by the end of the decade using high temperature reactors.

Indonesia

Although most of the work on nuclear hydrogen and ammonia has been at a research level, there is a major project in development in Indonesia, where four Danish companies - Copenhagen Atomics, Aalborg CSP, Alfa Laval and Topsoe - have signed a memorandum of understanding with Indonesian ammonia producer PT Pupuk Kalimantan Timur, together with Pertamina New & Renewable Energy to investigate building a facility in the city of Bontang on the eastern coast of the island of Borneo, in the province of East Kalimantan.

The facility – tentatively scheduled to open in 2028 - would produce 1 million t/a of low carbon ammonia, at an estimated investment cost of $4 billion. The facility would be based around 25 of Copenhagen Atomics' small modular nuclear reactors, each with a capacity of 40 MW, based on thorium technology. Aalborg CSP will design and supply thermal energy storage systems, molten salt based steam boilers providing the energy balancing required to integrate the energy production from the SMR modules with electricity production and waste heat from power turbines with production of ultra clean water. Alfa Laval will deliver heat exchangers to optimise the energy balance of the plant, and desalination to produce ultra-pure water for the electrolysis process. Topsoe would supply its own electrolysis cell technology, based on solid oxide electrolyser cells (SOEC) which are claimed be up to 30% more efficient than competing technologies in generating hydrogen, and would also design the 1 million t/a ammonia plant. All of the offtake would go to local partner Pupuk Kalimantan Timur (Kaltim). Pupuk Kaltim operates a total of 2.74 million t/a of ammonia capacity from its existing five ammonia plants licensed by KBR and Topsoe, making it the largest fertilizer company in southeast Asia. The ammonia is mostly used for downstream urea and ammonium nitrate production. In 2021, Indonesia exported about 0.90 million tonnes of ammonia according to the World Bank. Pupuk Kaltim contributes about one third of Indonesia's ammonia exports, shipping to east Asia and Australia. The company has 100,000 tonnes of ammonia storage capacity, as well as six jetties able to accommodate ships up to 55,000 dwt.

Thorium

The enabling technology is Copenhagen Atomics' modular thorium molten salt reactors, which the company says exceptional energy efficiency, capable of extracting 100 times more energy from each ton of mined materials compared to traditional reactors. Whereas a conventional reactor of the same scale

PHOTO: EDF

Construction of the new nuclear power plant at Hinckley Point C, UK.

would require 10 t/a of enriched uranium, the Bontang plant would only need 850 kilograms of thorium per year. Indonesia is believed to have considerable thorium reserves, around 250,000 tonnes.

Thorium also reduces the storage time for nuclear waste from around 100,000 years required for spent uranium to around 300 years. The efficiency comes from Copenhagen Atomics' 'Onion Core' design, which uses 1200 litres of heavy water, 200 litres of fuel salt, and 2000 litres of thorium blanket salt to run the nuclear reaction. The heat from the reaction is transferred to the molten salt at about 600°C. Then, the molten salt is cooled down with water that is evaporated to steam. The steam is then used in a turbine to generate electricity.

Costs

The investment cost is high, several times that of a conventional gas-based ammonia plant. However, once operational, operating costs are relatively much lower, and the companies involved believe that, over the plant's projected 25 year lifetime, it would actually be a relatively competitive green ammonia supplier. The projected price of ammonia is around $500/t[2], still high compared to 'grey' ammonia, but far lower than the estimated $700-1,400/t that wind or solar generated ammonia might cost. A Brazilian study using conventional nuclear generation came to a figure of $790/t for ammonia production for a 100,000 t/a ammonia plant[3], while a study by the Maersk McKinney Moller Center for Zero Carbon Shipping came in at $514/t for the levelised cost of ammonia, admittedly for a larger scale, 10 million t/a ammonia facility[4].

At present the project is in a six month feasibility study period, during which regulatory approvals will be sought for reactor construction on the designated site owned by off-taker Pupuk Kaltim. Funding remains an open question. It is anticipated that Pupuk Kaltim and the Indonesian government will contribute around 50% of the money, with international investors providing the rest. The investment cost is certainly lower than for another green ammonia project in Indonesia, being developed by Pertamina with Tokyo Electric Power and some other Japanese companies, which would use geothermal energy in North Sulawesi to produce up to 1 million t/a of ammonia, and require up to $8-10 billion.

Terrestrial Energy

The other main rival technology to Copenhagen Atomics comes from Canadian-based Terrestrial Energy. Terrestrial Energy is also pioneering a thorium-based nuclear reactor technology which uses molten salt as both a fuel and as a coolant; the Integral Molten Salt Reactor (IMSR). With integrated components, the IMSR can supply heat directly to industrial facilities or use it to generate up to 195 MW of electrical power. Terrestrial Energy says that the use of molten salt as both fuel and coolant also enables passive, or inherent, safety features to be built into the reactor design. It is based on technology developed at the USA's Oak Ridge National Laboratory, and integrates the primary reactor components, including the graphite moderator, into a sealed and replaceable reactor core unit with an operating lifetime of seven years. Looking towards ammonia production, Terrestrial Energy has entered into a partnership with KBR to integrate the processes for hydrogen and ammonia production, and is currently seeking permits for its technology in North America. It hopes to have its first reactors operational by 2030.

UAE

While the UAE is currently developing blue ammonia capacity using carbon capture technology, it is also looking towards nuclear power to help decarbonise and has indicated that it is interested in using nuclear energy to make ammonia. The Emirates Nuclear Energy Corporation (ENEC) recently successfully started-up a fourth reactor at its Barakah Nuclear Energy Plant which uses pressurised water to generate up to 1.4 GW of electricity. Once fully operational, Barakh will be providing 25% of UAE electricity demand. In advance of COP 28 in Dubai, ENEC also launched a programme called ADVANCE to evaluate technologies in the advanced, small modular reactor and microreactor categories, which can generate both electricity as well as process heat for industrial processes. It hopes to harness these to help decarbonise heavy and energy intensive industries, such as steel, aluminium, oil, gas, cement and chemical/fertilizer production in order to achieve the UAE's target of net zero carbon emissions by 2050. Last year, the UAE launched a national hydrogen strategy which forecast the production of 1.4 million t/a of low carbon hydrogen by 2031 and 15 million t/a by 2050. The country is aiming to generate 15 million tonnes by 2050. The plants will be developed in centres dubbed 'hydrogen oases'. Two hubs have already been identified: one in Ruwais and the other in Kizad, Abu Dhabi, with a third possibly to be established in the port emirate of Fujairah. The UAE has also established partnerships with Germany, Japan and South Korea to export its future production. ■

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Ammonium nitrate and its derivatives

Demand for nitrates has rebounded after a difficult period following the dislocations caused by the war in Ukraine, with UAN in particular seeing rapid growth. Technical ammonium nitrate is also growing on the back of increased mining activity.

Ammonium nitrate and its various derivatives; calcium ammonium nitrate (CAN) and urea ammonium nitrate (UAN) remain collectively the second largest nitrogen fertilizer sector by use after urea. While urea has often been preferred in warmer climates because it contains a higher percentage of nitrogen (ca 46% compared to an average of 33% for AN), and hence is a cheaper and more efficient way of transporting nitrogen nutrient, ammonium nitrate remains preferred in some key markets, particularly Europe, Canada and Russia, because it does not need to be hydrolysed to the nitrate form in the soil and hence is available for more rapid uptake by plants; important for shorter growing seasons in more northerly lattitudes. Ammonium nitrate generates 90% fewer ammonia emissions per unit of nitrogen than urea, which is a factor in many countries which are trying to reduce ammonia emissions, especially in Europe.

Manufacture

Ammonium nitrate is produced by the acid base neutralisation reaction of nitric acid with ammonia. As nitric acid is also made from ammonia oxidation, AN plants are typically co-located with ammonia and nitric acid production. The ammonium nitrate is formed as a solution in water. For production of solid AN it is then typically concentrated in an evapourator or concentrator to a solution strength of 95-99% AN at high temperature (ca 150C). This AN ‘melt’ is then passed to a prill tower or granulator to produce the solid AN prills.

Orica’s ammonium nitrate plant at Kooragang Island, Newcastle, Australia.

PHOTO: ORICA

Prill density can be varied by using different concentrations of ammonium nitrate melt. Low density prills, at a density of around 1.29, are formed from 95-97.5% AN melt, while high density prills, at a density of around 1.65, are formed from a 99.5-99.8% melt. Low density prills are more porous than high density prills and so absorb e.g. oil more easily. For this reason low density prills are used for making blasting agents – this is known as ‘technical’ or ‘industrial’ grade AN (TAN/IGAN). The higher density prills are used as fertilizers (fertilizer grade AN or FGAN), with a typical nitrogen nutrient content of 33-34%. Because of the similarity in IGAN and FGAN production, both from an ammonium nitrate liquor, the TAN industry originally evolved largely as an ‘adjunct’ to the production of FGAN. However, because of regulatory hurdles in storage and transport of AN, plants tend to be relatively close to areas of end user demand, and as fertilizer and mining areas are often not the same, there has been a gradual polarisation of the industry into dedicated facilities producing one or the other.

The melt can also be mixed with other chemicals to produce other end products. One popular method is to mix the melt 75-25% with calcium carbonate (limestone) to produce calcium ammonium nitrate (CAN). Dolomite (calcium magnesium carbonate) can be substituted for calcium carbonate to produce magnesium ammonium carbonate (MAN).

Finally, the non-concentrated ammonium nitrate solution direct from the reactor can instead be mixed with a solution of urea to produce a solution called urea ammonium nitrate (UAN). UAN is typically available in three different concentrations: 28%, 30% and 32% nitrogen. The most popular form – 32% nitrogen – is a mixture of 45% ammonium nitrate, 35% urea and 20% water. Ammonia and nitric acid are used to adjust solution pH to close to 7.

Since ammonium nitrate is hygroscopic in its solid form it is usually coated with an anti-caking compound.

Safety and security

Major incidents involving AN continue to occur. Often this is not explosive or technical grade AN, which tends to be more tightly monitored by authorities, but rather FGAN which has been improperly or dangerously stored. Explosions in the ports of Beirut and Tianjin (2015) and at West, Texas (2014?) were caused by stockpiles of FGAN, likewise explosions at manufacturing sites like Toulouse (2001) or Port Neal (1994?). Some countries have banned the sale of AN as a fertilizer, or introduced restrictions on how much can be stored or imported, although this often just leads to substitution into forms perceived as less dangerous such as CAN, UAN or NPK blends. However, the general utility of AN as a fertilizer means that it continues to be widely used.

Fertilizer demand

Fertilizer demand for nitrates is split between FGAN, CAN and UAN. Global demand for FGAN was 17.3 million tonnes product in 2023, for CAN this was 13.5 million tonnes product, and for UAN 24.2 million tonnes product. Demand for FGAN, CAN and UAN is concentrated in three main regions: Western Europe, North America, and Eastern Europe/Russia, which collectively account for two thirds of all consumption. However, each is quite different in terms of how that AN is used. In Western Europe, restrictions on the sale of straight AN fertilizer in countries such as Turkey, Germany, Ireland and parts of the UK due to its potential for misuse has led to substitution with calcium ammonium nitrate (CAN). Western Europe, including Turkey, is the only significant market for CAN, and is responsible for three quarters of all global CAN demand.

In the US, conversely, a preference for fertilizer solutions but a corresponding tightening of regulations on the storage, transport and use of ammonia for direct application, on grounds of safety and security, has led to a rapid increase in demand for UAN solutions, and the North American market is heavily skewed towards UAN, with straight AN mostly used as a mining explosive.

Consumption in Eastern Europe and Russia has been rising rapidly. Russian consumption of AN has more than tripled since 2000. CAN and UAN are not major features of this market. The rise in domestic consumption in Russia has helped alleviate one issue that had bedevilled the global AN market – allegations of so-called 'dumping', or sale of product at below cost price in order to increase market share. However, Russia remains a major exporter of FGAN and the war in Ukraine has complicated this considerably.

Outside of these regions, UAN use is also rising rapidly in Australia and Argentina.

Ukraine

Russia's invasion of Ukraine caused dislocations for the AN and downstream industries in particular. Although fertilizer has not been subject to sanctions, financial restrictions have made paying for fertilizer from Russia and Belarus much more complicated. Russia also placed quotas on exports of AN and other fertilizers in order to make sure that it had enough for the domestic market. Furthermore, the gradual shutdown of Russian natural gas exports to Europe over the course of 2022 added to what had already been a shortage of gas in Europe and led to record high gas prices which forced the shutdown of most (up to 65%) of Europe's domestic ammonia capacity. This in turn led to very high prices for AN, and consequently farmers reducing consumption considerably. European nitrate production dropped from 25.1 million tonnes in 2021 to 19.4 million tonnes in 2022.

Gas use curtailments, and a rapid expansion of LNG imports into the continent have brought that situation under control over the past two years, however, and gas prices are now back down to normal levels and much European nitrogen capacity has reopened. European nitrate production is expected to have recovered to 21.9 million tonnes in 2024. Russian FGAN exports likewise dropped by 50% in 2022 to just 1.5 million t/a, but are expected to have recovered to 2.2 million t/a in 2024. The destination of Russian exports has seen a wholesale shift, with only 15% of FGAN going to Europe in 2023, and 60% going to Brazil and Latin America.

Consumption increasing

Grain production in the US plays a crucial role in determining nitrates affordability and usage. US wheat output is expected to rise this year following an expanded spring planting area, supporting nitrate consumption in the region. Increasing wealth in developing nations is boosting consumption, and higher demand for agricultural commodities due to the global energy transition has increased use of crops as feedstock for energy products, with nearly 40% of US corn being used for ethanol and nearly 50% of US soybeans being used for biofuel. Furthermore, nitrates have become more affordable, particularly in Europe, as fertilizer prices have fallen from their 2022 peak. Global nitrogen consumption is projected to increase by 1.8% year on year in 2024, with significant increases in Indonesia, Turkey, Argentina, and Brazil and in spite of an 18% decline in Ukraine and some demand reduction in China due to more efficient fertilizer use.

For nitrates, FGAN consumption in East Europe/Russia is expected to recover by 2028, reaching 5.3 million t/a following a demand destruction as an aftermath of the Russia-Ukraine conflict. In 2024, Russian nitrogen fertilizer consumption is expected to remain at a similar level to 2023, but it is expected to grow by about 2.5% per year out to 2028, as new by new domestic FGAN capacity comes on-stream.

CAN usage remains concentrated in Europe and Turkey with a healthy increase projected in the medium term, driven by demand in Eastern Europe, where the fertilizer is favoured for its perceived environmental sustainability. Eastern European CAN consumption is expected to increase by 22% by 2028, led by Estonia, Hungary and Poland. Demand for CAN is also rising in Brazil and Argentina.

UAN consumption remained relatively stable in 2023 but is expected to grow in the medium term, reaching 27 million t/a by 2028. In 2024, consumption in France and the US is anticipated to increase by 8.2% and 5.3% respectively. Demand in the US is bolstered by enhanced application rates following a record corn harvest in the 2023–2024 crop year.

Production

More stable gas prices are leading to increases in European nitrate production. CAN, UAN and FGAN production in Europe is expected to increase by 5.2%, 13.5% and 4.2% respectively, in 2024. Over the next few years production will continue to climb, though it is not expected to reach the level of its 2021 pre-invasion peak (22.1 million t/a) until 2028.

US production is relatively stable, at around 13.7 million ta of UAN, and operating rates are already at 90%, supported by low gas prices and good demand, leaving not much room for expansion.

Thanks to its abundant gas reserves, Russia remains a low cost producer. While the Ukraine war has reduced its opportunities for exporting to Europe, it has gradually made up for that by expanding sales into Latin America. Russia is anticipated to produce approximately 11.5 million t/a of nitrate fertilizers in 2024, giving it a 42% share of the FGAN market. FGAN production is expected to increase to 8.2 million t/a by 2028, following the commissioning of new plants in 2026 Q4, primarily aimed at satisfying the export markets, particularly South America.

New production over the next few years is concentrated in Eastern Europe, Egypt and Russia/Central Asia, as shown in Table 1, although some of the larger projects are more speculative, and firm new capacity is only 2.2 million t/a in total out to 2028. Overall this is likely to lead to improved operating rates and higher prices over the medium term.

Trade

US UAN exports to Europe increased in 2023 as European production went through a downturn in 2022 because of shutdowns in European capacity following the gas shortage and high feedstock prices. Since then, European nitrate production has rebounded with many plants resuming operations and June 2024 curtailments remained low at 18%. Improving European production has reduced export opportunities to the region because of lower netbacks. As a result, 2024 Q2 US exports were 23.3% lower than the same period last year. Instead, US exports have found a new home in Australia and Argentina as both regions have seen a healthy increase in UAN demand. US exports are expected to slightly decrease by 2026 and stabilise thereafter in the medium-term as domestic demand increases.

Russia and Trinidad have been steadily increasing supply to the US with total 2024 Q2 imports around 28% higher than the same period last year. Other Russian UAN exports are primarily directed to France and Australia. Russian UAN exports rose 15% in 2023 compared to 2022 and are expected to remain fairly stable until 2027 before reaching 2.1 million t/a in 2028 when the new Ammonii Mendeleevsk plant is predicted to commission. Brazil is the largest consumer of Russian FGAN. With crops like sugarcane, corn and coffee requiring significant amounts of nitrogen fertilizers and growing plantation area. The region is highly dependent on imported fertilizer due to the lack of domestic production capabilities and Russia's cost position enables it to export competitively priced FGAN to the region.

Technical AN

In addition to the various fertilizer nitrates, AN remains the main component of the most widely used commercial explosives. Low density or technical grade AN (TAN) demand reached 17 million t/a worldwide in 2023, making it around one quarter of all demand for ammonium nitrate. TAN demand is driven almost exclusively by mining uses, with coal, iron ore, copper and gold mining collectively representing the lion's share (70%) of demand. Coal is the most important of these, and coal production globally is reaching a peak at present, and is likely to decline over the next few years as power production switches to lower carbon generation, particularly in the US and China. Indian consumption will rise, but not enough to counteract an overall fall. Conversely, iron and copper demand is increasing, and new copper mines in Chile, Peru and the US will lead to more TAN demand. Additional iron ore production is expected in Australia, Ukraine and Brazil. Gold mining is forecast to fall over the next few years, reducing TAN demand by about 200,000 t/a. Overall, TAN demand will rise modestly, to about 17.5 million t/a in 2028.

TAN production tends to be closer to the mine sites, as restrictions on shipping and storage of explosive precursors like TAN tend to be quite stringent. Production is concentrated in Russia, China, the US and Australia, but India's growing appetite for coal is leading to new TAN capacity being built there, with Deepak bringing new capacity on-stream at Taloja and Gopalpur this year and Chambal at Gadepan in 2025, totalling 1.0 million t/a of new TAN capacity, bringing TAN production to a potential 18.1 million t/a by 2028.

Green production

In Europe, nitrogen fertilizer prices could rise over the next decade as a result of EU targets on ammonia producers, with significant implications for fertilizer affordability. The cost of fertilizer grade ammonium nitrate (FGAN), which is driven by the cost of ammonia, could rise to as much as ~$1,500/t N in real terms in 2030 if produced with green ammonia in line with EU policy obligations. The same product was selling for as low as ~$800 /t N in 2020 when produced with conventional 'grey' ammonia. If using the lowest cost form of imported green ammonia from the USA, the cost of FGAN would be roughly half, at ~$800 /t N in 2030. A similar cost would also be achieved using blue ammonia from the USA. ■

Table 1: **Fertilizer AN capacity additions 2023-28**

Company	Location	Capacity	On-stream date
NCIC	Ain Sokhna, Egypt	500,000 t/a FGAN/CAN	2023
Koch	Fort Dodge, USA	35,000 t/a UAN	2024
Gemlik Gubre	Gemlik, Turkey	165,000 t/a UAN	2025
Jinguan	Baiyin, China	50,000 t/a UAN	2025
Grupa Azoty	Tarnow, Poland	495,000 t/a FGAN	2026
Uralchem	Berezniki, Russia	83,000 t/a FGAN	2026
Kuaz	Togliatti, Russia	660,000 t/a FGAN	2026
KIMA	Aswan, Egypt	220,000 t/a FGAN	2027
Abu Qir	Alexandria, Egypt	790,000 t/a FGAN	2027*
Ammonii	Mendeleevsk, Russia	150,000 t/a UAN	2028
Anwil	Wloclawek, Poland	396,000 t/a FGAN	2028
Kazazot	Aktau, Kazakhstan	500,000 t/a FGAN	2028*

Source: CRU

* project assessed as speculative

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Nitrous oxide and the fertilizer industry

The nitric acid industry has made great strides in reducing nitrous oxide emissions over the past few decades, but emissions from agriculture due to nitrogen fertilizers remain a problematic source of N_2O in the atmosphere.

PHOTO: GETTY IMAGES

Sheep grazing in pasture, Wiltshire, UK

Nitrous oxide (N_2O) is a long-lasting greenhouse gas that is around 270 times more potent than carbon dioxide (CO_2). It is the third-largest contributor to climate change, after carbon dioxide and methane. Nitrous oxide emissions in 2022 were 2.97 billion tonnes of CO_2 equivalent, out of a total anthropogenic CO_2 equivalent release of 53.8 billion tonnes[1], or around 5.5% of human greenhouse gas emissions. The concentration of atmospheric nitrous oxide also reached 336 parts per billion in 2022, a 25% increase over pre-industrial levels that far outpaces projections previously developed by the Intergovernmental Panel on Climate Change (IPCC).

Nitrous oxide budget

A recent report assessed of the origins and climate impacts of the world's nitrous oxide emissions[2]. It was led by researchers from Boston College in the US and involved an international team of scientists including researchers from the University of East Anglia (UEA), UK, under the umbrella of the Global Carbon Project. In total, the team was comprised of 58 researchers from 55 organizations in 15 different countries. The research, published in Earth System Science Data, assessed both natural and human-caused sources of nitrous oxide to see how they have changed over time and how they are contributing to climate change, using a range of satellite data, models, algorithms and inventories.

Various natural sources generate nitrous oxide, including microorganisms in the world's oceans and soils. These natural emissions accounted for 65% of all nitrous oxide emissions over the period 2010-19. Human activities caused the remaining 35% of emissions, particularly nitrogen fertiliser use and manure management in agriculture. The study found that, while natural sources had remained fairly constant over the past four decades, human-caused nitrous oxide emissions had "significantly increased" from 1980 to 2020, growing by 35% during this time period. This rise was spurred on, in part, by growing demand for meat and dairy. Agriculture was the "major driver" of increased human-caused nitrous oxide emissions over the past four decades, responsible for 74% of these emissions over 2010-19, reaching 8 million t/a in terms of N_2O as nitrogen in 2020. This is attributed mainly to the use of commercial nitrogen fertilizers and the use of animal waste on croplands. In addition, increased levels of nitrogen run-off from fields affects inland waters and rivers, and increases N_2O emissions from lakes, ponds, and coastal ecosystems. However, the study also found that while agricultural emissions have increased over time, other human-caused nitrous oxide emissions

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from fossil fuels and industry decreased slightly between 1980 and 2020.

The main sink for N_2O is the stratosphere, where secondary products of its breakdown react with ozone, and both are broken down as a result. Estimates indicate that between 12.2 and 13.4 million t/a N_2O-N were depleted in the stratosphere every year between 2000 and 2019. This does not balance the emissions of nitrous oxide, however, so in net terms an increasing amount of nitrous oxide remains in the atmosphere every year. For the years 1990 to 1999, this is estimated at 3.6 million t/a N_2O-N, rising to 6.4 million t/a N_2O-N in 2020. This surplus is distributed in the earth's atmosphere and explains the increasing absolute proportion of N_2O.

Regional trends

The study also examined emissions in 18 different regions: China, India, the US, Brazil and Russia were the five biggest nitrous oxide emitters in 2020, as shown in Table 1. Anthropogenic emissions increased by 157% in India, 135% in China and 131% in Brazil over 1980-2020. China alone made up 40% of the overall increase in global human-caused nitrous oxide emissions between 1980 and 2020.

On the other hand, nitrous oxide emissions have reduced in several parts of the world since 1980: Europe, Russia, Australia, New Zealand, Japan and Korea. Europe – the biggest nitrous oxide emitter in 1980 – has seen the most significant drop in the four decades since. Emissions fell by almost one-third (31%) during this time, largely due to nitric acid industry emissions cuts in the 1990s. Agriculture-related nitrous oxide emissions have also significantly decreased in the EU and Russia to less than 0.4 million t/a and 0.1 million t/a N_2O-N per year respectively. In the EU, this is mainly attributed to political measures to reduce the use of nitrogen fertilizers in agriculture, while in Russia it is due to the collapse of the agricultural cooperative system since the 1990s. Emissions in China have slowed since the mid-2010s. In the US, agricultural emissions continue to creep up while industrial emissions have declined slightly, leaving overall emissions rather flat.

The ten largest emitters from agriculture in 2020 are China with over 0.6 million t/a N_2O-N, followed by South Asia, the EU, Brazil, the USA, Southeast Asia, North Africa, Equatorial Africa, Southern South America and the Middle East. From 1980 to 2020, nitrous oxide emissions from agriculture more than tripled in Equatorial Africa and Southeast Asia, and more than doubled in South Asia, North Africa, Brazil, China, Canada and the Middle East.

Reducing N_2O emissions

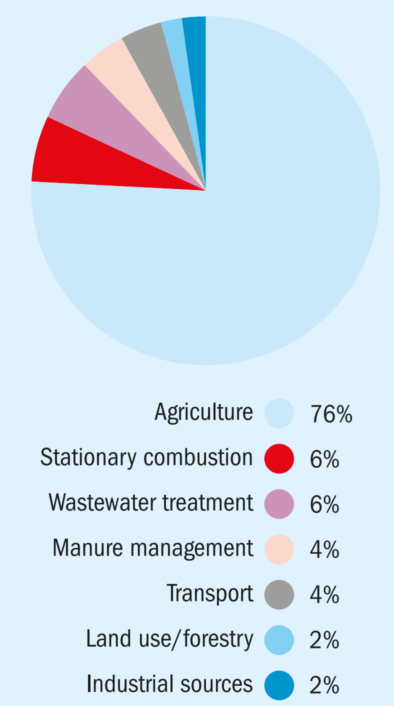
As our articles elsewhere in this issue illustrate, the nitric acid industry has made great strides in reducing emissions of N_2O. As Figure 1 shows, in the US, industrial emissions of all kinds (including acrylonitrile/fibre manufacture and other nitrogen using processes as well as nitric acid) amount to less than 2% of all emissions. It is now agriculture which remains the dominant source.

The main starting point for reducing nitrous oxide emissions are the direct anthropogenic sources from agriculture. Experts suggest closing the nitrogen cycle and avoiding losses during use in agriculture and livestock farming. In addition, they suggest considering systemic changes that reduce nitrogen losses, for example in human and animal nutrition and in the use of fertilizers. Tangible measures range from lower-protein diets for dairy and beef cattle and pigs to the more targeted use of fertilizers in arable farming, the treatment of liquid manure and special landscape management measures.

Biomass emissions can be prevented by processing rather than burning it on arable land. Biomass can be replaced by other fuels in household stoves. Natural fires can be influenced by controlled burning. An effective reduction in emissions from fossil fuels and industry is feasible through technical measures. Their introduction can be accelerated by legal requirements, international agreements and inclusion in emissions trading systems, as already in existence in the EU. Nitrous oxide emissions from wastewater can be controlled especially through certain treatment steps in multi-stage wastewater treatment plants.

Requirements to cut nitrous oxide emissions, particularly from livestock, have been a major political issue in the Netherlands and other countries. Nitrous oxide emissions are "expected to continue rising" over the next few decades due to the growing demand for food, the study says. ■

Fig. 1: **Sources of US man-made N_2O emissions, 2022**



Source: US EPA

Table 1: **National share of man-made nitrous oxide emissions**

China	14.2%
India	9.7%
USA	8.5%
EU-27	7.2%
Brazil	6.5%
Mexico	4.0%
Russia	2.8%
Indonesia	2.6%
Pakistan	2.5%
Rest of world	32.0%

Source: Tian et al[2]

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1. MW Jones *et al*. "National Contributions to Climate Change Due to Historical Emissions of Carbon Dioxide, Methane and Nitrous Oxide". Scientific Data. Zenodo, March 19, 2024.
2. H. Tian *et al*, "Global nitrous oxide budget (1980–2020)", *Earth System Science Data*, 16, 2543–2604, June 2024.

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Decarbonisation of the maritime industry

As the industry pushes towards more sustainable practices, ammonia is emerging as a promising alternative fuel for ships. Effective management of by-product NOx, NH_3 and N_2O emissions from the combustion of ammonia is crucial to the success of ammonia as an alternative fuel. A new catalyst has been developed by Enercat to treat these three molecules in one bed. **Jean-Rémi Stephany** and **Emmanuel Rohart** of Enercat – Alsys Group report on this new technology which has been developed in marine ammonia combustion engine conditions.

The maritime industry, a cornerstone of global trade, is currently facing increasing pressure to reduce its environmental footprint. Traditional marine fuels, primarily diesel, produce significant greenhouse gas and contribute extensively to air pollution. As the industry pushes towards more sustainable practices, ammonia is emerging as a promising alternative fuel for ships.

In many cases, ammonia demonstrates highly interesting benefits for the marine transport transition. Its energy density in volume of 13.6 GJ/m³, ranks it between hydrogen and gasoline. In addition, its favourable storage properties allow it to be stored as a liquid at relatively moderate pressures and temperatures. Moreover, ammonia benefits from existing production and transportation infrastructure that can be easily adapted for maritime applications. Finally, recent advancements in engine technologies are making it feasible to retrofit existing diesel engines to run on ammonia, further easing the transition.

Beyond all the previously listed advantages of ammonia as a fuel, one of the most compelling reasons to consider ammonia as a marine fuel is its potential for zero carbon dioxide (CO_2) emissions, which makes it a very attractive option for meeting the International Maritime Organization's (IMO) ambitious targets of halving greenhouse gas emissions in shipping by 2050.

However, while ammonia combustion releases no CO_2 in the atmosphere, careful attention must be paid to the possible formation of by-products during the process such as nitrogen oxides (NOx), ammonia (NH_3) and nitrous oxides (N_2O). The first two molecules are well known for their impact on human health, while the third one is a potent greenhouse gas with a global warming potential that exceeds that of CO_2 by 300 times.

To make ammonia not only a promising but a serious candidate for energy transition in the marine industry, effective management of these emissions is crucial.

Simultaneous treatment of NOx, NH_3 and N_2O

On the one hand, selective catalytic reduction (SCR) systems are well known solutions to mitigate NOx emissions with NH_3 injection in diesel engines post-treatment. On the other hand, some catalytic formulations have proved their ability to treat N_2O in various chemical processes such as nitric acid production plants.

Enercat has developed and patented a catalytic formulation used for more than 15 years for the simultaneous treatment of NOx and N_2O with NH_3 injection in nitric acid plants.

Based on this technology, Enercat has developed and supplied in 2022 a tailor-made flue gas treatment solution for a chemical plant in France. The system was designed to reduce large quantities of NOx, with very high and sudden variations, while abating N_2O in the same reactor (inlet conditions shown in Table 1). The specificity of the process was the variability of the NOx concentration at the inlet, driving Enercat to inject NH_3 in excess to achieve the required NOx conversion. The drawback of injecting large quantities of NH_3 was the potential NH_3 slip at the stack when the NOx to be treated at the inlet suddenly dropped.

Therefore, the solution relied on a single reactor process containing two catalytic beds in series (see Fig. 1). The first bed allows N_2O and NOx to be treated simultaneously with NH_3 injection using Enercat's patented catalytic technology. The second bed reduces potential ammonia emissions using Enercat's "ammonia slip" catalyst (ASC). The combination of the two beds allows the conversion of more than 99% NOx and 95% N_2O without releasing a single ppm of NH_3 at the stack.

Table 1: **Inlet conditions of simultaneous NOx, NH_3 and N_2O treatment**

Parameters	Values
O_2, %	1.5
H_2O, %	1.0
NO, ppmv	500 – 3,000
NO_2, ppmv	500 – 3,000
N_2O, ppmv	900 – 1,000
Gas flow, kg/h	3,000
Temperature, °C	50

Source: Enercat

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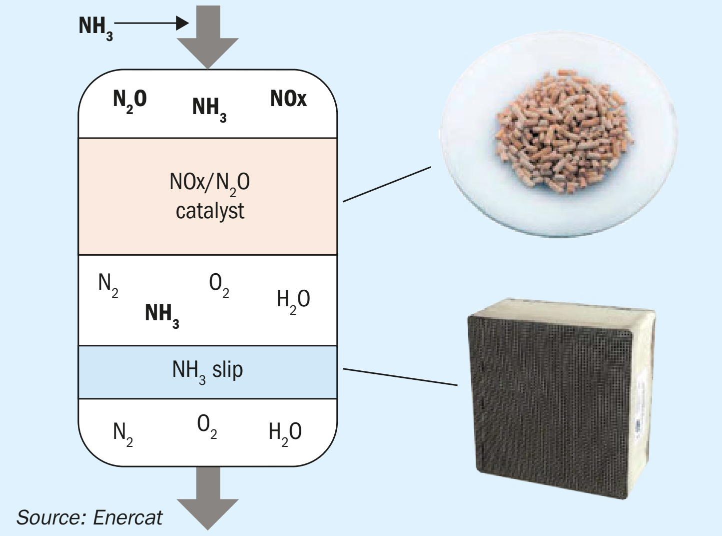
Fig. 1: **Simultaneous NOx, NH_3 and N_2O reactor**



Source: Enercat

Table 2: **Catalyst testing conditions**

Parameters	NH_3-rich conditions	NH_3-poor conditions
Pressure, atm	1	1
Temperature,°C	300 – 550	350 – 550
Inlet NOx, ppmv	1,500	4,000
Inlet N_2O, ppmv	150	100
Inlet NH_3/NOx ratio (mol/mol)	2	1
O_2, vol-%	2	6
H_2O, vol-%	10	15
NO/NO_2, %	70/30	70/30

Source: Enercat

From chemical plant to marine applications

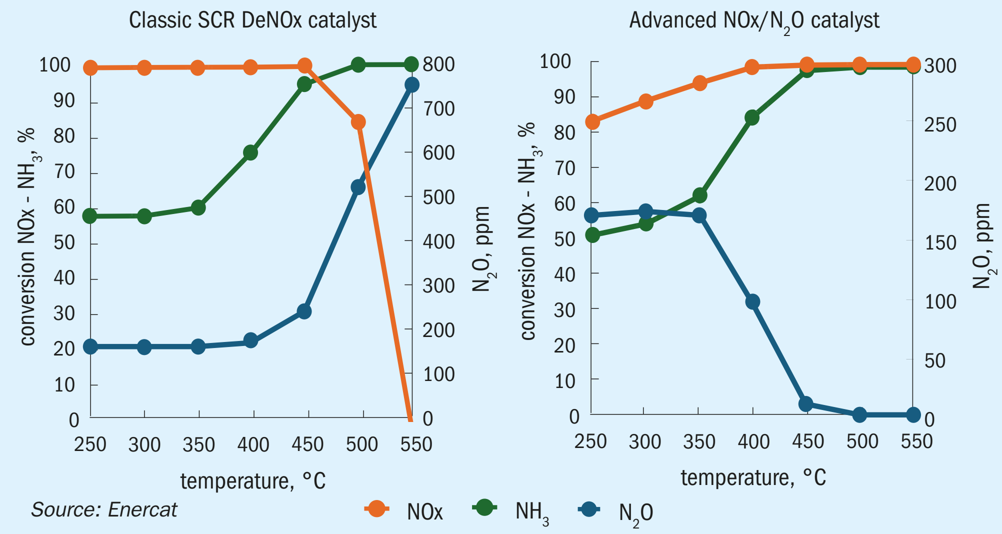
Based on the internal developments described previously, Enercat decided to push innovation further and develop a catalyst capable of treating the three molecules in one bed. This technology has been developed in marine ammonia combustion engine conditions, as the need for treating NOx, NH_3 and N_2O is a key for the success of ammonia as an alternative fuel.

Two types of conditions were shortlisted (see Table 2). One with a large quantity of residual unburned NH_3. And the second with the stoichiometric quantity of ammonia required to ensure NOx reduction over the catalyst. The developed technology was compared to a classic DeNOx SCR technology used in diesel engines post-treatment.

The first results show that the performance of the classic SCR catalyst is high for the reduction of NOx below 400°C, but the catalytic formulation shows no activity for N_2O decomposition. Furthermore, above 450°C, an important decrease of DeNOx performance is observed, associated with rocketing N_2O formation on the catalyst.

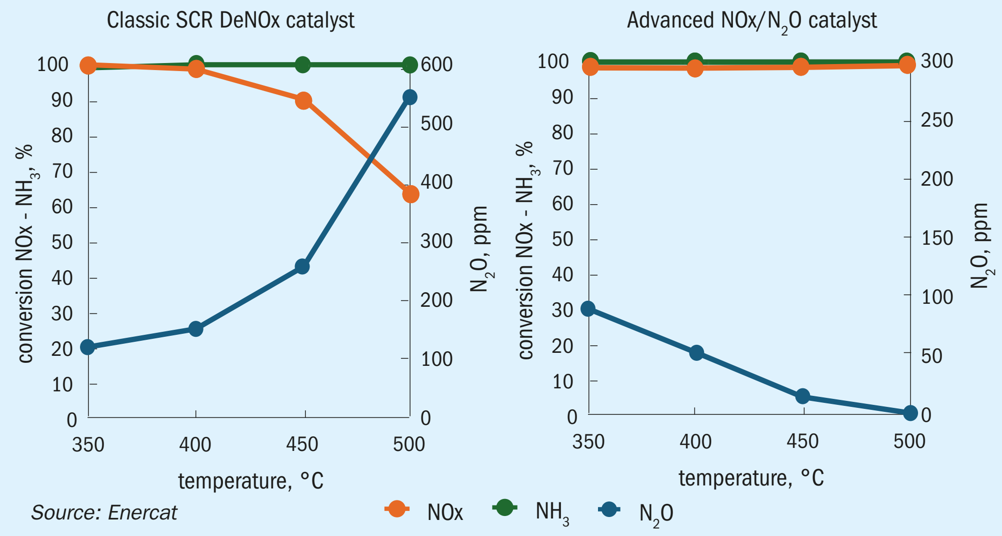
On the other hand, the catalyst developed by Enercat shows very good performances at 450°C and above in both conditions, especially compared to the classic SCR DeNOx catalyst, allowing full conversion of the three targeted molecules (NOx, NH_3 and N_2O) with only one catalyst. Although the current catalytic formulation enables very high conversion rates to be reached, ongoing further developments should enable the performance to be increased at lower temperatures.

Fig. 2: **Catalyst comparison in NH_3-rich conditions**



Source: Enercat

Fig. 3: **Catalyst comparison in NH_3-poor conditions**



Source: Enercat

This very promising solution allows the implementation of compact and cost-effective post-treatment systems for ammonia combustion engines, making ammonia as a fuel an even more serious candidate for the decarbonisation of the maritime industry. ■

Double temperature scrubbing for cleaner exhaust air

Casale's fluid bed granulation tail gas treatment for nitrogen-based fertilizer employs double temperature scrubbing technology, which handles the granulator exhaust air separately from the cooler exhaust air. The technology can combine dust removal with ammonia abatement in the same installation to meet strict tail gas limitations such as 10 mg/Nm³ for dust and 10 mg/Nm³ for ammonia. **Ken Monstrey** of Casale explains the key features of the Casale scrubbing technology.

The Casale fluidised bed granulation finishing technology for nitrogen-based fertilizer was originally developed by Green Granulation Technology (GGT). This fluid bed granulation was coupled with the in-house developed "double temperature" scrubbing process to remove the dust from the airstream and guarantee cleaned tail gas emitted to the atmosphere. Casale fully acquired GGT in 2022 as a company as well as the full IP portfolio and references in the market.

Typically, a fluidised bed granulation process uses considerable airstreams through the system in order to realise adequate cooling of the fluidised bed layer and provide the much needed movement of particles inside the bed. The cooling is required for e.g, urea-based processes in which the heat of crystallisation of the liquid urea feed must be removed from the granulator in order to keep the bed temperature within acceptable limits. The movement in the bed is vital for the process to produce prime quality product and ensure efficient and homogenous product build-up. Since there are no moving/motorised parts in the granulator, the fluidisation air together with the atomisation air of the liquid sprayers, are the driving forces to realise the movement in the bed. Without proper movement, the liquid nozzles do not receive enough fresh seeds to spray on and the spray zones would be overloaded leading to low water evaporation and a final product with high moisture content.

In most cases, the granulator is followed by at least one fluidised bed cooler in order to cool down the product before further handling and finally sending it to storage or bagging. The air going through the fluid bed cooler(s) also entrains some dust released from the friction between the particles.

The resulting airflows, for the granulator this is the sum of fluidisation air and atomisation air and for the cooler(s) this is all of the cooling air, have to be cleaned before they can be vented to the atmosphere. For this purpose, Casale makes use of the patented "double temperature" scrubbing technology, using horizontal scrubbers with vertically installed droplet separation stages.

Double temperature scrubbing

In the double temperature scrubbing technology, the granulator exhaust air is handled separately from the cooler exhaust air. There are two individual scrubbers (which can be combined in one vessel for the smallest plant capacities), one granulator scrubber and one cooler scrubber, that feature specific treatment of the air according to the nature of the pollutants.

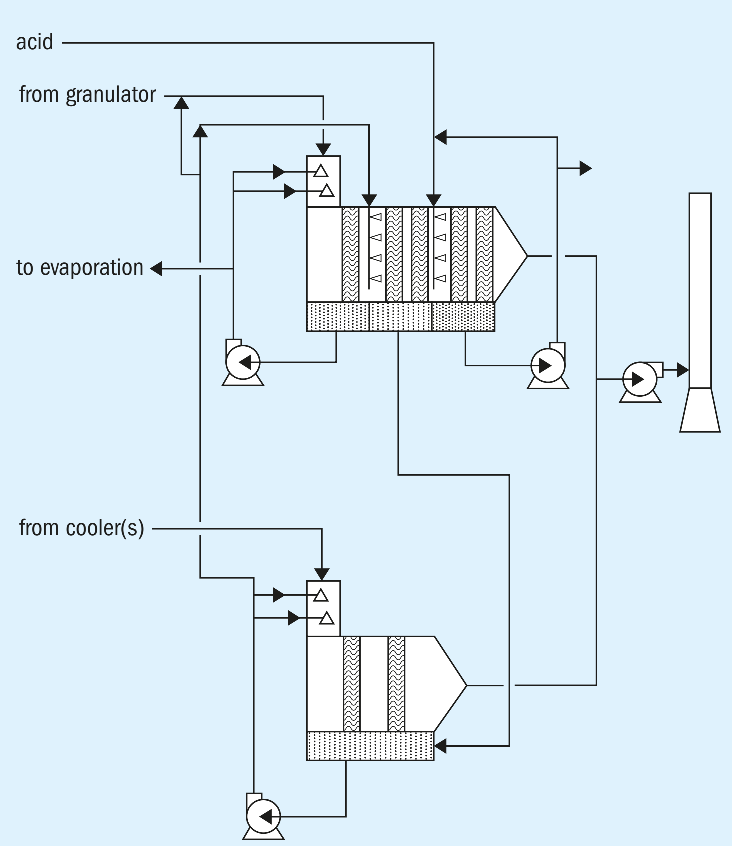
The double temperature technology can be applied in various fields, with references in urea granulation, ammonium nitrate granulation, but also the more complex fertilizer production processes like urea with ammonium sulphate (UAS). The technology can combine traditional dust removal with ammonia abatement in the same installation. The number of stages installed in each scrubber is determined by the emission restrictions determined at the design stage. Very strict tail gas limitations such as 10 mg/Nm³ for dust and 10 mg/Nm³ for NH_3 can be met by the Casale scrubbing technology.

The vast majority of the dust and NH_3 originates in the granulator. The dust particle size can range from 0.5 mm particles to sub-micron particles. The coolers only account for minor traces of dust, which consists of larger and easy-to-catch dust particles and minor traces of NH_3. Therefore, the air treatment in the granulator scrubber is much more intensive than the treatment required in the cooler scrubber.

The granulator exhaust air starts its treatment in the inlet duct of the granulator scrubber where it is intensively mixed with aqueous scrubbing solution from the rich solution scrubber tank. This intensive wetting followed by the droplet separation in the first stage of the granulator scrubber will remove the majority of the dust, leaving only the smallest dust particles in the airstream.

Similar to the granulator exhaust air, the combined coolers exhaust air flows start their treatment in the inlet duct of the cooler scrubber where there is also an intensive mixing with aqueous scrubbing

Fig. 1: **Casale double temperature scrubbing flow scheme**



Source: Casale

PHOTO: CASALE

IEFCL Indorama Eleme, Nigeria.

solution, but in this case, the liquid from the lean solution scrubber tank is used. This intensive wetting followed by the droplet separation in the first stage of the cooler scrubber is adequate to remove the dust from the coolers.

The essence of the "double temperature" lies in the introduction of lean scrubbing solution from the cooler scrubber tank to the second stage of the granulator scrubber. Fine atomisation of this lean and colder solution into the saturated, warmer airstream from the first stage of the granulator scrubber leads to an immediate condensation effect and the formation of micro-mist. The dust scrubbing of tail gas carrying a wide variety of dry dust particles is most effective when the dust particles can be transformed into droplets. The dust particle is dissolved in the droplet and is carried to the droplet separators where small droplets are transformed into bigger droplets by the coalescence effect inside the scrubber pads. When forming the micro-mist in the second stage of the granulator scrubber, the sudden condensation will transform the remaining dust particles, which can be as small as sub-micron level, into droplets. Since these micro-mist droplets are too small to be de-misted, the droplets must first grow in size by coagulating with other droplets in the airstream. This happens by the coalescence action inside the demister stages. By transforming the sub-micron dry dust particles into droplets that are large enough to be separated from the air stream, the dust comprising exhaust air from the system can be efficiently cleaned before venting.

The airstreams are moved through both scrubbers by the negative pressure from the exhaust air fan(s). To protect the fan(s) and to avoid any droplet carry-over to the stack, a dry final demister stage is installed in the scrubber outlet.

One of the main dust sources in the fluid bed granulation process is the recycled oversize product that was crushed by the roll crushers to serve as seed material for the build-up of granules. Part of this crushed material is so fine that it is carried out of the fluidised bed by the airstream and is entrained to the granulator scrubber. Another source of dust is the dust created by the friction between granules and the surficial solidified crystals that remain on the skin of the granules when these are dried in the non-sprayed zones of the fluidised bed layer. Both these dust sources

Table 1: **Reference cases of installed scrubbers**

Hainan CNOOC Fudo Co., Ltd. in P.R. China

Design basis:
- Urea granulation: 1,000 t/d
- Urea dust content in tail gas (dry basis) from the stack: maximum 10 mg/Nm³
- Ammonia emission in tail gas (dry basis) from the stack: maximum 30 mg/Nm³.
- Total air flow handled by scrubbers: 340,000 m³/h

Indorama Eleme Fertilizer & Chemicals Limited (IEFCL) in Nigeria

Design basis:
- Urea fertilizer granulation: 1,000 t/d + option of cattle feed grade
- Urea dust content in tail gas (dry basis) from the stack: maximum 30 mg/Nm³.
- Total air flow handled by scrubbers: 416.000 m³/h
- Negotiations for addition of NH_3 abatement started.

produce dust particles that are relatively large in size and quite "easy" to catch. The more challenging very fine dust particles are formed by the sprayers. In the case of urea granulation, these are on the one hand fine urea solution droplets that crystallised before hitting a fluidised particle and on the other hand ammonium cyanate (NH_4OCN), an isomer of urea, that is stripped out by the high temperature of the urea feed and the atomisation air surrounding the urea liquid nozzles. When stripped in the sprayer, the ammonium cyanate will split into two elements, NH_3 gas and cyanuric acid gas. These two gaseous elements will recombine as a base acid reaction to ammonium cyanate, and form sub-micron dust particles. The ammonium cyanate is unstable and when further cooled down (in the scrubbers) the ammonium cyanate will transform into urea ($NH_4OCN \rightarrow (NH_2)_2CO$). Scrubbing out the sub-micron particles would require very fine filtering resulting in a very high pressure drop over the system. Thanks to the double temperature action in the Casale scrubbing technology, the sub-micron particles are transformed into relatively large droplets that can be recovered in the consecutive coalescence and demister stages.

Also in other processes such as ammonium nitrate and UAS fluid bed granulation, sub-micron "dust" particles are formed and need to be removed by the double temperature action.

Removing NH_3 from the tail gas

Apart from dust, the fluid bed granulation of nitrogen-based fertilizers also features an amount of free NH_3 in the tail gas. The NH_3 is present in the liquid feed to the granulator sprayer array and is stripped out by the action of the atomisation air surrounding the liquid nozzle. Depending on the feed to the granulator, urea, ammonium nitrate, urea + ammonium sulphate or others, the amount of free NH_3 may differ. Residence time at elevated temperature will increase the amount of free NH_3 and hence the feed concentration will largely determine the NH_3 content. Most of that free NH_3 is stripped out at the sprayers and will be entrained by the exhaust air.

Recovering the NH_3 from the gas flow can be realised by adding an acidic abatement agent to the scrubbing liquid and binding the NH_3. Sulphuric acid or nitric acid are the most common abatement agents. In ammonium nitrate, the choice for HNO_3 is logical whilst the NH_3 and HNO_3 will react to form ammonium nitrate that is recycled to the evaporation section. In UAN, the choice for H_2SO_4 is logical whilst the NH_3 and H_2SO_4 will react to form ammonium sulphate that can be recycled to the process. In urea production, there is the choice between H_2SO_4 and HNO_3, where the ammonium sulphate can be removed from the process to serve as a by-product or the recovered urea-ammonium nitrate solution can be sent to a liquid UAN production unit.

The NH_3 abatement can be realised in a separate stage where the acid is added under pH control and where the recovered ammonium salt is collected in a closed loop with a dedicated tank. In case the ammonia salt is allowed to be recycled in the granulation process, there is no need for a separate tank. The same principle is valid when the scrubbing liquid can be sent to a UAN preparation unit. ■

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Urea dust scrubbing system with WESP

TOYO has recently introduced new proprietary urea technologies to its technology portfolio including a novel dust scrubbing system with integrated wet electrostatic precipitator (WESP) for ultimate clean-up of granulation or prilling exhaust air, to achieve urea dust emissions of less than 5 mg/Nm³. **Takuhiro Minato** of Toyo Engineering Corporation explains how the new system works.

Toyo Engineering Corporation (TOYO), a global leading engineering contractor and urea process licensor, has developed water scrubbing technologies for urea plants with high efficiency (<30 mg urea/Nm³) and low pressure loss, focusing on the characteristics of urea dust, which dissolves well in water. Since the 1960s more than 50 scrubbing units have been installed for urea plants. However, to meet recent stricter requirements for urea dust, the development of new technologies is required. Emission regulations vary depending on plant site, and currently 5 mg/Nm³ is the most stringent value. TOYO has focused on WESP as a technology that complies with stricter environmental regulations, and can collect very fine particles with high efficiency and low pressure loss. To explore the feasibility of utilising WESP technology, TOYO carried out pilot plant tests, in cooperation with Petro Vietnam Ca Mau Fertilizer Jointstock Company (PVCFC) and AWS Corporation Srl (AWS), using actual exhaust gas from a granulation plant.

The WESP consists of discharge electrodes and collecting tubes. By applying a high voltage to the discharge electrodes, a potential difference is generated between the discharge electrodes and the collecting surface. Electrons are emitted from the discharge electrodes by corona discharge. The electrons emitted by the corona discharge charge the target fine particles in the gas stream, and the charged particles are separated from the gas stream by adhering to the collecting surface by Coulomb force. Since dust collection performance deteriorates when target particles adhere to collecting tubes and discharge electrodes, periodic washing is necessary. Fig. 1 shows the WESP principle of operation with a collecting tube, which is widely used in WESP. Discharge electrodes are arranged at the centre of the collecting tubes. The equation that represents the WESP dust collection efficiency is known as the Deutsch equation and is expressed as follows.

$$\eta = 1 - e^{-\frac{\omega \times A}{Q}} \qquad (1)$$

where η = dust collection efficiency, which is represented as $\eta = (C_{in}\text{-}C_{out})/C_{in}$, where

C_{in} = inlet dust concentration (mg/Nm³) and

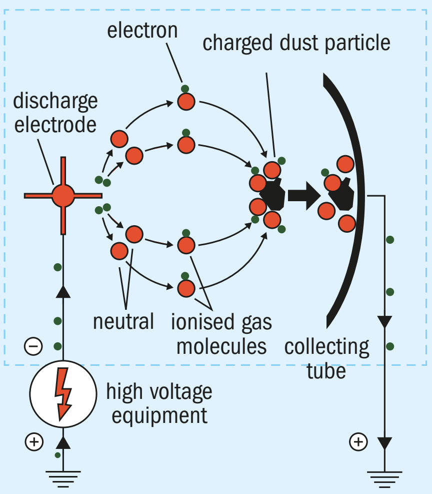
C_{out} = outlet dust concentration (mg/Nm³)

A = dust collecting surface (m²)

Q = gas flow rate (m³/s)

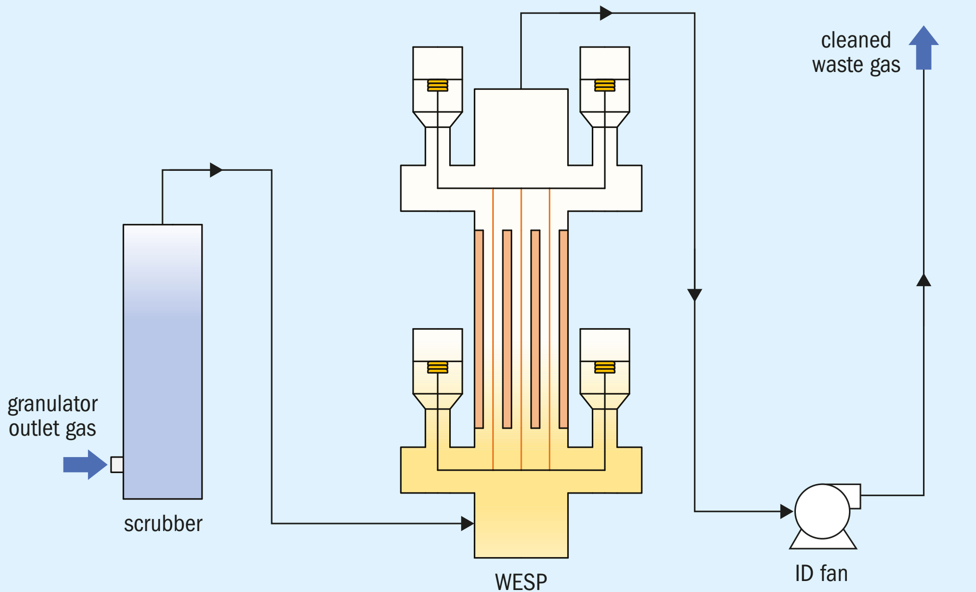
ω = migration velocity (m/s), which is the velocity at which target particles move toward collecting tubes and is an important parameter in the sizing of a WESP system.

Fig. 1: **WESP principle of operation**



Source: AWS

Fig. 2: **Schematic flow of pilot plant**



Source: TOYO

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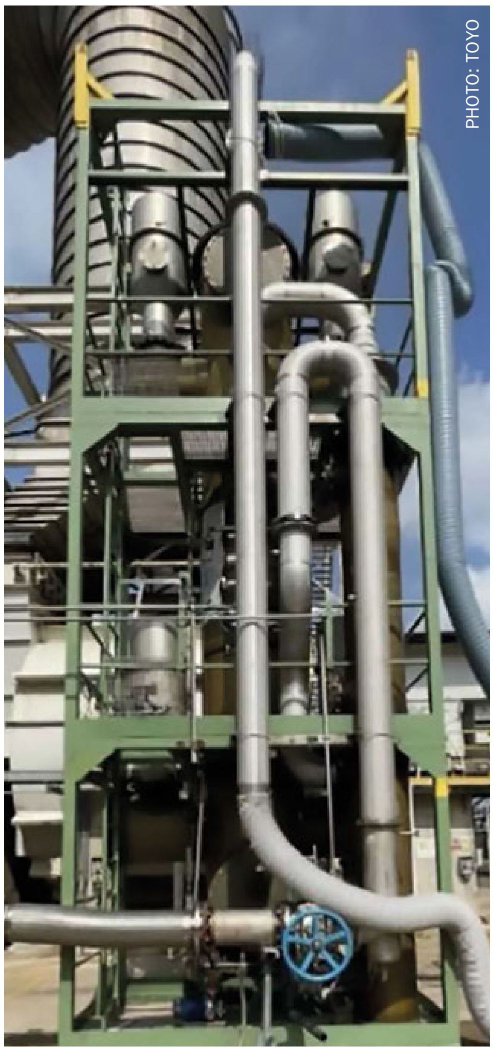


Fig. 3: Side view of pilot plant

Pilot plant test

Figs. 2 and 3 show the schematic flow and the side view of the pilot plant, respectively. The pilot plant consists of a scrubber, an induced-draft fan (ID fan) and the AWS WESP unit. The gas containing urea dust from the granulator was first introduced to the scrubber section of the pilot plant, where the urea dust concentration was adjusted to desired levels before being introduced to the WESP, where the remaining fine urea dust and mist were removed. The cleaned waste gas from the WESP was drawn by the ID fan, and then discharged to the atmosphere via a stack.

Dust removal performance of the AWS WESP

The pilot plant test confirmed that the WESP could effectively remove the urea dust from the exhaust gas from the granulator, achieving a urea dust concentration of below 5 mg/Nm^3. The graph in Fig. 4 shows dust collection efficiency η against gas velocity v in the collecting tubes. In equation (1), dust collecting surface A and gas flow rate Q are represented as

$$A = 2\pi rLN \text{ and } Q = \pi r^2 vN$$

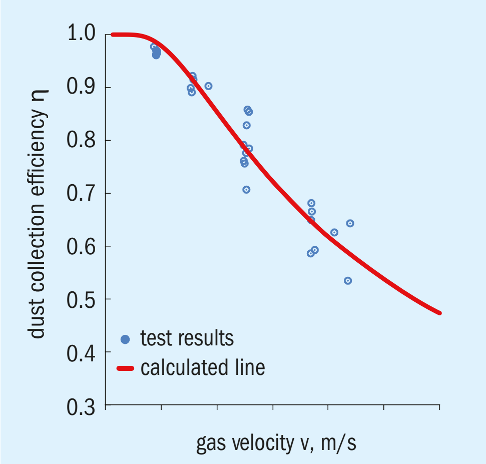
Where:
r = radius of the collecting tubes (m)
L = length of the collecting tubes (m)
N = number of collecting tubes
v = gas velocity (m/s)

Therefore, the dust collection efficiency can be expressed as a function of gas velocity by substituting dust collecting surface A and gas flow rate Q into equation (1).

In Fig. 4, the red solid line shows the dust collection efficiency calculated by equation (1) using the migration velocity obtained in the pilot plant tests. The blue dots show the actual data measured in the tests. The tests were carried out by varying the urea dust concentration at the WESP inlet and the gas velocity in the collecting tubes over a wide range.

As a standard practice, the WESP is designed to operate within a low-velocity range, in order to minimise risks of droplet entrainment at the outlet and to avoid interference with the corona discharge. The pilot plant tests showed that the WESP dust collection efficiency aligns well with the calculated values, even at higher gas velocities. Furthermore, the tests confirmed that the WESP can be designed for a broad range of velocities, maintaining efficiency without being affected by the urea dust concentration at the inlet. This indicates that integrating pre-treatment equipment with the WESP can lead to an optimised system design for consistent dust collection performance.

Fig. 4: **Dust collection efficiency against gas velocity**



Source: TOYO

Migration velocity

Fig. 5 shows observed migration velocity ω calculated by equation (1) against gas velocity v in the collecting tubes at a certain voltage (blue dots). The red line represents averaged migration velocity. As shown in Fig. 5, the migration velocity was almost constant regardless of the gas velocity in the collecting tubes, although it has been generally reported that increasing the gas velocity in the collecting tubes interferes with corona discharge and reduces migration velocity.

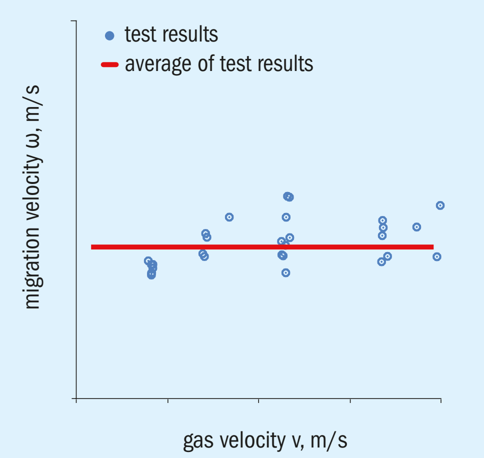
Operability and maintainability

The pilot plant was operated for a cumulative total of more than 300 hours, including a 108-hour trial operation without washing the collecting tubes and discharge electrodes. No deterioration in the WESP performance was observed in the period of the trial run, and no accumulation of urea dust was observed on the collecting tubes and discharge electrodes after the trial operation. The operation and inspection results indicate that long-term continuous operation of an industrial scale WESP without influencing the operation of commercial granulation units is possible with scheduled online washing.

Integration of WESP and TOYO's dust scrubber

Based on the test results, TOYO is now ready to design a WESP scrubbing system by integrating AWS's WESP and TOYO's dust scrubber. Fig. 6 shows a typical arrangement of a WESP added to the

Fig. 5: **Migration velocity against gas velocity**



Source: TOYO

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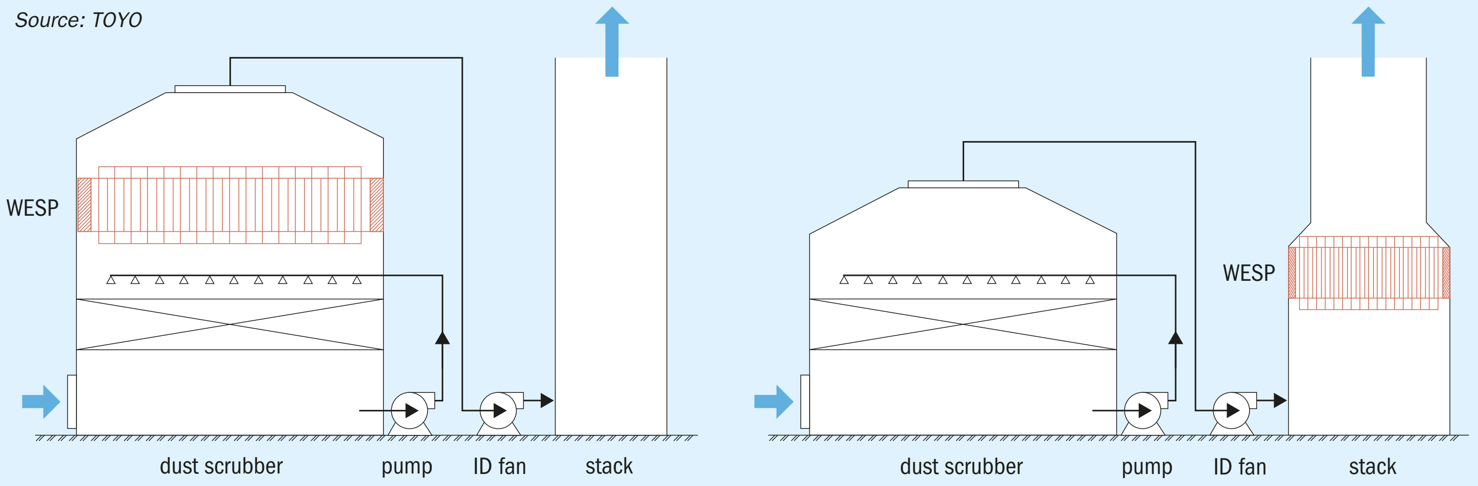
Fig. 6: **Typical WESP arrangement, on dust scrubber (left) and downstream of ID fan (right)**

Source: TOYO



scrubber. In case of direct installation on a dust scrubber, the WESP outer size could be the same as the dust scrubber, and a common support/structure can be utilised. Such an arrangement is advantageous in reducing plot area compared to installing a WESP separately from the dust scrubber. On the other hand, when installed downstream of an ID fan, the WESP can be installed at a lower position. Since the WESP is a heavy item of equipment, it is important to consider the foundation strength and the feasibility of adding additional steel structures to determine the location of the WESP especially when adding to an existing plant. The integration of the WESP and TOYO's dust scrubber optimises the system to achieve urea dust emission of less than 5 mg/Nm³ with a total pressure loss of less than 100 mm H_2O. This is a significant improvement compared to the 500 mm H_2O pressure loss in other conventional WESP and dust scrubbing systems.

As the gas velocity increases, the number of collecting tubes decreases, leading to a certain reduction in capex, but some increase in opex due to the increased pressure loss in the WESP. AWS and TOYO can provide a WESP with an optimised gas velocity taking this into consideration. ■

Catalyst management and monitoring in nitric acid plants

Based on 16 years of experience, **Muhammad Nabeel Shakir** of Fatima Fertilizer Company outlines a methodology to achieve optimum performance of the PGM catalyst and catchment system in nitric acid plants.

The PGM (Platinum Group Metals) ammonia oxidation catalyst along with the catchment system play a vital role in the manufacturing of nitric acid. Besides ammonia (feedstock), the PGM catalyst is the main consumable which drives the cost of nitric acid whether it is an intermediate or final product.

PGM catalyst usually consists of platinum and rhodium or platinum, rhodium and palladium depending upon the catalyst type meeting nitric acid manufacturer requirements, whereas the catchment system consists of palladium mainly. The catchment system is designed to recover the volatilised losses associated with ammonia oxidation. The ammonia oxidation process results in the loss of platinum as a gaseous oxide which then undergoes a transfer reaction on the catchment gauze. The catchment system is designed for recovery of volatilised platinum lost from the catalyst.

In view of risk associated with the damage of PGM catalyst during commissioning (mainly), start-up and normal operations of the nitric acid plant, keeping an expensive PGM catalyst in inventory as spare is always a challenge for nitric acid manufacturers.

The impact of nitric acid plant downtime and a long outage is significantly higher especially for large scale manufacturers producing fertilizers as the final product. For such large-scale manufacturing facilities, reliable and sustainable operation of the nitric acid plant is important to keep downstream units running.

PHOTO: FATIMA

Nitric acid plant at Fatima Fertilizer Company.

This article highlights the significance of a structured approach towards nitric acid PGM catalyst performance management which is beneficial for nitric acid manufacturers in achieving desired targets covering key areas such as customised design of the PGM catalyst and catchment system, good operational practices, process safety features, and a performance monitoring programme.

Selection of PGM catalyst and catchment system

Specification of the PGM catalyst and catchment system depends on multiple variables and factors specific to the nitric acid manufacturer. All applicable data is usually exchanged and discussed among nitric acid and PGM catalyst manufacturers to finalise the most appropriate and best suited option. Key factors include campaign length, design parameters, operating philosophy of plant (commissioning phase, normal steady state operations, cyclic operations with frequent planned start-up and shutdowns, plant facing reliability issues with unplanned shutdowns, regulatory compliance requirements, metals recovery targets, etc.).

The campaign length – the design life of one complete catalyst and catchment system – is usually evaluated based on the ammonia oxidation reactor operating pressure, ammonia loading and catalyst replacement outage philosophy. Nitric acid plants with a low- to medium-pressure ammonia oxidation reactor are better suited to longer campaign lengths compared to high-pressure ammonia oxidation reactors due to the impact of pressure on mechanical strength and associated losses. Longer campaigns in general impact overall catalyst recovery, especially in case of contamination and excessive number of start-ups and shutdowns resulting in higher mechanical loss and hence higher net metal loss. Shorter campaigns involve catalyst replacement outage, fresh catalyst purchase cycle and spent catalyst refining process more than once per year depending upon the exact campaign duration. In such scenarios, ammonia to NO conversion efficiency and net metal losses are carefully analysed in comparison to additional catalyst replacement and refining expense due to shorter campaigns.

Operating philosophy and condition of plant is also crucial when selecting the PGM catalyst and catchment system as the probability of contamination (generally by iron) from the plant itself and through feedstock is higher for commissioning campaigns. In addition, frequent shutdowns and trips are also common during the plant commissioning phase which mechanically weakens the gauzes, resulting higher net metal loss.

A high number of starts and stops also favours the formation of rhodium oxide on the gauzes due to temperature cycling. The tendency for rhodium oxide formation increases with the amount of rhodium in the gauze. Rhodium oxide lowers the oxidation efficiency due to ammonia loss in unwanted side reactions. The rhodium content in the overall composition is evaluated based on strength requirement, operating zone (°C) of ammonia burner and rhodium oxide formation temperature (critical zone).

PGM catalyst gauze lightening (start-up) procedure is also critically important, and trained operating teams ensure passing the rhodium oxide formation temperature rapidly as far as practically possible.

An evaluation of the optimum metal content and composition also covers the financial and regulatory impact associated with overall N_2O emissions from the nitric acid plant which is controlled through primary, secondary and tertiary abatement depending upon the system requirements and provision in design. Comparatively lower N_2O contents can be achieved through a customised PGM catalyst pack as primary abatement. Operating conditions also play a key role in the actual performance of the catalyst as the N_2O content at the ammonia oxidation reactor varies with mixed gas temperature. The PGM catalyst should therefore by designed at mixed gas temperature after incorporating the effect of varying ambient conditions. Operating conditions and variables are modelled to evaluate the optimal metal content and expected levels of metal loss during the campaign. Permanent metal loss during the complete campaign should be considered carefully while evaluating the initial cost of a new catalyst pack and other benefits.

Another key consideration when evaluating the optimum cost-efficient solution, is less catalyst weight or fewer layers, which may result in ammonia slip downstream of the catalyst. In addition to productivity loss, i.e., lower ammonia to NO conversion efficiency, this ammonia slip also poses an explosion hazard in the downstream equipment by decomposition of ammonium nitrate. The presence of ammonium nitrate due to possible ammonia slippage is also verified through laboratory sampling in the downstream circuit after start-up and during normal operations to identify the root cause and corrective measures in view of the associated hazard.

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PHOTO: FATIMA

PGM catalyst in a nitric acid plant.

Sustainable performance through a structured monitoring programme

After careful selection of the PGM catalyst, the next step is to monitor the health and performance of the catalyst to achieve the desired performance. Besides visual monitoring for any dark spots, a structured programme should cover the monitoring of probable contamination sources, periodic inspections of piping and equipment at the ammonia oxidation reactor and upstream, health assessment and timely replacement of the air filters contributes to longer campaigns, reduced metal losses and higher ammonia to NO conversion.

Replacement of the complete catalyst pack is preferred for detailed performance analysis of the overall campaign and subsequent optimisation based on plant specific conditions. Evaporation and wear of the catalyst pack is comparatively lower when the gauzes are exchanged after each campaign. If gauzes are used for more than one campaign, they tend to get fragile, resulting in significant mechanical losses. Another advantage of full replacement is that every campaign can be controlled individually by a precious metal balance and the production data. For each campaign, platinum, rhodium and palladium losses per ton of acid can be calculated. This data is essential for further gauze design optimisation steps, and to reduce the cost of nitric acid production mainly through reduction of ammonia and net metal losses.

In addition, a nitrogen balance reporting mechanism covering estimation of side reactions and ammonia to NO conversion efficiency, based on online analysers, flowmeters and laboratory analysis, helps nitric acid manufacturers to quantify and verify the performance of the PGM Catalyst. A detailed metal loss accounting exercise after completion and refining of each campaign is also very important. All these monitoring efforts and performance data eventually set the baseline for further optimisation and corrective measures where required.

Significance of system based process safety features

Spare catalyst and emergency management philosophy for nitric acid plants depends upon risk appetite and controls in place, which is evaluated based on fresh catalyst lead time, any previous history of catalyst damage, availability, and adequacy of Basic Process Control systems (BPCS) and the emergency shut down system (ESD), operating procedures and the operating team competency evaluation programme. An ammonia explosion in the oxidation reactor is one of the main hazards associated with nitric acid plants due to liquid ammonia carry over which eventually can damage the PGM catalyst and catchment system. Availability of layers of protection and key safety features availability and defeat protocols supports the decision making process as far as spare catalyst philosophy is concerned and also ensures safe and reliable operations.

When to replace catalyst?

In general the catalyst pack is designed for a certain amount of total produced acid with minimal disturbances and steady state operations. In addition, tolerable variances including start-up and shutdowns are also estimated at the time of PGM catalyst and catchment system finalisation. In case of stable plant operations at slightly lesser load, the catalyst can run for longer than the design campaign life meeting design production provided no significant variation in ammonia to NO conversion is observed.

Increasing production rate (plant load) above the nominal value (design ammonia loading) to reach total production amount (design tonnes/campaign) before design campaign length (no. of days) could reduce the ammonia to NO conversion efficiency, which can have a negative cost impact for the nitric acid manufacturer.

In case lower ammonia to NO conversion efficiency (i.e., higher Ammonia consumption) is observed and reported, due to reasons whether known or not, it is always beneficial to run a cost benefit analysis for early replacement of the PGM catalyst if the estimated ammonia loss is significantly higher.

Lesson learned – successful performance recovery of PGM catalyst

In 2012, a sudden rising trend in N_2O content and subsequently ammonia consumption was observed. Due to the continuous rising trend, the plant was shut down safely and the ammonia burner head was removed for physical inspection of the PGM catalyst. Cleaning of the PGM catalyst was performed successfully to remove dust particles, which caused blockage of active sites. After start-up the desired N_2O content and ammonia consumption factor was reinstated and the same catalyst achieved the planned campaign life.

A detailed investigation was performed, and no stone was left unturned. Actions based on system causes were identified and incorporated in the catalyst management and monitoring programme. No such issues have been faced since then due to the effective measures in place.

How to achieve your target?

In summary, successful campaigns can be achieved by having:

- clarity in business objectives while selecting PGM catalyst and catchment packs considering all applicable factors;
- a well-defined operational philosophy and control measures based on available layers of protection;
- a structured technical monitoring program;
- and by avoiding frequent shutdowns and temperature cycling during campaigns, as well as no contamination as far as practically possible. ■

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A tailored approach to reducing GHG emissions

Stefano Cicchinelli and **Carmen Perez** of Stamicarbon (MAIRE) explore the latest advancements in tertiary abatement technologies, their implementation in nitric acid plants, and the implications for the fertilizer industry.

The nitric acid production industry plays a crucial role in the global agricultural sector, primarily due to its use in producing nitrogen-based fertilizers. However, the environmental impact of nitric acid plants, particularly their greenhouse gas emissions, has become a significant concern. Tertiary abatement technology presents a viable solution to reduce these emissions and align with increasingly stringent environmental regulations.

Nitric acid production

Nitric acid production is one of the key processes of the fertilizer industry, essential for synthesising ammonium nitrate. Most nitric acid plants rely on the high-temperature catalytic oxidation of ammonia, a method known as the Ostwald process. This process runs in two stages: First, ammonia (NH_3) is oxidised to produce nitric oxide (NO), which is then further oxidised to form nitrogen dioxide (NO_2). Second, nitrogen dioxide (NO_2) is absorbed in water (H_2O) to produce nitric acid (HNO_3).

Stamicarbon, the nitrogen technology licensor of NEXTCHEM's Sustainable Technology Solutions BU (MAIRE group) offers the NX Stami Nitrates™ technology, which utilises its proven mono- or dual-pressure design. Mono-pressure technology in nitric acid production naturally operates at a single pressure level, optimising ammonia oxidation and nitric acid absorption with a compact layout and in a cost-effective manner. In contrast, dual-pressure technology works with two different pressure levels – medium pressure for ammonia oxidation and high pressure for nitric acid absorption – allowing for higher production capacities and greater energy efficiency. This layout increases catalyst life and reduces operational costs, making it a preferred choice for high-capacity nitric acid plants.

Renowned for their longevity and low maintenance requirements, Stamicarbon nitric acid plants excel in maximising high-quality steam export (see Table 1) and, hence, energy efficiency. Despite continuous improvements in the design of next-generation plants over the years, the performance of existing installations – some of which have been in service for 40 to 50 years – remains competitive in the market, making their dismantling for the construction of new plants unjustified.

Environmental impact

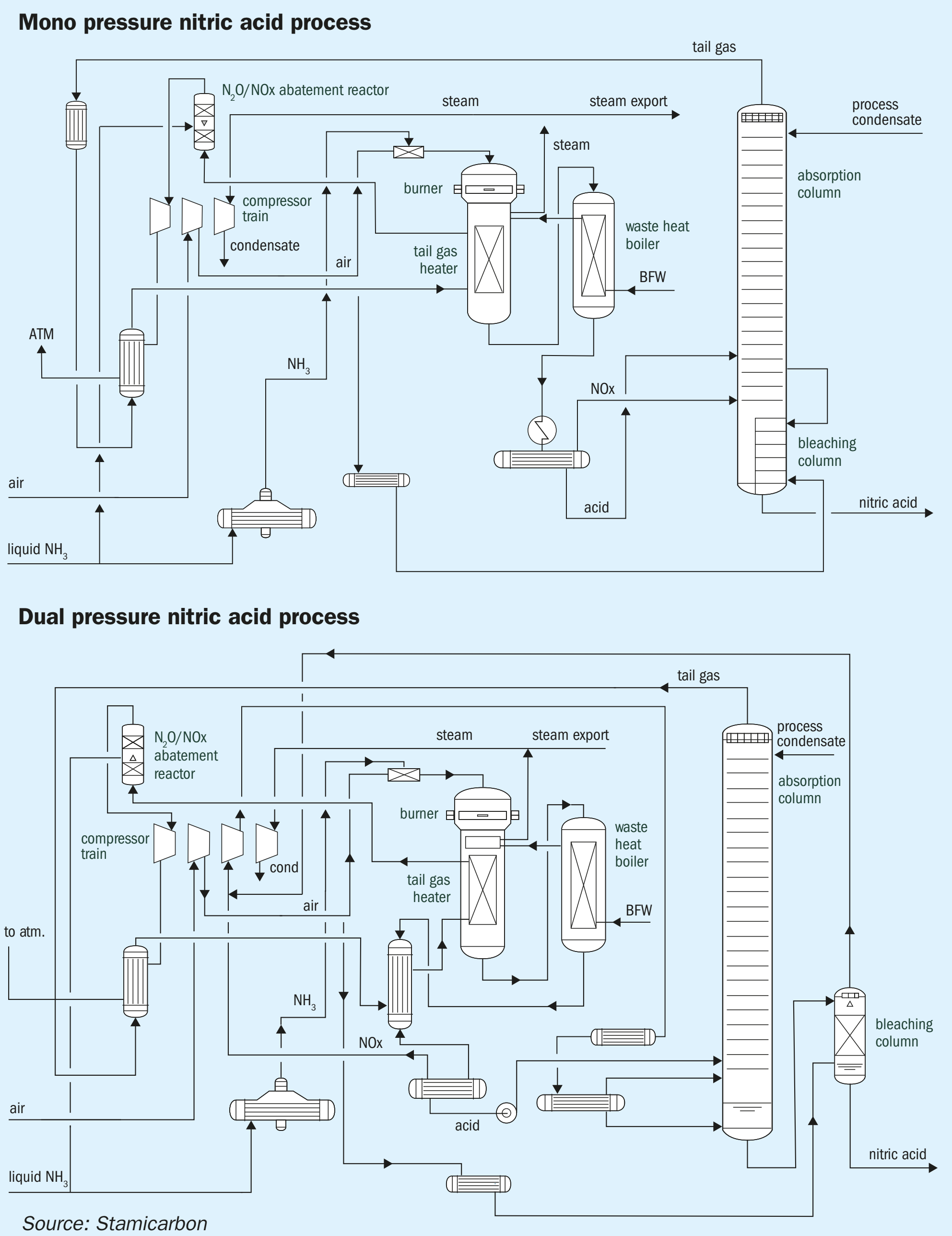
Notably, emissions were not a significant concern in plants built until the 1990s, when the legislation on NOx emissions began to be implemented. Regulations on N_2O emissions were introduced later and are still not enforced in some countries. Over the years, there has been an increasing push to curtail emissions from nitric acid production facilities, largely driven by legislative mandates aimed at reducing greenhouse gas emissions and mitigating climate change. In certain situations, companies have also taken voluntary steps towards a greener transition, including the reduction of N_2O emissions, as part of their corporate social responsibility and sustainability goals.

Although most existing nitric acid plants are operating smoothly, modernisation is necessary to enhance sustainability. For new nitric acid plants designed by Stamicarbon, a tertiary abatement reactor capable of effectively removing or nearly eliminating NOx and N_2O from tail gases released into the atmosphere is offered as a standard solution. This reactor integrates seamlessly with the production technology where the tail gas temperature is around 480°C. For other existing plants with tail gas temperatures between 450 and 500°C, this tertiary abatement system can be implemented with minimal modifications to the plant layout, making it a viable option for upgrading older facilities to meet modern environmental standards. In this layout, N_2O is removed by thermal decomposition. For plants where the tail gas temperatures ranges between 350 and 500°C, the same solution can be applied, but N_2O should be removed by reduction with natural gas.

Solutions for low tail gas temperatures

While many nitric acid plants operate at high tail gas temperatures, challenges arise when plants run at low tail gas temperatures, significantly below 350°C. In these cases, tailored solutions are required to maintain effective abatement of NOx and N_2O emissions without necessitating extensive modifications to downstream equipment, such as the need to upgrade the material of the expansion turbine. Stamicarbon is implementing new catalysts that can perform efficiently at these lower temperatures. In some cases, using the advanced catalysts can achieve

Fig. 1: **Process flow diagram of Stamicarbon's mono- and dual pressure nitric acid technology**



Source: Stamicarbon

Table 1: **Steam export for mono- and dual-pressure nitric acid plants**

Steam export (45 bar, 450°C)	
Mono pressure	Dual pressure
>650 kg/t HNO_3 (100%)	>800 kg/t HNO_3 (100%)

competitive N_2O emission values, thereby simplifying necessary layout modifications and reducing investment costs.

A current solution involves increasing the tail gas temperature because N_2O abatement must occur at higher temperatures. This approach demands using external energy sources to heat the tail gas at the entrance of the abatement system and subsequently lowering the temperature to meet the maximum design value of the tail gas expander downstream of the abatement reactor. Modifications may involve adding an electric heater, as shown in Fig. 2, or a gas-fired furnace. However, this raises an important question: is it wise to reduce greenhouse gases from tail gases while directly or indirectly producing other greenhouse gases? This consideration is crucial as it underscores the balance between achieving immediate emission reductions and the broader goal of sustainable and environmentally responsible operations.

Choosing between tertiary and secondary catalysts

Another relevant consideration arises when plant owners must choose between adding a tertiary or secondary catalyst, as illustrated in Fig. 3. While adding a secondary catalyst to the existing NH_3 burner might seem cost-effective and less impactful on the plant layout, careful analysis often reveals that the secondary catalyst is not the optimal solution.

First, existing burner conditions must be assessed, as many of these units have been operational for many years, making substantial modifications challenging. Therefore, the mechanical integrity of the equipment and the potential pressure drop in the process gas must be evaluated. Second, reactor modifications and catalyst installation entail several days of downtime, resulting in production losses. Lastly, it is not possible to achieve high conversion rate of N_2O with secondary abatement since the reactor size has a size limitation and it is expected that more stringent regulations will be issued in the near future resulting in it not being possible to keep adding catalyst to the secondary catalyst basket.

A more reasonable and future-proof approach might involve replacing the entire burner with a new one specifically designed to accommodate the secondary catalyst. However, the economic feasibility of this solution depends on whether the plant is prepared to simultaneously increase its capacity to optimise the return on investment. Beyond the mere reduction of N_2O emissions from tail gases, the purpose extends far deeper, a topic that will likely feature in an separate article.

Stamicarbon is an advocate of tertiary abatement as the superior alternative. This equipment can be installed while the plant is operational, requiring minimal shutdown time for line connections. Additionally, the greater N_2O reduction leads to significant carbon tax relief, making it a cost-effective and sustainable choice in the long run.

Considerations for higher tail gas temperatures

Unlike plants operating at low tail gas temperatures, certain nitric acid plants employ technologies where the tail gas must

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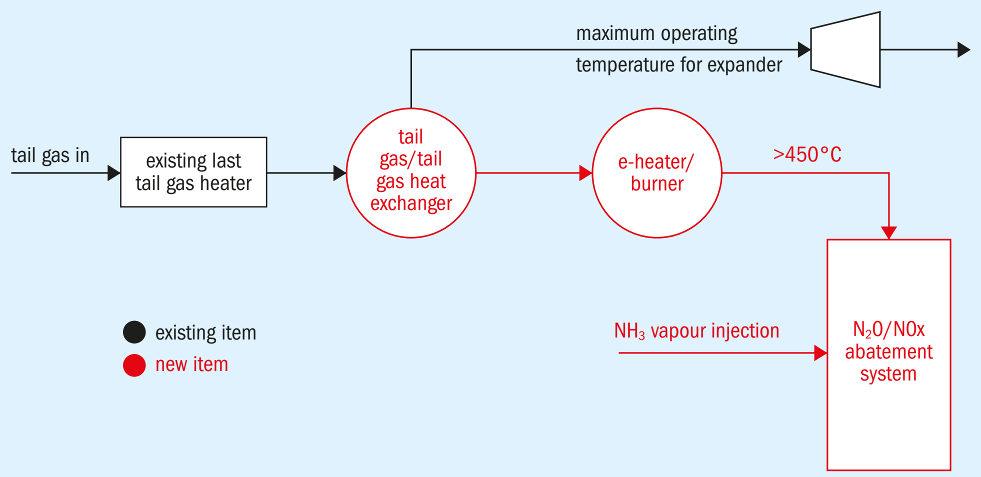
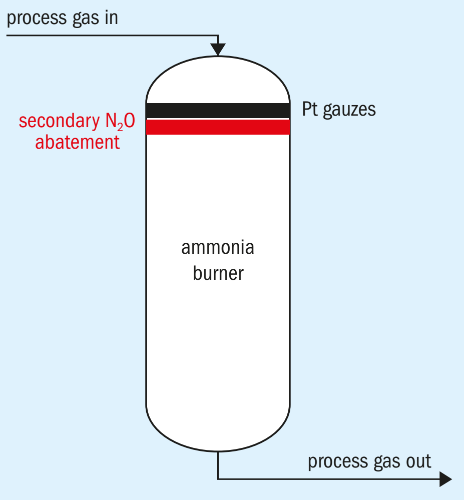
Fig. 2: **Typical scheme with tertiary abatement system for low tail gas temperature**



Source: Stamicarbon

Fig. 3: **Secondary abatement system for N_2O removal**



Source: Stamicarbon

reach very high temperatures upstream of the expansion turbine, typically between 700-800°C. In these plants, N_2O removal is generally not in place. Instead, a non-selective catalytic reduction (NSCR) reactor is used to increase the temperature and reduce NOx emissions simultaneously.

In such cases, a more straightforward alternative involves taking additional measures downstream of the abatement process. Specifically, to allow the tail gases to enter the expander at the required temperature, either an electric heater or a furnace must be employed. These devices ensure that the energy balance remains unchanged without requiring significant modifications.

> **The need to reduce emissions remains crucial both for addressing greenhouse gas pollution and complying with legislative requirements.**

However, these installations already feature NOx abatement reactors that utilise expensive NSCR catalysts. An alternative approach proposed by Stamicarbon is to consider replacing the old catalyst, as shown in Fig. 4, with a new one, such as the honeycomb catalyst based on precious metal. This replacement minimises plant modifications while maintaining the overall energy balance. However, it is important to evaluate the required volume of catalyst and the price of these precious metals compared to the additional operational cost of having an electrical heater or a gas fired burner.

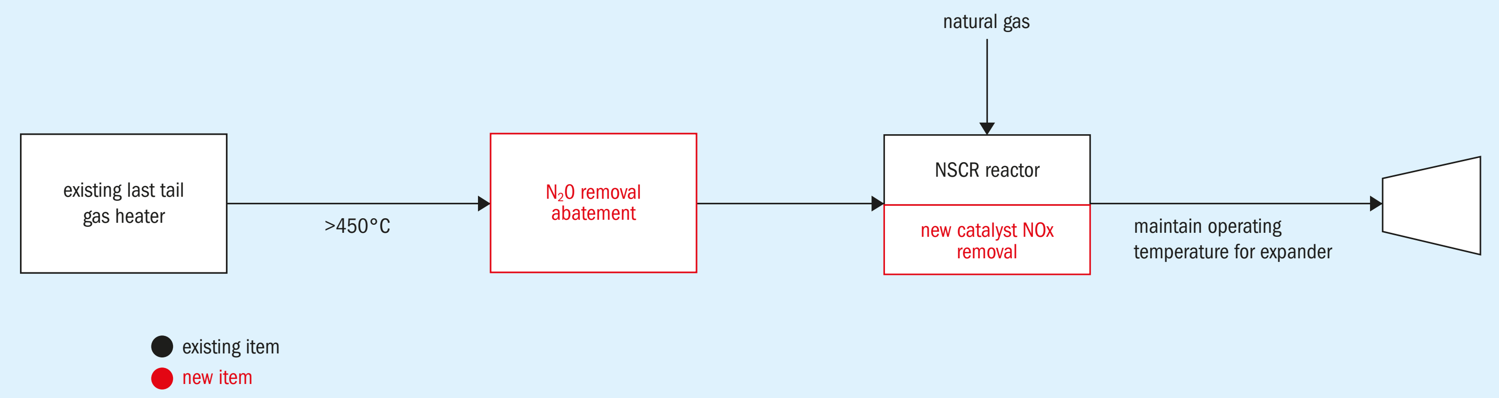
As we navigate the complexities of temperature requirements, catalyst choices, and energy balances, the path forward becomes clearer. Whether seamlessly integrating with existing technologies or exploring innovative catalysts, Stamicarbon is committed to finding optimal solutions for minimising the fertilizer industry's environmental impact.

Conclusions

In the context of nitric acid plants, the pursuit of sustainability and environmental responsibility is vital. While existing installations have demonstrated technological reliability over decades, the need to reduce emissions remains crucial both for addressing greenhouse gas pollution and complying with legislative requirements.

By embracing tertiary abatement, emissions are addressed and pave the way for a sustainable future where longevity, performance, and environmental stewardship coexist. ■

Fig. 4: **Typical scheme with high tail gas temperature**



Source: Stamicarbon

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Catalyst systems for N_2O abatement

Innovative catalyst systems from Heraeus and Łukasiewicz Research Network – New Chemical Syntheses Institute contribute to reach climate goals by reducing N_2O emissions during nitric acid production. **Dr Uwe Jantsch** and **Jens Hesse** of Heraeus Precious Metals report on the process performance results achieved for N_2O reduction in nitric acid production using FTC gauze systems and iron oxide based secondary catalysts.

During the production of nitric acid, nitrous oxide gases are released into the atmosphere as a byproduct. This greenhouse gas has roughly 273 times the global warming potential of carbon dioxide and is a major contributor to global warming.

Heraeus Precious Metals is pushing for sustainable industry solutions and offers the possibility to reduce N_2O emissions within the catalytic gauze system using its well-known FTC-technology. This primary N_2O abatement is fully customisable, making it suitable for full as well as partial loads. The catalytic gauze system in combination with secondary or tertiary solutions helps nitric acid producers to meet the latest abatement requirements in the demanding N_2O emission markets. Besides catalytic gauze systems, Heraeus offers, together with its partner Łukasiewicz Research Network – New Chemical Syntheses Institute, secondary catalyst systems for further N_2O emission reduction. Highly efficient catalysts from Heraeus and Łukasiewicz Research Network – New Chemical Syntheses Institute can significantly reduce nitrous oxide emissions up to 95%. Heraeus and Łukasiewicz Research Network – New Chemical Syntheses Institute as partners are installing this reduction technology in existing nitric acid plants around the world, supporting global climate goals and helping with the fight against global warming.

High performance catalysts

Heraeus and Łukasiewicz Research Network – New Chemical Syntheses Institute (formerly INS (Instytut Nawozów Sztucznych)) have a long-time partnership for the supply of high performance catalysts for nitrous oxide abatement in nitric acid production.

Heraeus, a leading producer of precious metal catalyst gauze systems worldwide for more than 100 years, is well-known for its gauze catalyst systems and services and has a global team and production facilities in Germany, USA, China and India.

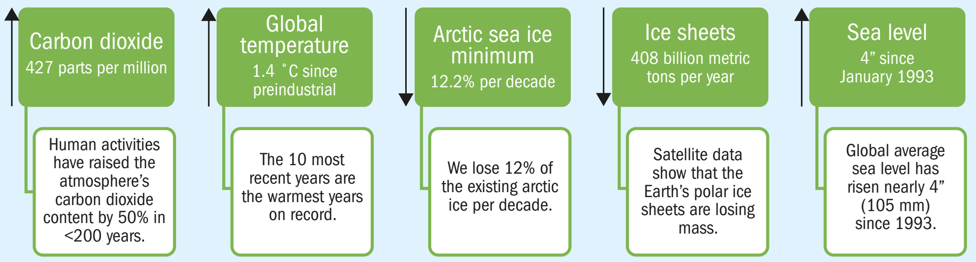
INS, a well-known state centre in Poland since 1935, became part of Łukasiewicz Research Network in 2019 with 32 research institutes located in 12 cities across Poland. It is the third largest research network in Europe.

The innovative catalyst systems from both partners contribute to reach climate goals by reducing N_2O emissions during nitric acid production.

Climate change status 2024

All of us recognise the signs of climate change on the planet: Human activities have raised the atmosphere's carbon dioxide content by 50% in less than 200 years. Satellite data show that ice sheets are losing mass. Summer Arctic sea ice

Fig. 1: **Climate change with signs from the planet**[1]



Source: Heraeus

Fig. 2: **Ammonia converter in a nitric acid plant with primary and secondary catalyst**

Source: Heraeus

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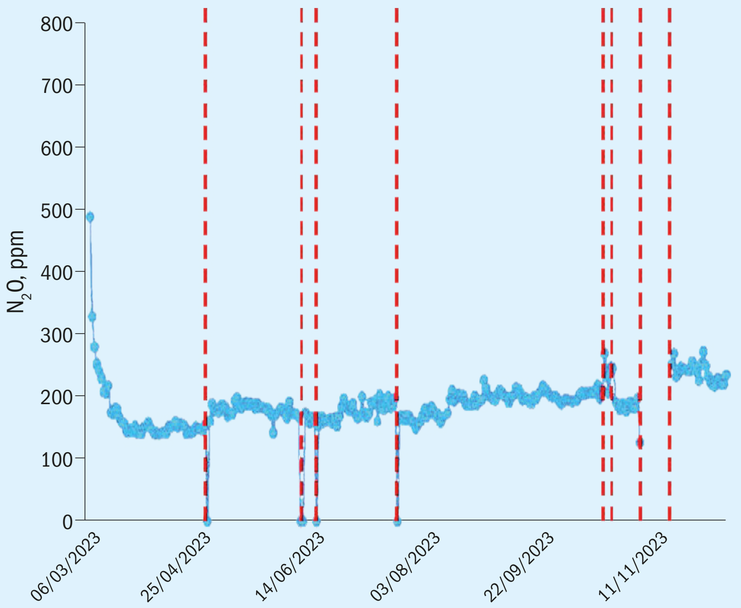
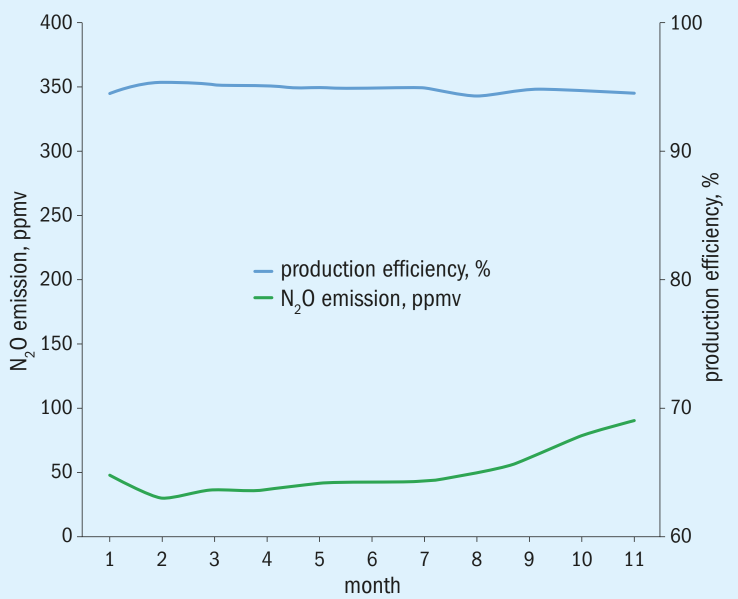
Fig. 3: **N_2O emission of low-pressure plant with FTC flex gauze system**



Source: Heraeus

Fig. 4: **High and stable production efficiency at low N_2O emission in medium pressure plant (pressure < 5 bar)**



Source: Heraeus

is shrinking by 12.2% per decade due to warmer temperatures and the average sea level has risen by nearly 4 inches since January 1993 (see Fig. 1).

In addition, the earth's average global temperature has risen by 1.4 degrees since the 1880s. This is the research result of several scientific organisations including NASA. The past ten years have also been the ten warmest years since records began[2].

N_2O emission reduction in industrial nitric acid plants with limited space for secondary catalyst

During the oxidation of ammonia in the nitric acid production process, the greenhouse gas N_2O is formed in a side reaction. It passes the nitric acid plant without any further reaction and is finally released to the atmosphere.

Main reaction:

$$2NH_3 + 2.5O_2 \rightarrow 2NO + 3H_2O$$

Undesired side reaction:

$$4NH_3 + 4O_2 \rightarrow 2N_2O + 6H_2O$$

Once N_2O has been released into the atmosphere, N_2O remains there for a very long time and it contributes significantly to the global warming effect. In comparison to CO_2 its global warming potential is higher by a factor of 273 according to the sixth IPPC report. Therefore, it is very important to use advanced catalyst technologies to reduce N_2O emission in nitric acid plants.

Typically, the ammonia converters of existing nitric acid plants have been engineered without taking into account the space needed for secondary catalysts for N_2O emission reduction. To make use of the high temperature generated during the NH_3 conversion reaction, the secondary catalyst should be installed directly under the catalytic gauze system. However, the space between the catalytic gauze system and the cooling tubes in the reactor, as shown in Fig. 2, is quite limited and the design of the supporting structure does not meet the requirements of a secondary catalyst application. Before installation of secondary catalyst, a careful inspection and in most cases a redesign of the support structure is necessary.

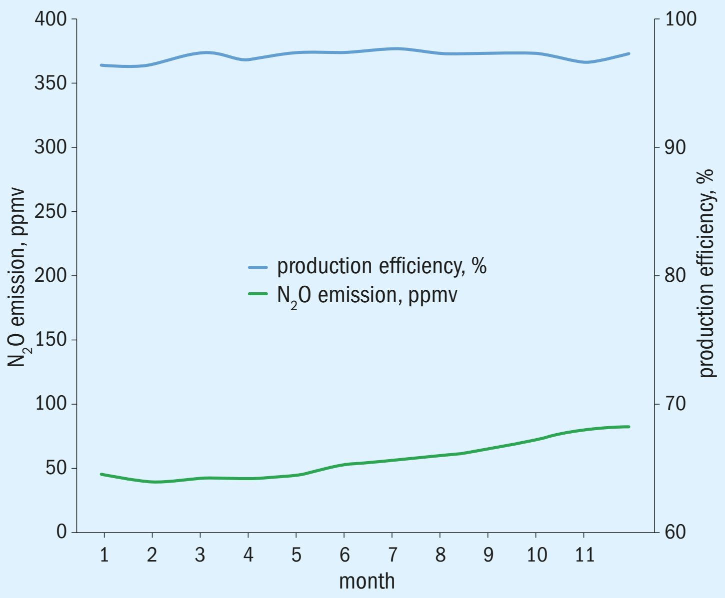
Heraeus and Łukasiewicz Research Network – New Chemical Syntheses Institute have been looking for ways to reduce the emission of N_2O since many years. In their role as partners Heraeus provides N_2O abatement with catalytic gauze systems and Łukasiewicz Research Network – New Chemical Syntheses Institute produces secondary catalyst for N_2O abatement – PKR-2 (iron oxide based). For international markets, Heraeus acts as an exclusive distribution partner of secondary catalyst from Łukasiewicz Research Network – New Chemical Syntheses Institute. Both catalysts are coordinated to achieve the highest N_2O reduction rate.

Heraeus has been developing special FTC flex gauze systems which generate less N_2O compared to state-of-the-art gauze systems, without sacrificing production capacity or NH_3 conversion efficiency. The latest results from industrial tests show that with FTC flex gauze systems, the N_2O emission can be reduced up to 70% compared to state-of-the-art gauze systems. Fig. 3 shows the low N_2O emission of a low-pressure plant over the operating time. This can be achieved by using special FTC flex gauze systems with different PGM composition from top to bottom of the entire gauze system. This technology was patented and is available exclusively from Heraeus.

It is well known that catalyst gauzes lose precious metal weight by high temperature evaporation during operation of the nitric acid plants. Typically, this issue leads to changes of the chemical composition of the gauzes and an increase of N_2O emission over time. Heraeus has managed to significantly reduce the N_2O emissions over the entire production period. Nevertheless, the reduction of N_2O emission with catalytic gauze systems is not sufficient to achieve the environment targets in future. In higher loaded medium or in high pressure plants, it is more difficult to achieve low N_2O emissions with catalytic gauze systems only. Therefore, it is important to use additional N_2O abatement technologies.

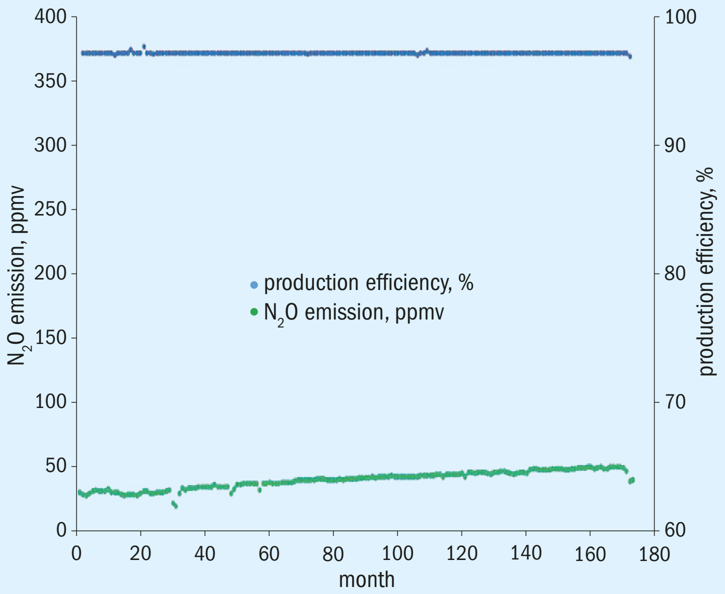
The installation of secondary catalysts directly under the FTC flex gauze system reduces N_2O emissions further to a very

Fig. 5: **N_2O emissions of a medium pressure plant (pressure < 5 bar) with Heraeus new FTC flex gauze design and secondary catalyst**



Source: Heraeus

Fig. 6: **N_2O emissions (average < 40 ppmv) of a medium pressure plant (pressure > 5 bar) with an FTC gauze design and secondary catalyst**



Source: Heraeus

low N_2O emission level. The volume of secondary catalyst which can be installed under the FTC gauze system depends strongly on reactor type and design and condition of the mechanical supporting structure. Using the $Fe2O_3/Al_2O_3$ catalyst, the shape and the size of the secondary catalyst particles can be optimised and adjusted to the operating conditions of each plant. Depending on the available space under the catalytic gauze system and on the hydrodynamic gas flow conditions, the appropriate geometry of secondary catalyst will be recommended.

Technical service engineers from Heraeus and Łukasiewicz Research Network – New Chemical Syntheses Institute visit the customer's nitric acid plant to support the installation of the catalytic gauze system and secondary catalyst into the burner. By carefully tailoring this two-stage catalyst system to each reactor, customers can stay below desired emissions targets, e.g., to comply with the EU ETS.

The graphs in Figs. 4 to 6 show examples of N_2O emission reduction of medium pressure plants over the entire gauze campaigns, using Heraeus FTC flex catalyst gauze systems and INS secondary catalysts. In these cases, the extrudate type catalyst PKR-2 has been used in combination with high emission reduction FTC flex gauze systems.

Typically, a gauze campaign in a medium pressure plant lasts up to one year. Due to evaporation of platinum on the upper gauzes and absorption of Pt on lower gauzes the composition of the gauze layers changes with time. Additionally, the impurities carried into the reactor with the mixed gas partly deactivate the catalyst gauze surface over time. It results in a degradation of the catalytic activity and consequently in a slight decrease of NO conversion efficiency and hence in increasing N_2O emissions. Fig. 4 shows the graphs of the N_2O emission, and the production efficiency results in a medium pressure plant with a long campaign length of around one year. The catalytic gauze system is the newly developed FTC flex gauze system with low N_2O emission.

In Fig. 4 the N_2O emission during the campaign was on average around 50 ppmv with a high and stable production efficiency during the entire production period. At the end of the campaign the N_2O emission increases because of the deactivation effects of the gauze catalyst described above.

Fig. 5 shows the N_2O emission and the production efficiency in the same plant after improvement of the process condition inside the burner. This resulted in some improvement of the production efficiency compared to the previous gauze campaign (Fig. 4) and the N_2O emissions were kept in the same low range without changing the secondary catalyst. This was the result of the close cooperation between the customer and the supplier of the catalysts.

Fig. 6 shows the N_2O emission of another medium pressure plant with a burner pressure of more than 5 bara. In this example the low N_2O emission results were achieved by a well-adjusted combination of FTC gauze catalyst together with an iron oxide based secondary catalyst and a well-designed supporting structure. The campaign duration here is around six months. In this case the average N_2O emission is below 40 ppmv.

Conclusion

Successful process performance results were achieved for N_2O reduction in nitric acid production using FTC gauze systems and iron oxide based secondary catalysts. Innovative catalyst systems from Heraeus and Łukasiewicz Research Network – New Chemical Syntheses Institute have demonstrated their ability to efficiently reduce N_2O emissions of nitric acid plants and support the nitric acid industry to achieve the environmental requirements. ■

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Pastillation of specialty urea products

IPCO has expanded its Rotoform range with the high yield XG model for granulation of suspensions. Designed for applications such as sulphur bentonite and urea mixes as well as NPK and other fertilizers, this new Rotoform model can convert solid-containing product melts into consistent, high quality pastilles from 2-4 mm diameter.

IPCO has announced the introduction of the Rotoform XG, a high capacity pastillation system for fertilizer finishing, offering superior handling of low viscosity melts containing solid particles. Further enhancements incorporated into this latest addition to the company's Rotoform range include significantly easier cleaning and maintenance.

Designed for applications such as sulphur bentonite and urea mixes as well as NPK and other fertilizers, this new Rotoform model can convert solid-containing product melts into consistent, high quality pastilles from 2-4 mm diameter. The XG is also able to process other products containing solid additives or contaminant particles up to 200 µm in size.

Offering twice the throughput rates of the base model Rotoform 4G, the XG is capable of processing slurries with melt viscosities up to 100 mPas.

The design follows the same basic principle that has seen more than 2,500 Rotoform systems installed since the process was first launched. Liquid product is delivered to a stator then deposited in drop form via a rotating perforated outer shell onto a continuously running steel cooling belt.

However, the XG incorporates a number of innovations including a sliding base frame that allows the Rotoform to be pulled out for easy access, and a floating stator that makes cleaning and maintenance much easier. A bearing system with fewer parts and increased wear resistance further reduces maintenance requirements.

"This is a major development in terms of handling slurry and abrasive products," says Ulrich Nanz, Global Product Manager, Chemicals, at IPCO. "The high capacity of the system maximises productivity, while easier cleaning and maintenance equates to lower costs."

IPCO can also supply upstream solutions including blending and grinding units to combine liquid and solid products into suspensions, enabling the production of specialty urea products such as:

- urea + sulphur
- urea ammonium sulphate (UAS)
- urea + potassium
- urea blended with micronutrients

Other special fertilizers that can be produced on these systems include ammonium nitrate, calcium nitrate, magnesium nitrate, and sulphur bentonite. The company can also supply a complete range of downstream handling and bagging systems.

One of the major advantages of IPCO's in-line systems is that production can be switched from one product to another with only minimal modification. This ability to control dosing allows product ratios to be varied to meet different needs. It also means that new fertilizer products can be brought to market more economically. And if production capacities need to be increased, multiple Rotoforms can be run in parallel.

This flexibility makes IPCO's Rotoform XG ideal for debottlenecking, for upgrade projects or for reducing overall plant emissions by transferring a proportion of existing production to pastillation.

Rotoform solidification – one principle, multiple applications

IPCO introduced the Rotoform rotary drop-forming technology in the late 1970s and while the core principle – direct-from-the-melt solidification on a steel belt cooler – remains unchanged, the technology behind it has undergone significant development over the years.

In 2013 the company – then operating as Sandvik Process Systems – introduced the Rotoform 4G, a model that today forms the foundation of an entire family of systems capable of meeting a wide range of process requirements. These include the granulation of abrasive and sediment materials, melts requiring a high feed temperature (e.g. bitumen, resins), and the pastillation of subcooling melts in supercooling plants (e.g. antioxidants).

Other previous developments include the Rotoform HS, a high speed model capable of processing up to 350 tonnes of sulphur per day.

The core Rotoform design is based on a heated stator and a perforated rotating shell that turns concentrically around the stator. A pump delivers the molten product from a vessel or pit to

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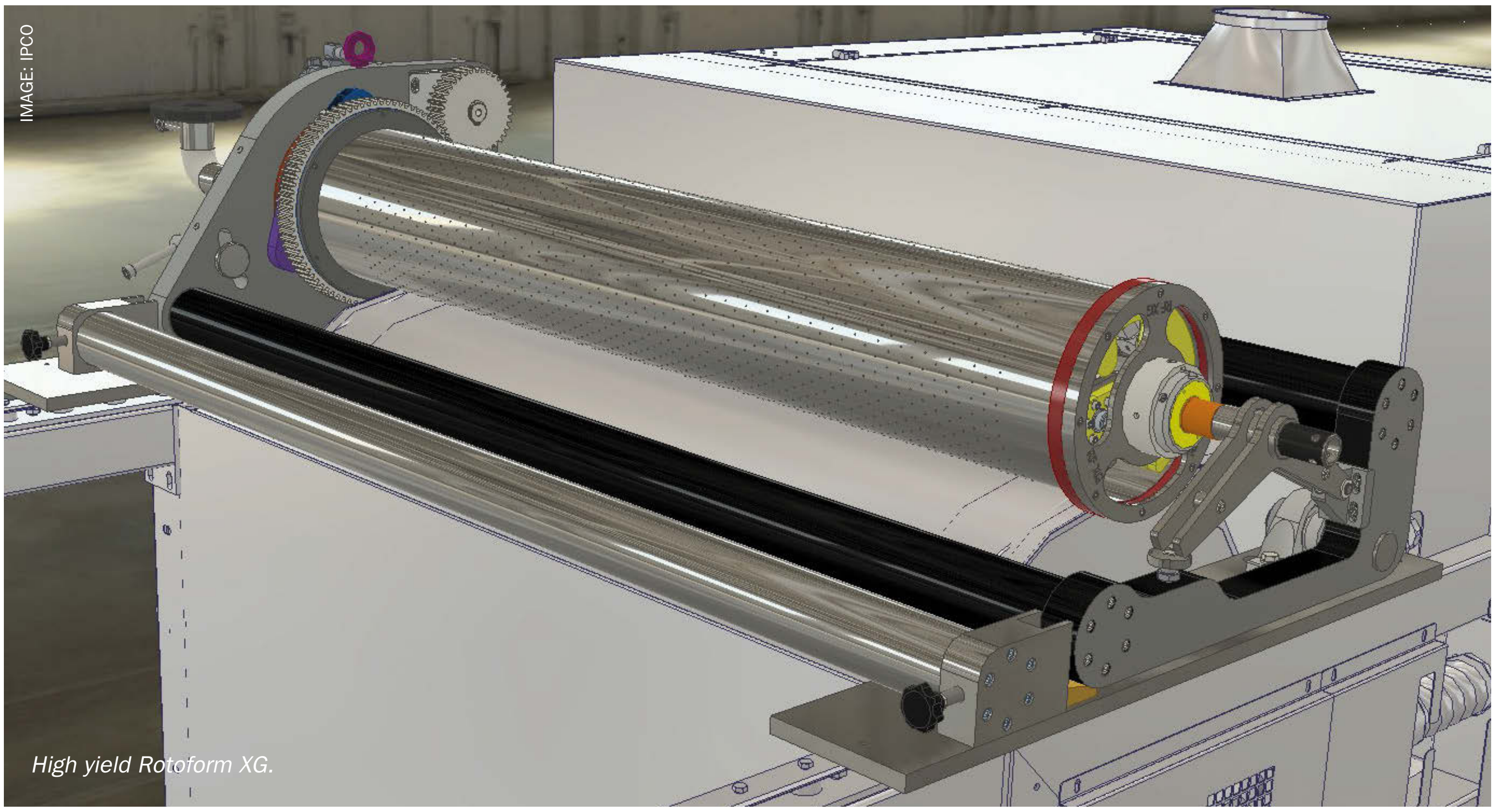
IMAGE: IPCO

High yield Rotoform XG.

the Rotoform system via heated pipes and a filter.

The design of the system takes into account a number of factors including the required pastille diameter, the density and viscosity of the molten product, the surface tension, and the mechanical acceleration applied to the droplet. The droplet weight and volume, and the distance between the outer shell of the Rotoform and the steel belt must also be determined on a product-by-product basis. These parameters are calculated either by computer simulations or pilot plant testing at one of IPCO's global productivity centres.

A system of baffles and internal nozzles built into the stator delivers uniform pressure across the whole belt width, ensuring even flow through all holes of the perforated rotary shell and a uniform end product. Precisely metered drops of the product are deposited by the nozzle bar across the whole operating width of a continuously running stainless steel cooling belt.

The rotational speed of the unit is synchronised with the speed of the steel cooling belt to allow the liquid droplets to be deposited without deformation. After the drop has been deposited, any residual product remaining on the outer shell is returned to the Rotoform by a heated refeed bar, which keeps the outer shell clean. Heat released during cooling and solidification of the melt is transferred via the steel belt to cooling water sprayed underneath.

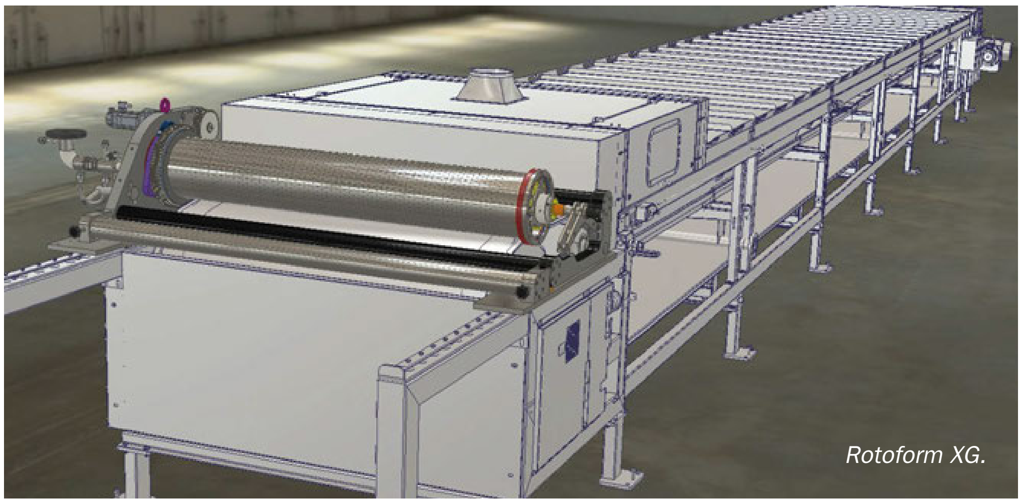
IMAGE: IPCO

Rotoform XG.

The product droplets are then discharged as solid, hemispherical granules at the end of the cooling system. To eliminate the possibility of product damage during discharge – and to further minimise dust – a thin film of release agent can be sprayed onto the steel belt. This is managed using IPCO's ProForm system, a purpose-designed solution consisting of two parts:

- ProMix: This automates the mixing of water and a release agent (different types used for different fertilizers), ensuring a uniform ratio for precise dosing and optimum performance.
- ProSpray: This advanced spraying bar system delivers the release agent to the steel belt in a controlled and targeted way to ensure clean discharge of the end product and most efficient use of materials.

The Rotoform process offers a number of environmental advantages. Closed loop cooling means that the cooling water never comes into direct contact with the product so there is no risk of cross contamination; the water can be collected, re-cooled and used again.

Secondly, rapid solidification results in very low emission values. And low levels of dust levels mean no need for exhaust air treatment.

Finally, with extremely low energy consumption requirements, Rotoform solidification represents an economical as well as sustainable solution for fertilizer producers, farmers, and the environment.

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The odyssey of green ammonia: optimising levelised cost

Green ammonia production facilities can be situated in remote areas with access to often fully off-grid renewable power supply. This article examines plant concepts and discusses the challenges and solutions for these plant architectures. Through a case study, an efficient and innovative methodology to compare options and optimise the sizing of the plant is presented. The methodology addresses the intermittency of the power production, the flexibility limits of the main process units, and the costs of investment and operation, using proprietary techno-economic dynamic simulation software, Odyssey.

Geoffrey Guindeuil (Technip Energies), Marieke Maenhaut (Technip Energies), Carolina Nugroho (Rely)

Ammonia today and tomorrow

Ammonia, traditionally derived from fossil sources, has been used in various industries such as fertilizers and chemicals. Recently, the shift towards green ammonia – ammonia created using renewable energy through water electrolysis – signals a change in market trends. The future of the ammonia market will not only rely on its established applications but also on new potential uses, namely as a maritime fuel, power generation fuel, and as a carrier for hydrogen. Market experts anticipate that the ammonia industry could expand two to five times over the next 30 years, with most production plants likely transitioning to cleaner versions like green or blue ammonia, depending on regional contexts.

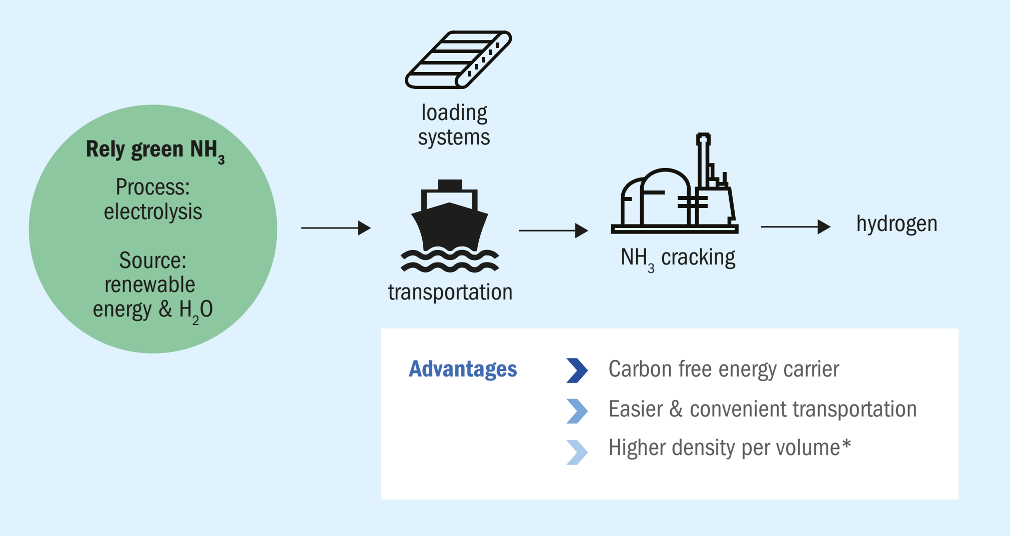
For decades, Technip Energies has led the construction of large-scale ammonia facilities across the globe. Its portfolio includes over 30 projects in both conventional and low carbon ammonia.

The current challenge of green hydrogen derivatives like ammonia is clear: bridging the gap between them and their conventional alternative. To meet this challenge, Technip Energies and John Cockerill, global market leaders in Hydrogen & derivatives EPC and OEM, joined forces in November 2023 to create Rely, a unique provider of competitive, integrated green hydrogen and power-to-X solutions providing end-to-end solutions to the complete value chain.

The green ammonia chain starts with renewable power generation, water electrolysis, ammonia synthesis, and can extend further to hydrogen regeneration if ammonia is used as a H_2 carrier, as shown in Fig. 1.

Regardless of its final use, the first technology blocks are about producing renewable power, green hydrogen, and ammonia; this is the part of the chain where intermittency and flexibility matter most, and thus on which the present article focuses.

Fig. 1: **Green ammonia production chain as a hydrogen carrier**



Source: Technip Energies

**Compared to other liquid hydrogen carriers*

Fig. 2: **Green ammonia production building blocks**

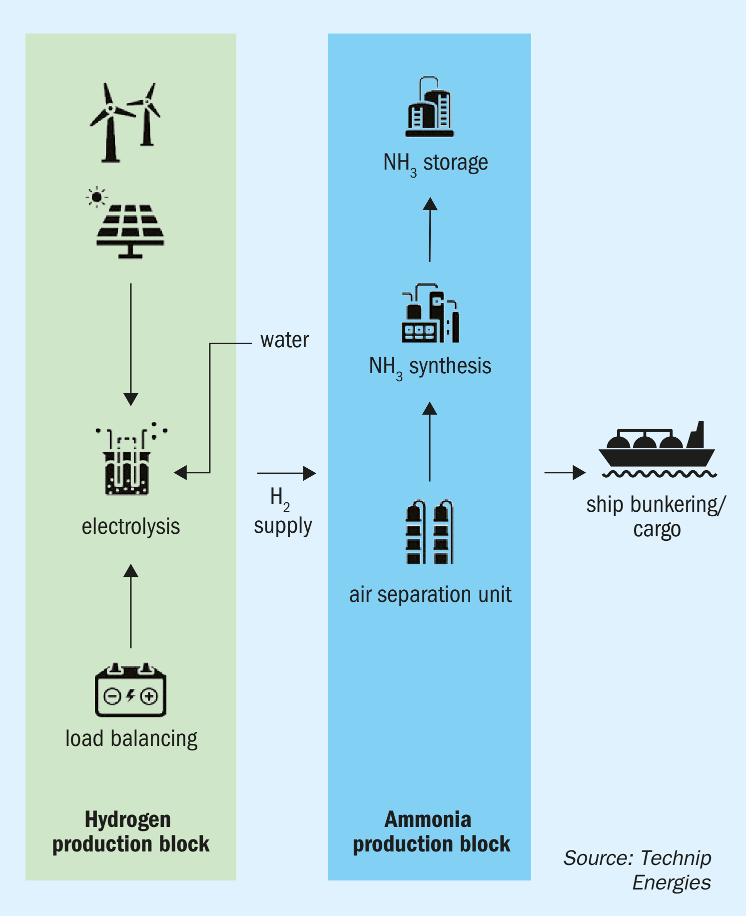


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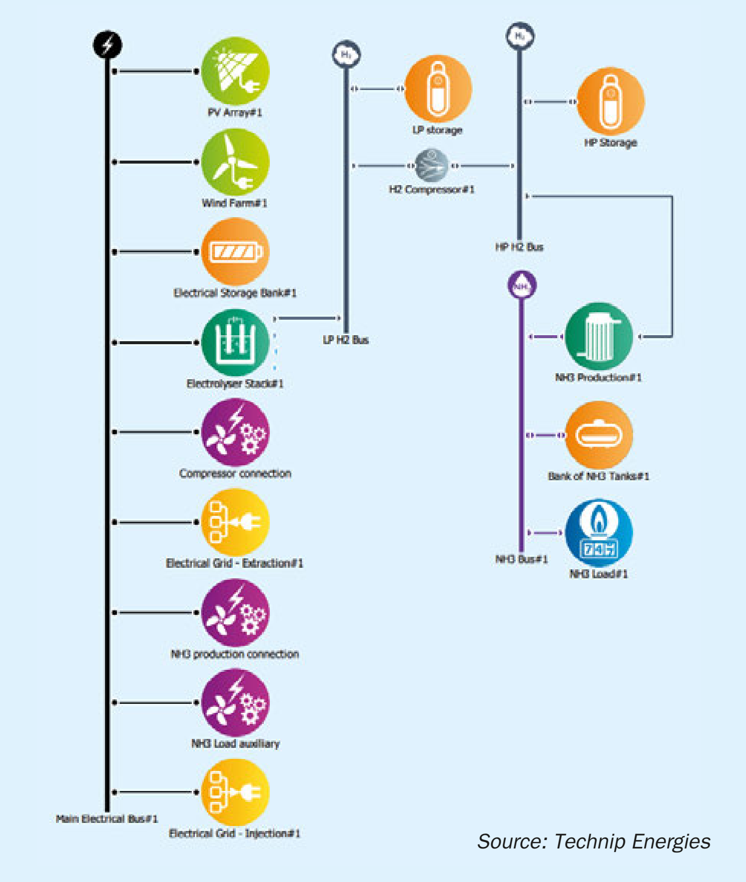
Fig. 3: **Example of Odyssey model user interface for green ammonia production**



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Bridging electrons to the ammonia molecule: process basics

Renewable power (REN), supplied either by the grid or off-grid, is the starting block of green ammonia production (Fig. 2). Most transported as high voltage alternating current (AC) through the power grid, a power conversion unit (PCU) is needed for voltage reduction and current conversion to direct current (DC), necessary for water electrolyser stacks. Within these electrolysers – whether alkaline water electrolysers (AWE), proton exchange membrane (PEM), or solid oxide electrolyser cells (SOEC) – water is split into hydrogen and oxygen in multiple cells comprising a stack, demanding roughly 4.5-5 kWh of power per Nm^3 of hydrogen. This green hydrogen is then purified, dried, compressed, and directed to the ammonia synthesis loop. When pressurised electrolysers are used, intermediate hydrogen compression may be bypassed.

Green ammonia synthesis process consists of three steps: Feed gas compression, synthesis loop, and ammonia refrigeration. In feed gas compression, green hydrogen is mixed in stoichiometric proportions with nitrogen produced by cryogenic air separation (ASU) and the mix is compressed to enter the ammonia synthesis loop. The design of the green synthesis loop is very close to a conventional synthesis loop. Most licensors have references of standalone synthesis loops without the front-end syngas generation, using nitrogen and pipeline hydrogen, and develop solutions specific to the green ammonia industry, such as improving their dynamic process controls and material selection for better fatigue resistance.

The utility needs for a green ammonia facility are similar to those of a traditional plant, with key differences. The water treatment units need to be larger to supply purified water for electrolysis in addition to standard uses like cooling towers and steam generation. For cooling, a green ammonia plant might use cooling towers, air coolers, or hybrid systems, with the option for separate cooling circuits for hydrogen production and ammonia synthesis. The cooling requirements for hydrogen production tend to dominate, potentially doubling that of the rest of the plant. Compressed air and nitrogen are supplied from the ASU. The substantial electrical demands for producing green hydrogen mean that the power system is a significant portion of the plant's capital expenses, shifting the project paradigm.

Flexibility of main building blocks

Green hydrogen and derivatives production technologies need flexibility to cope with variable renewable power sources. A green hydrogen plant can adjust its load relatively quickly. However, the ammonia synthesis process involves a high pressure and high temperature catalytic process as well as cryogenic parts, that need more stable operation. A conventional ammonia plant can only operate between 60-100% capacity with slow ramp rates. The cryogenic air separation unit has similar constraints.

How to cope with intermittency?

Numerous green ammonia initiatives consider off-grid, renewable powered ammonia production in remote locations. This article emphasises the variability of power supplies like solar or wind, as opposed to the stability of hydropower. Because weather can be unpredictable, these fluctuations occur seasonally, daily (as with solar), or at random times, thus affecting ammonia plant design and operations. These include rapid power changes, blackout periods, and frequent on-off cycles. From hydrogen creation to ammonia storage, plants should flexibly adapt to available power. While most electrolysis technologies such as pressurised alkaline or PEM can more easily adjust to the dynamics of power supply variability, ammonia synthesis is less adaptable. Ammonia production faces several challenges: typically steady-state plant operations with limited adaptability, equipment-specific operational constraints (such as turndown), and increased wear and fatigue due to instability. The goal is to manage these variations, maintain flexibility for fluctuating power supplies, and remain economically viable. Three primary targets must be achieved to succeed.

First target: Electrical grid stability

The plant should handle power outages and surpluses. Backup and essential power units can prevent black-outs, while batteries or other systems can store or sell excess power. Storing excess renewable energy can also maintain a more consistent green hydrogen output, and thus ammonia. Battery systems can also help with electrical load balancing.

Second target: Hydrogen production stability

The plant should limit and mitigate green hydrogen intermittency. Water electrolysers are flexible, but smoother operation extends their lifetime. The design capacity and number of balance-of-plant units, such as deoxidation, dehydration, and compression, should be carefully determined for hydrogen production stability.

Additionally, intermediate hydrogen storage buffers load variation, and provides a stable hydrogen feed to the ammonia synthesis loop. Hydrogen storage is pressurised, in pipelines, vessels, or buried pipes. The storage should allow continuous ammonia production, smoothen load fluctuation, and minimise stoppages. Nitrogen is also stored to buffer the ASU output, which is less flexible.

Third target: Ammonia production flexibility

A green ammonia plant can be designed to vary its output depending on the process and the renewable energy sources, and this is currently a strong trend in the industry.

The key parameters of an ideal flexible green ammonia plant are:

- Ramp-up/down rates: as fast as possible, up to 3%/min for some licensors;
- Number of start/stop operations: as many as possible during the year;
- Minimum turndown: as low as possible, 10% achievable by several licensors;
- Idle or stand-by mode: sustainable for a long time;
- Time required to start-up: as short as possible;

For higher flexibility and faster start-ups, electrically-driven compressors are often selected, using steam generated from process heat to power a steam turbine generator.

To ensure reliable and safe supply of all utilities, adequate storage capacity is crucial. Water treatment units, which are sensitive to load changes, may also need back-up power.

Rely has developed Clear100+, a standardised 100 MW green hydrogen plant solution optimally conceived to offer performant, affordable, safe and certain production at scale. Offering an optimal balance of plant design, it is suited for flexibility range from 15-100%, integrating John Cockerill's proven pressurised alkaline electrolyser technology with high reactivity to load variations. The Clear100+ is designed for seamless integration with a downstream ammonia production unit, making it an ideal solution for projects connected to renewable electricity.

New type of plants, new challenges, new methods

Considering an off-grid green ammonia plant, powered only or mainly by renewable intermittent power sources, changes the way to size the plant at feasibility stage. Indeed, given an objective of annual ammonia production, the size of the plant (hydrogen and ammonia production) depends on its load factor which is a function of renewable installed capacity, of renewable power source load factor and of the plant's operating philosophy. Various sizing combinations of renewable power sources, hydrogen plant and ammonia plant can lead to the same annual production, but for different costs.

For early-stage sizing optimisation at project inception, Rely proposes a versatile, dynamic, techno-economic simulation tool called Odyssey (Fig. 3). Developed by Seed Energy, a spin-off from CEA, it is now incorporated within Technip Energies as of June 2023.

Fig. 4: **Schematic of case study plant configuration**

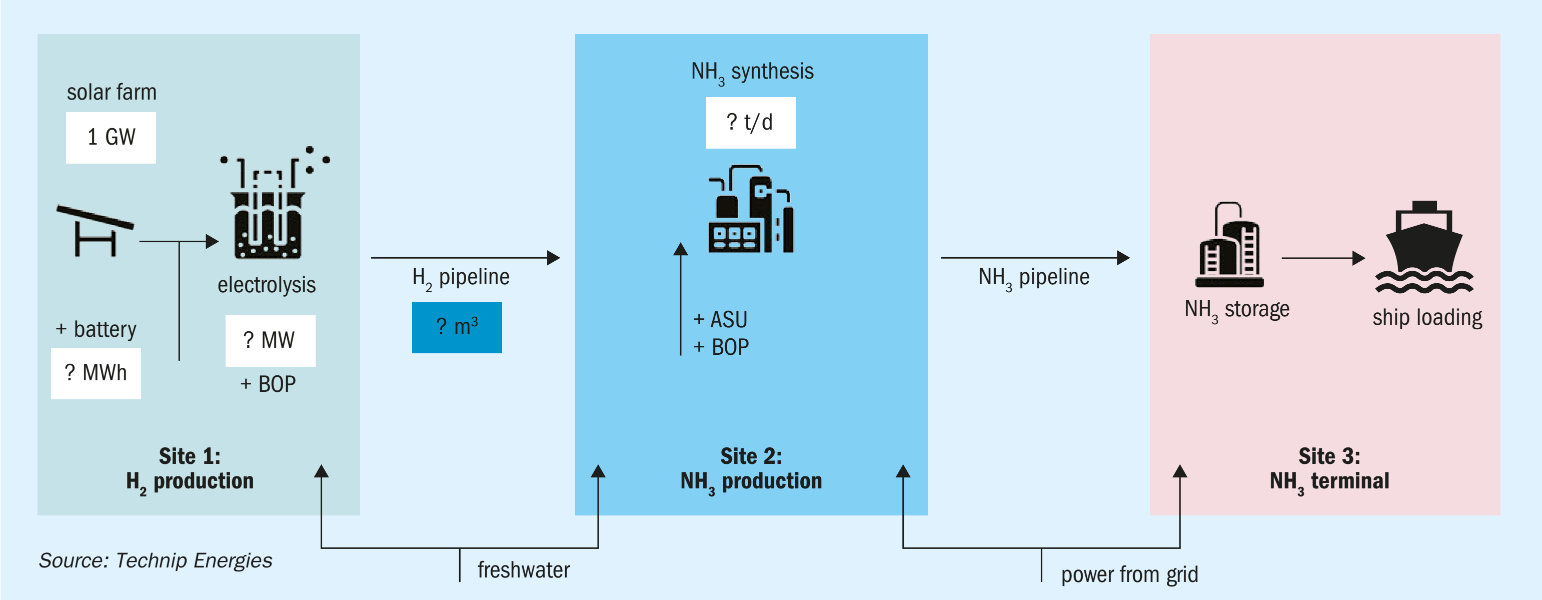

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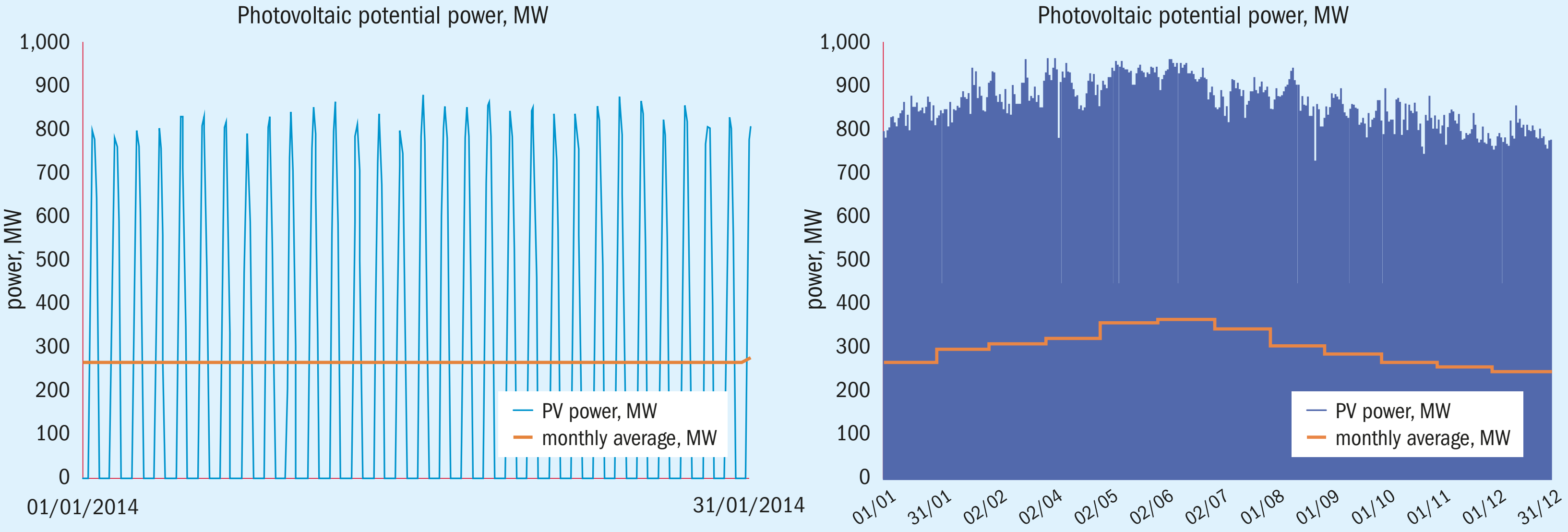
Fig. 5: **Power profiles (for one month and one year) for the site location and a given photovoltaic panel technology**



Source: Technip Energies

Odyssey serves two main purposes:

- a high-level dynamic simulation tool, using process and technology data to simulate plant operations over its lifetime and calculate total power or product yield;
- a techno-economic simulator, utilising investment and operational cost data to estimate the plant's total discounted cost over its lifespan.

Odyssey is especially adapted to assess evolution of the plant production considering an intermittent source of power (or product), and the corresponding levelised cost of product.

It performs parametric or optimisation studies simulating multiple design configurations and operating philosophies, comparing them and selecting the optimum sizing for the plant.

A case study using solar power

In this study, let's consider a project aimed at generating green ammonia using only solar power in a remote location (Fig. 4). The plan is to install 1 GW of solar energy, with flexible ammonia production target. The main task will be to conduct techno-economic optimisation to determine the most cost-effective plant design and operation to minimise the cost per ton of ammonia. This includes determining the size of various components: The electrolysis and ammonia synthesis capacities, an intermediate hydrogen storage for when the electrolyser is not producing, and a battery energy storage system to keep essential while ammonia synthesis occurs close to a port terminal. The two sites are connected by a pipeline serving also as hydrogen storage. While the ammonia site uses grid power, the electrolysis facility relies solely on solar or stored battery power.

The model is fed with technical data such as potential renewable power production from the site. Odyssey considers the daily and annual evolution of power production as well as the degradation and ageing occurring during the plant lifetime.

Fig. 5 presents an example of the potential power profile used as input of the analysis.

Technical performance data for the plant are also integrated in the model: electrolysers efficiency, utility systems power consumption, ammonia synthesis unit power consumption, as function of the load and of the size of the plant. Any degradation and ageing data available can also be simulated. The model is made as closely representative as possible of the behaviour of the plant for any size and any condition of operation. The model includes all flexibility data for the different units: start-up, turndown and ramp-up/down rates are required to correctly simulate the transient phases.

Different operating philosophies can be envisaged both for electrolysis and ammonia synthesis. The operating philosophy shall define how the electrolysers will react depending on the variation of renewable power. Typically for an off-grid condition, hydrogen production will be set to follow the variations of power production. Power requirement of the whole plant will also be minimised during the night to avoid the need for large battery

Fig. 6: **Dynamic variations of production rates over time**

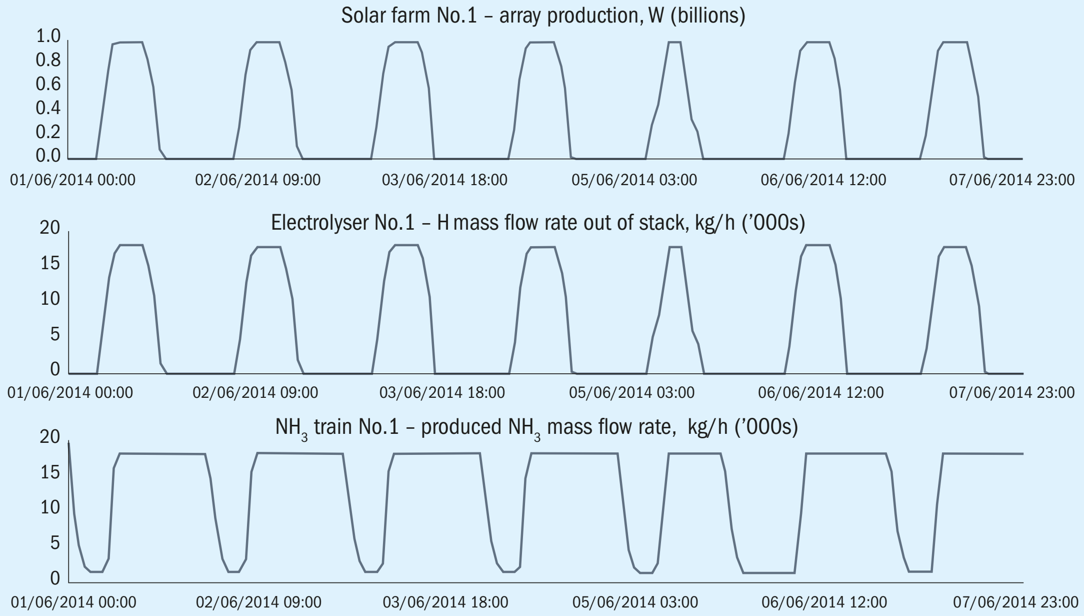


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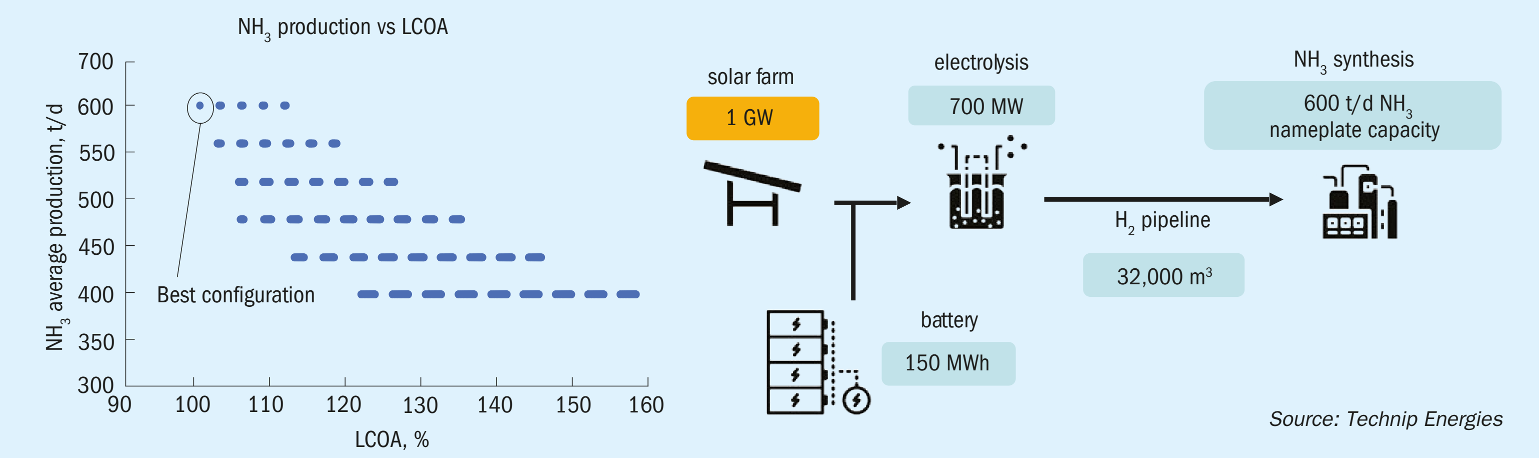
Fig. 7: **First operating philosophy – optimisation results**



Source: Technip Energies

energy storage. In some configurations, more advanced strategies can be proposed, and, for example, for hydrogen plants connected to a grid, operating philosophies related to the variation of electricity price can be envisaged and simulated. The ammonia synthesis unit is less flexible: Start and stop of this unit daily is not conceivable. Hydrogen storage is thus required to feed the ammonia plant when there is no hydrogen production. Still, different operating philosophies can be envisaged for this unit, with relative flexibility. In this article, two operating philosophies are compared:

- conventional continuous and stable ammonia production;
- flexible ammonia production depending on hydrogen availability.

More advanced operating strategies depending on forecast of power/hydrogen production could also be proposed depending on project specificities.

When an operating philosophy is defined for the plant, with a given size of electrolysers, hydrogen storage and ammonia synthesis unit, Odyssey can be used to quantify the evolution of power consumption, hydrogen production and ammonia production along the plant lifetime. Fig. 6 shows the dynamic variations of production rates over time.

Yet, to compare various configurations and operating philosophies, economic data are required in the analysis. The model includes preliminary investment and operational costs for each unit modelled in the facility. These costs are estimated depending on the unit size to allow more realistic assessment when comparing different plant sizes.

For each studied dataset (technical data, economic data and operating philosophy), an optimisation study is carried out with the tool. It involves simulating multiple configurations with different sizes of electrolysers, battery energy storage, hydrogen pipeline (used as hydrogen storage) and ammonia synthesis units. For each case, it assesses the total hydrogen production, total production of ammonia and total cost, over the plant lifetime. This analysis facilitates the calculation of the levelised cost of hydrogen (LCOH) and ammonia (LCOA) for each configuration.

Typically, the results are presented on a graph where each dot corresponds to one simulated configuration, showing the LCOA and the ammonia average production over the plant lifetime. The best configuration is found along the Pareto front combining minimum LCOA and maximum ammonia production.

For the first operating philosophy (Fig. 7), with constant ammonia production, the configuration showing the minimum LCOA also produces the maximum quantity of ammonia: 600 t/d, obtained with a 700MW electrolysis plant, a 600 t/d capacity ammonia plant, a 150 MWh battery energy storage and 32,000 m³ of hydrogen storage in a pipeline between the two sites.

For the second operating philosophy (Fig. 8), the ammonia production and its corresponding hydrogen consumption is allowed to decrease during the night, when there is no hydrogen production. A larger ammonia plant is required to produce the same quantity of ammonia, with a lower load factor. At the same time, it decreases the required pipeline storage volume and allows increasing the electrolyser size, producing more hydrogen and in the end more ammonia, with a reduced total cost.

The selected configuration from Fig. 8 results in the lowest LCOA, which is 8% less than the 1st operating philosophy.

Fig. 8: **Second operating philosophy – optimisation results**

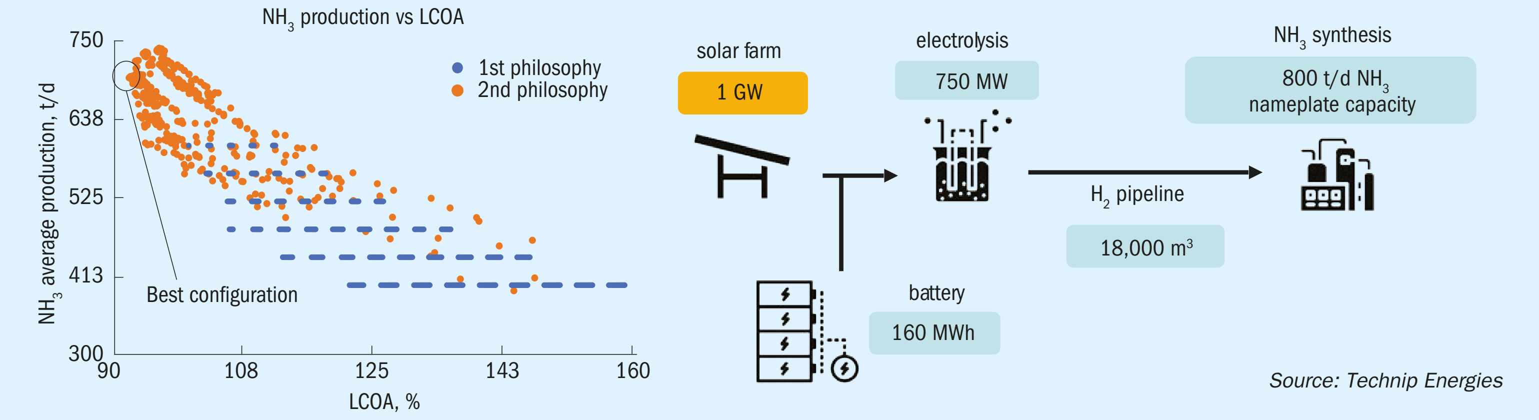


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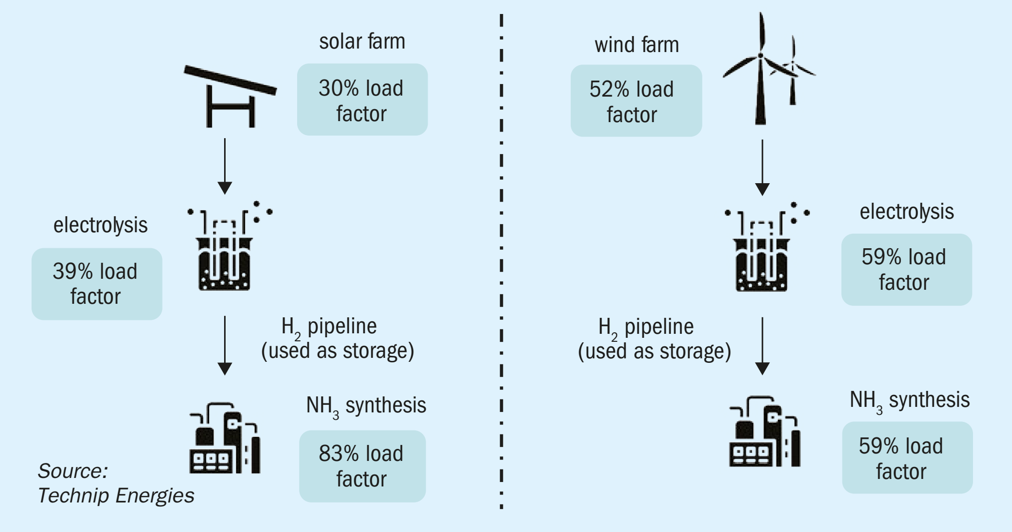
Fig. 9: **Optimisation results comparison for two different studies**



Source: Technip Energies

Additionally, the average ammonia production is increased to 700 t/d, an increase of 17% compared to the first philosophy. Other configurations under this second operating philosophy could yield even higher ammonia outputs, albeit with a higher LCOA. If the project values the higher production of ammonia sufficiently to outweigh the increased costs, another configuration from the Pareto front might be preferrable.

Renewable power source: wind, solar or both?

Depending on the type of power source (wind, solar, or mix, with or without back-up from the grid) and its load factor, sizing of the electrolysers and ammonia synthesis unit can vary largely. The sizing indicated in this article cannot thus be extrapolated easily to other projects. The example in Fig. 9 shows that the optimisation of two different architectures, both off-grid green ammonia plants with two production sites linked with a hydrogen pipeline result in very different configurations, due to the nature of the power source (solar versus wind) and the selected operating philosophies.

Breaking down the LCOA

Finally, Fig. 10 presents examples of cost breakdown constituting the LCOA for green ammonia plants:

- The left diagram shows an off-grid facility: 35% of expenses from renewable energy and 38% from hydrogen production. The ammonia synthesis & terminal represent 27%. Economically, it's justifiable to oversize the ammonia unit to lower overall LCOA.
- Conversely, the grid-connected plant on the right has a higher electricity cost. Here, electrolysers operate with higher load factor, decreasing the relative hydrogen production cost, while the ammonia section represents 30% of total costs.

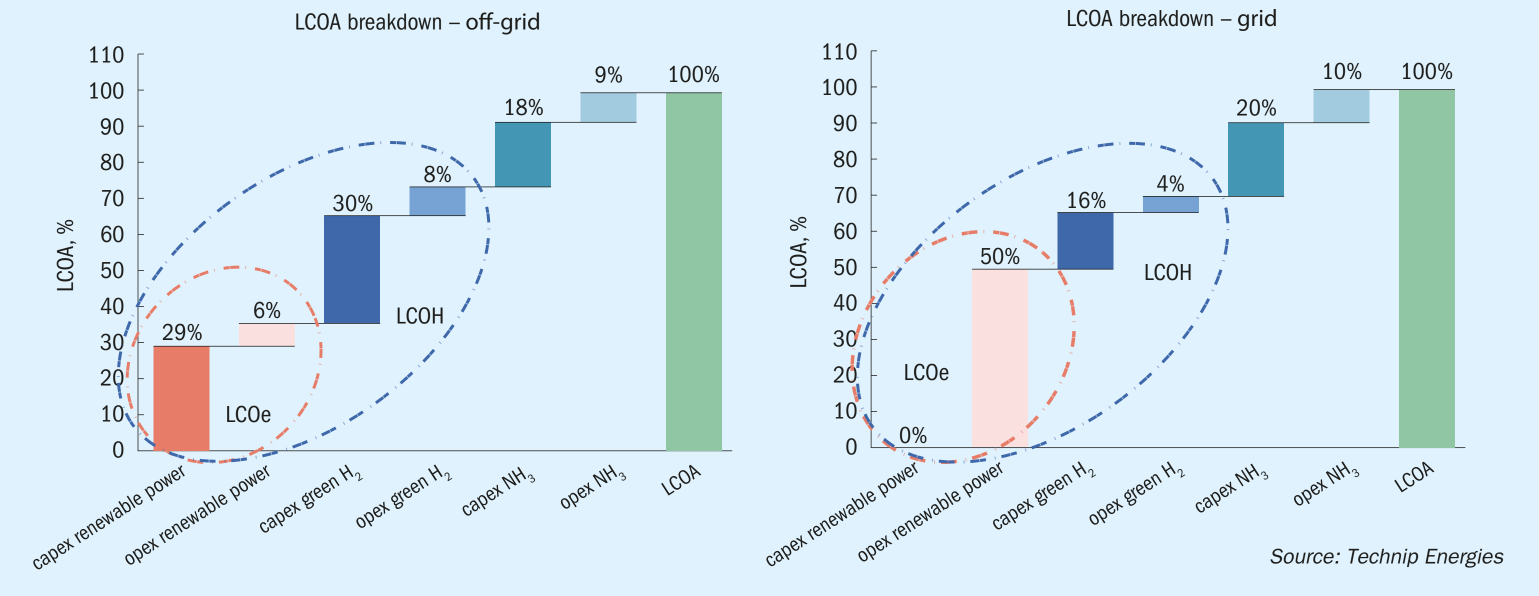
Conclusion

The main challenges for off-grid green ammonia production facilities are production variability and managing intermittency. New methods and tools are needed to optimise the design of green ammonia facilities, incorporating greater flexibility whilst remaining competitive. Rely's versatile and fit-for-purpose method using Odyssey allows early framing and orientation of project architecture. Using power profiles, historical technical and economic data, with little input data needed, Odyssey techno-economic optimisation studies evaluate multiple plant configuration options and select optimal plant sizing from early project stages.

Thanks to the relative comparisons between options and preliminary LCOAs associated, Project can confidently select capacity and develop the design, to further refine and optimise the sizing. This end-to-end approach is key to making the right choices and optimising the LCOA.

Green hydrogen production cost makes up the majority of the LCOA. With LCOH reduction as its key driver, Rely's Clear100+ solution offers a standardised 100 MW green hydrogen plant. It offers unparalleled flexibility, thanks to a design specifically adapted to fluctuating renewable power sources. Easily integrated with a downstream ammonia unit, it makes an optimal end-to-end solution for off-grid green ammonia projects. ■

Fig. 10: **Example of LCOA breakdown for an off-grid green ammonia plant and a plant connected to the grid**



Source: Technip Energies

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