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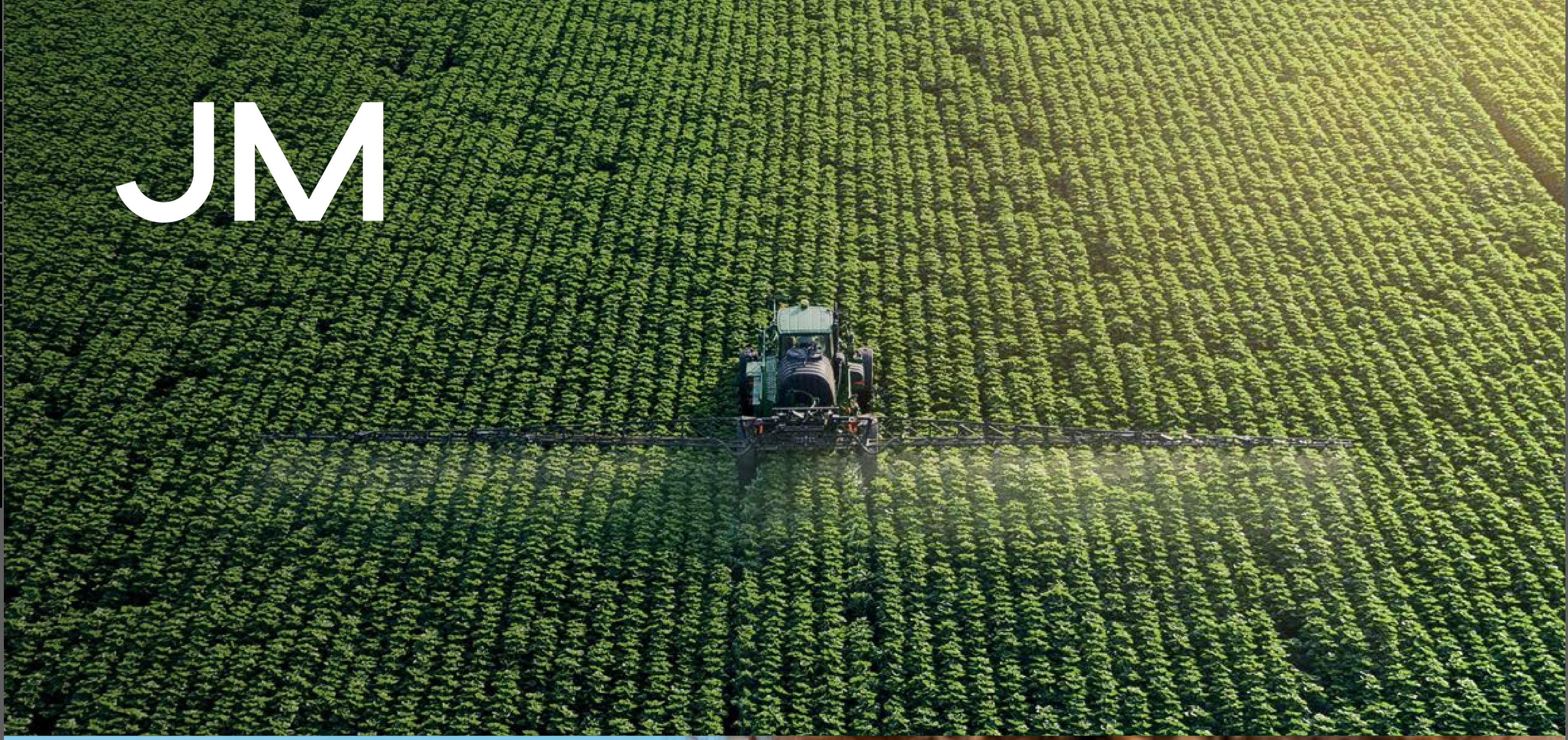
Certification of blue ammonia

Merchant ammonia markets

Ammonia plant hybridisation

Methylene-urea fertilizer



Cover: Aerial drone top down photo of LNG tanker.
Aerial-motion / shutterstock.com

23

Blue ammonia

Issues to resolve over certification

48

Urea granulation

New technologies from TOYO

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NUMBER 386
NOVEMBER | DECEMBER 2023

CONTENTS

REGULARS

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56

Is a Black Sea deal back on the agenda?

> **The UN sees a return of the deal as a key means of preventing humanitarian crises ...**

While the world's attention has been grabbed by the terrible situation in the Middle East, the Russian-Ukrainian conflict continues to drag on. Of particular concern in recent months has been the deal to allow export of grain from Odessa, which lapsed in July 2023, a year after it first began. The deal had allowed 33 million tonnes of grain to be exported, around 60% of it to the developing world. However, Russia had always insisted that continuing with the deal was contingent on (a) a resumption of Russian ammonia exports via Odessa and (b) removing SWIFT payment restrictions on the Rosselkhozbank agricultural bank, allowing easier export of fertilizer. Fertilizers remain exempt from sanctions on Russia, but the difficulty in securing payment, the closure of the ammonia pipeline to the Black Sea, and high maritime insurance rates for traversing the Black Sea have made exports much more difficult. And although Ukraine continues to export grain, now mostly via rail to ports like Ismail and Reni on the River Danube, Russia has done its best to disrupt this, striking ports and warehouses and laying mines in shipping lanes. Around 300,000 tonnes of grain has been destroyed, according to Ukraine, as well as up to three ships hit by mines and one possibly by a missile on November 8th. Furthermore, bottlenecks in rail transit and port capacity and the difficulty in getting ships to the ports mean that actual volumes of grain exported are considerably reduced, with only around 700,000 tonnes exported via the Danube Ports from August to the start of November.

The absence of exports continues to weigh on global food markets, especially in developing countries, and the World Food Programme has warned that expensive fertilizer and grain is leading to a growing global food crisis in many developing countries which had previously relied upon grain and fertilizer shipments from Ukraine and Russia. Consequently, since the collapse of the deal, the United Nations appears to have been engaged over the past few weeks and months in intensive closed-door negotiations with both parties aimed at meeting Russia's concerns, particularly on ammonia shipments, in order to get the grain flowing again. The UN sees a return of the deal as a key means of preventing humanitarian crises in parts of the developing world due to high food prices. A delegation of African countries also visited Russia at the end of July to press for a resumption of exports. The proposed deal as reported by Reuters would see Russia's Uralchem able to ship 2 million t/a of ammonia to Yuzhnyy, near Odessa, where it would be bought and onward distributed by US trading firm Trammo (formerly Transammonia Inc). The return of Russian ammonia shipments would help calm fertilizer markets, which have been volatile and prices often high due to European gas prices.

The parties have reportedly been tantalisingly close to a deal at various points, though both sides have used incidents in the conflict, from a strike on the Kerch Bridge to attacks on ports to back off from a final agreement, and there are reported ongoing disagreements on the financial sanctions and the return of Ukrainian detainees. On November 8th, Russian foreign minister Sergei Lavrov said that there was "no sign" of a deal, and on the same day UN Secretary General Antonio Guterres said that achieving a deal would be "difficult". However, both sides stand to benefit from a resumption of Black Sea grain and fertilizer trade, not to mention the wider world. With winter approaching, and the potential for gas price curtailments in European ammonia production on the cards again, there will be many hoping that an export deal can be revived. ■

Richard Hands, Editor

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56

Price Trends

Market Insight courtesy of Argus Media

NITROGEN

A $50/t rise to the Tampa ammonia contract for November has kept the near-term outlook relatively stable, and price ranges are narrowing across most regions with sellers unable to achieve prices above last done business. The Tampa settlement brought the region more in line with European delivered prices, but a lack of demand is underpinning most import regions, and weighing on price negotiations for spot cargoes.

Industrial demand for ammonia remains below average in Asia, Europe and the Americas, but this is being cancelled out by additional seasonal demand from the fertilizer sector. Supply is steadily improving in key supply regions, apart from Algeria, keeping buyers out of the market, anticipating lower prices in December.

Recent market drivers include Tampa price rises: Yara and Mosaic's Tampa monthly contract price was announced at a $50/t increase for November, settling at $625/t c.fr. This nets back to $575-580/t f.o.b. Caribbean. Meanwhile Pupuk Indonesia is looking to issue a sales tender at the end of October/start of November. The spread between European production costs and import prices remains relatively narrow, but no fresh curtailments in Northwest European ammonia production have been confirmed yet in the region.

China domestic ammonia prices have risen. Further exports are unlikely in the near term, as a surge in Chinese domestic ammonia prices limits fresh offers, and supply improves in southeast Asia. The December outlook is pointing towards lower prices as seasonal fertilizer demand wanes and buyers wind down stocks ahead of the end of the year.

Urea prices fell again in most regions in late October as limited import demand - except from India - weighed on the global balance. India secured 1.7 million tonnes of urea under IPL's 20 October tender at $400-404/t c.fr, with low demand in other regions and high producer inventories driving some suppliers to accept lower netbacks than they had previously hoped for.

Prices in the other major import markets generally fell. Brazil mostly traded in small lots and oscillated between $390-405/t c.fr, while US prices slipped and Europe was almost silent.

Recent market drivers include Chinese export controls; ambiguity in the intensity of the restrictions on urea exports from China, particularly those to India, and this continues to cause uncertainty in the market.

Barring any shocks from outside the market, cautious importer buying patterns seem set to continue, which should limit the extent and duration of any price rally. But strong sales commitments to India and impending rise in European and Brazilian demand should limit the downside risk to prices.

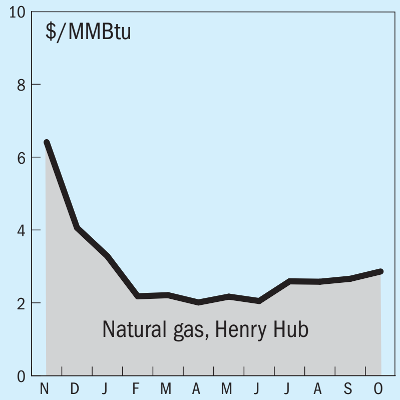
Table 1: **Price indications**

Cash equivalent	**mid-Oct**	**mid-Aug**	**mid-Jun**	**mid-Apr**
Ammonia ($/t)				
f.o.b. Black Sea	n.m.	n.m.	n.m.	n.m.
f.o.b. Caribbean	525-575	260-310	270-340	330-400
f.o.b. Arab Gulf	445-550	290-320	210-260	250-320
c.fr N.W. Europe	620-680	380-410	355-365	385-410
Urea ($/t)				
f.o.b. bulk Black Sea	320-390	340-400	220-285	250-335
f.o.b. bulk Arab Gulf*	340-405	346-400	240-316	300-375
f.o.b. NOLA barge (metric tonnes)	370-418	390-400	294-310	360-385
f.o.b. bagged China	365-405	370-395	270-340	330-370
DAP ($/t)				
f.o.b. bulk US Gulf	550-589	573-600	468-506	627-699
UAN (€/tonne)				
f.o.t. ex-tank Rouen, 30%N	284-315	302-324	253-283	275-310

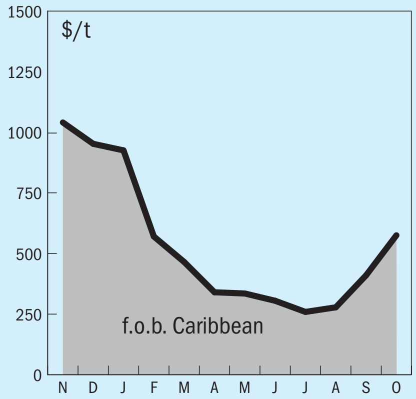
*Notes: n.a. price not available at time of going to press. n.m. no market. * high-end granular.*

END OF MONTH SPOT PRICES

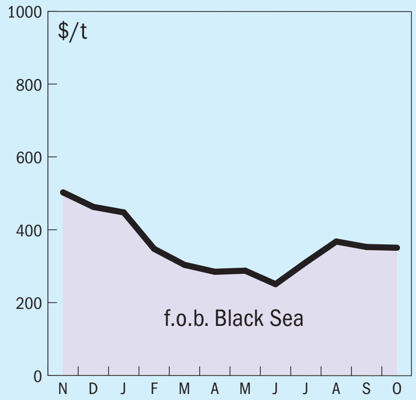
natural gas



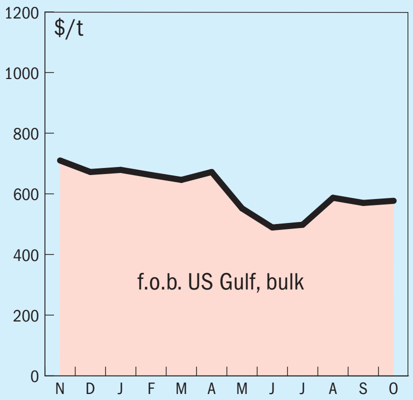
ammonia



urea

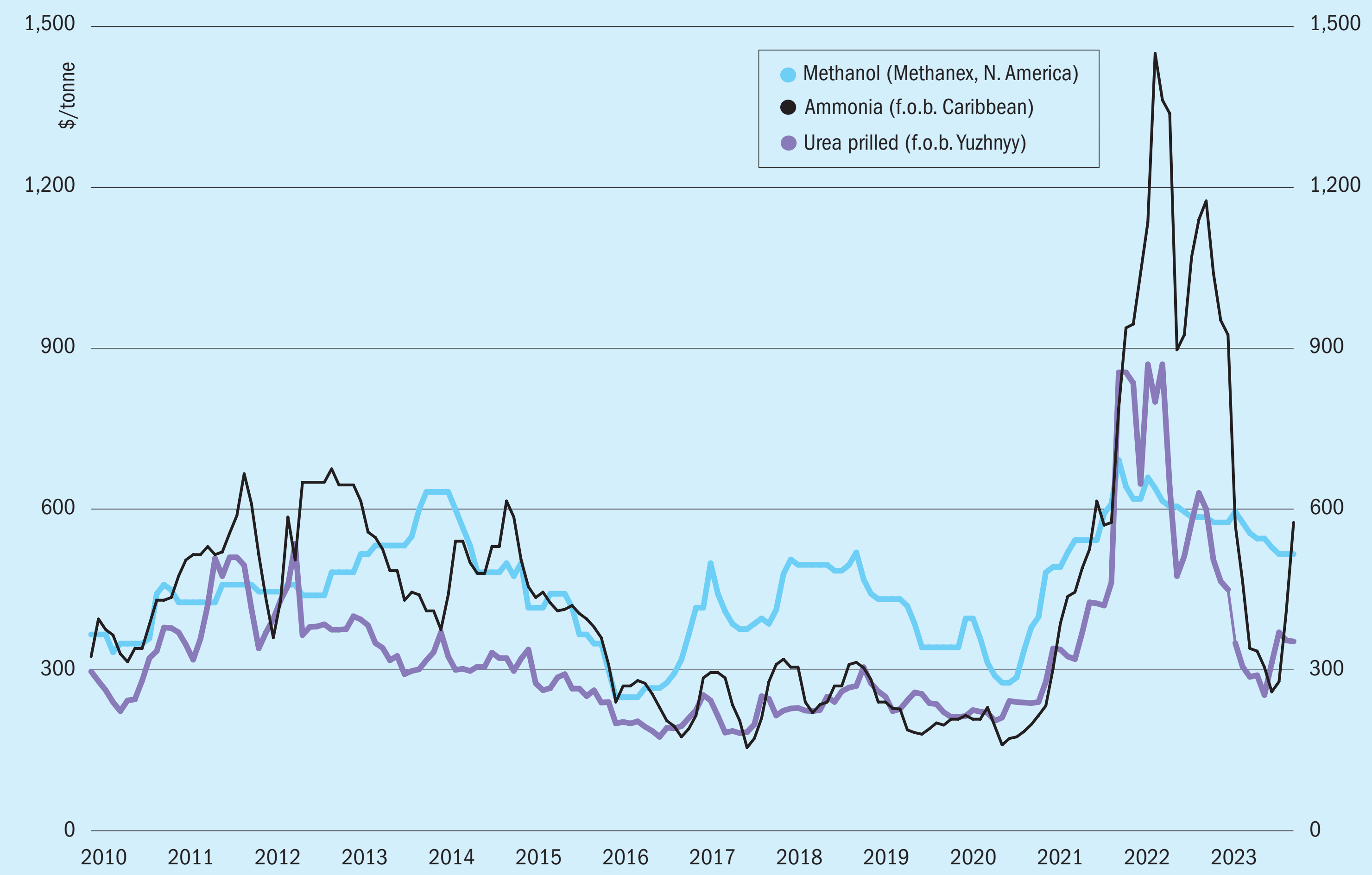


diammonium phosphate



Market Outlook

Historical price trends $/tonne



Source: BCInsight

AMMONIA

- Tampa ammonia contract prices increased dramatically during September, from \$395/tonne c.fr to \$575/tonne c.fr. The main culprit was plant outages and reduced production at several plants in the region. The tight supply situation was exacerbated by a delay to the restart of Ma'aden's 1.1 million t/a ammonia plant in Saudi Arabia.
- Tampa prices firmed further for November, up to \$625/t c.fr., but this was running against the grain of prices elsewhere. The restart of Ma'aden led to lower prices in the Middle East. Dutch TTF gas prices have been much lower than for the same period last year, easing pressure on European producers.
- Indian ammonia imports year to date have been about 20% higher than their value for last year, but this has been more than matched by a doubling in Chinese exports to 590,000 tonnes to end Q3.

UREA

- India's IPL has been busy in import markets, with 1.1 million tonnes secured for September, mainly from China. China appears to be adequately supplied now and able to export significant volumes in spite of customs inspection rules designed to reduce exports and force producers to preferentially serve domestic markets. In spite of a run-up in prices from around June/July, additional Chinese supply is likely to cap prices at close to Chinese domestic prices. China exported 2.8 million tonnes of urea to end Sept 2023, compared to 1.6 million t/a for the same period last year.
- Indian imports are overall slightly up on last year, but uncertainty remains about how much more they will need to buy.
- Sluggish demand in Europe has forced producers in Nigeria and Egypt to accept lower prices for cargoes into South America.

METHANOL

- The Brent crude oil spot price increased during September to an average of \$94/bbl, before falling below \$90 per barrel during the first week of October. However, continuing production restrictions by OPEC+ indicate that forecast crude oil prices will rise over the coming months, and therefore likely higher methanol prices in the short term.
- Methanex's new gas supply arrangement with Trinidad will effectively remove almost 200,000 t/a of capacity from the island, though the company is close to completing its 1.8 million t/a Geismar 3 methanol plant in Louisiana, with operations expected to begin before the end of the year.
- Most methanol markets saw fairly stable prices during August and September, but prices began to climb again in most major markets in October. The European Q4 contract price rolled over from Q3 at euro 360/tonne. ■

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56

Nitrogen Industry News

UNITED STATES

New blue ammonia plants

Proman has signed a memorandum of understanding (MoU) with Mitsubishi Corp to collaborate on the development of a blue ammonia plant at Lake Charles, Louisiana. This new facility will aim to produce around 1.2 million t/a of low carbon ammonia, making it one of the largest of its kind in the world. The plant will incorporate carbon capture and sequestration technology. Proman says that this development aligns with the company's commitment to sustainability and reducing greenhouse gas emissions. The proposed ammonia plant will be located at Proman's existing site in Lake Charles, adjacent to its gas-to-methanol plant, which is also currently being developed.

The signing ceremony took place at the Third International Conference on Fuel Ammonia (CFA), which was organized by Japan's Ministry of Economy, Trade, and Industry. Mitsubishi is interested in offtake of the ammonia from the plant for export to Japan as a fuel, in order to reduce emissions from coal-fired power plants.

CF Industries is also looking at a joint venture blue ammonia plant in partnership with the Korean steelmaker Posco Holdings at CF's Blue Point Complex in nearby Ascension Parish, Louisiana. The plant will use an autothermal reformer to make the hydrogen needed for the ammonia from natural gas, and the carbon dioxide emissions will be captured and stored; Posco will use the ammonia for fuel in its coal-fired power facilities in South Korea. It also plans to convert ammonia into hydrogen for use in power plants and directly in the steelmaking process.

Inpex, Japan's top oil and gas producer, has also recently begun a feasibility study into developing low-carbon ammonia production on the Houston Ship Channel in the United States. As with the two projects above, it is part of Japan's plans to reduce emissions by mixing ammonia with coal to fire power plants and for use in other industries. Inpex said that it and three other project partners would work on the pre-front-end engineering design (pre-FEED) for the U.S. project, which would aim to produce over 1.1 million t/a of low-carbon ammonia per year by the end of 2027 in its first phase. ■

CF Industries to expand nitric acid production

CF Industries also says that it plans to modify its number 3 the nitric acid plant and diesel exhaust fluid (DEF) Unit to increase production of both merchant-grade nitric acid and DEF. The nitric acid plant improvements include adding an air chiller to cool the process air supplied to the unit, which, together with other upgrades, will allow the production of 65% nitric acid, rather than the 60% strength produced today. The DEF production enhancements include the addition of a demineralised water storage tank, additional process analysers, and pumping system upgrades to allow increased production. A nitric acid storage tank, product pumps, and a DEF rail loading facility will be included, as these are required to store and ship the additional product. The total investment in this expansion is around $75 million. The project is set to start in early 2024 and be completed by end of 2025.

KBR partners with electrolysis technology company

KBR, Inc. has signed a memorandum of understanding with renewable energy company SolydEra. The strategic partnership aims to offer an integrated solution for producing cost-effective clean ammonia using renewable energy sources. Under the terms of the MoU, KBR will incorporate SolydEra's solid oxide electrolysis (SOE) technology into its proprietary K-GreeN process with a key focus on achieving competitive levelised costs for carbon-neutral ammonia production. KBR says that it hopes to drive the cost efficiencies necessary to position clean ammonia as a competitive alternative energy source.

BELGIUM

Ammonia engines for new gas carrier vessels

EXMAR LPG BV, a joint venture between EXMAR and Seapeak, will use ammonia as fuel for its two new mid-size gas carriers (MGCs), currently on order at the Hyundai Mipo Dockyard in South Korea. The ships will be the first ever ocean-going vessels to be propelled by dual-fuel ammonia engines, allowing for close to zero emissions trading when using ammonia. The engines will be delivered by WINGD and the fuel supply system by Wärtsilä Gas Solutions. The 46,000 m3 MGCs are scheduled for delivery in early 2026.

"As leading global transporters of ammonia, we are proud to be developing vessels with an operational carbon footprint reduction of 90%, which significantly exceeds the International Maritime Organization (IMO)'s emissions reduction targets. This is possible thanks to the decades of experience of EXMAR's operational and technical teams, and the joint effort and contribution of all our project partners," said Carl-Antoine Saverys, Executive Director at EXMAR.

Throughout the design and development phase of the vessels, close attention has been given to operational safety due to ammonia's potential toxicity, using a risk-based design appraisal conducted by classification society Lloyds Register, combined with input from experienced crews.

DENMARK

Sumitomo to partner Skovgaard Energy for green ammonia production

Sumitomo has signed a letter of intent with Danish renewable energy developer Skovgaard Energy for future collaboration in green ammonia production. Skovgaard is constructing a flexible green ammonia plant powered directly by 100% wind and photovoltaic power to demonstrate that ammonia synthesis can work as a potential energy storage technology without intermediate hydrogen storage. It is funded by the Danish Energy Technology Development and Demonstration Programme (EUDP), which has Topsoe and Vestas as project partners. The plant will be in Ramme, near Lemvig, Jutland, with an annual production of 5,000 t/a of green ammonia. Power will be supplied from 50 MW of solar panels and 12 MW of wind turbines. The project is based on a flexible renewable ammonia production technology eliminating energy storage capacities such as batteries or water reservoirs. First production is slated for Q2 2024.

"We look forward to collaborating with Skovgaard Energy, which we consider highly competent in their field. Located in

Europe's hotspot for the green transition with great wind and solar resources, state-of-the-art infrastructure and backup by local stakeholders, it is obvious for us to begin our journey in this field here," said Head of Energy Innovation Initiative, Ko Akiyama, from Sumitomo Corporation Europe Limited.

"We are thrilled to be at the forefront of this transformative project that combines renewable energy and green ammonia production. By replacing natural gas with green electricity, we can help farmers and vessel operators reduce their carbon footprint and secure more stable food and fuel prices. The flexible ammonia production technology setup is a significant step forward for democratising access to cheap, green ammonia. Together with Sumitomo we will have both resources and competencies for future upscaled projects," said Chief Sales Officer Bjarke Mollerup Bitsch from Skovgaard Energy.

UNITED ARAB EMIRATES

Fertiglobe signs MoU with AD Ports Group

Fertiglobe, the strategic partnership between ADNOC and OCI Global has signed a non-binding memorandum of understanding (MoU) with AD Ports Group to explore logistics and supply chain opportunities for storing and shipping urea and ammonia at ports in Egypt and the UAE. The two companies say that they will explore opportunities to leverage AD Ports Group's state-of-the-art cargo handling and storage infrastructure, as Fertiglobe strengthens its urea and ammonia storage and shipping capabilities, reduces its greenhouse gas (GHG) footprint, enhances operational efficiency and further automates its logistical activities. Fertiglobe is the world's largest seaborne exporter of urea and ammonia combined, the largest nitrogen fertilizer producer in the Middle East and North Africa (MENA) region, and an early mover in sustainable ammonia.

Ahmed El-Hoshy, CEO of Fertiglobe, commented: "We are pleased to partner with AD Ports Group, a UAE national champion and a global leader in maritime trade and logistics. Through this MoU we will identify compelling opportunities across our logistics and supply chain management requirements, enabling us to bolster our ability to store and ship urea and ammonia from Egypt and further optimize our logistics' cost structure. Today, our strategically located production facilities benefit from direct access to international ports and distribution hubs, allowing us to easily access major end-markets and regions with high demand. This MoU will enable us to expand our partnership beyond Egypt and the UAE, as well as to the shipping and storage of green ammonia, in line with our commitment to deliver more sustainable products to the world."

The companies say that they will explore potential collaboration opportunities in other geographies as well as the development of supply chain solutions for green ammonia, a hydrogen carrier, with Fertiglobe's existing operations strategically located near key shipping routes.

Fertiglobe also announced recently that it will instal a 10 t/d carbon capture unit manufactured by UK-based Carbon Clean at its ammonia plant at Ruwais. The installation will be carried out by Fertiglobe partner ADNOC.

ADNOC to build direct air capture unit

ADNOC has signed a deal with Occidental for a feasibility study on a large scale direct air capture (DAC) plant, the first outside the US. The study will assess the proposed 1.0 million t/a facility, which would be connected to ADNOC's pipeline dioxide infrastructure for injection and permanent storage into saline reservoirs not used for oil and gas production. The agreement is the first project to reach a technical feasibility stage since ADNOC and Occidental signed a strategic collaboration agreement in August to explore carbon capture, utilisation and storage (CCUS) projects in the UAE and the US.

Musabbeh Al Kaabi, executive director for low carbon solutions and international growth at ADNOC, said; "This joint investment in the proposed first megaton direct air capture facility in the region exemplifies our commitment to leverage partnerships and promising technology to accelerate our decarbonisation journey on the way to net zero by 2045." ADNOC recently revised its plans to reach net-zero emissions by 2045, from an original target of 2050. The company also aims to achieve zero methane emissions by the end of the decade.

PHOTO: ADNOC

ADNOC's urea plant at Ruwais

SOUTH AFRICA

Green ammonia plant proposal

Solar power producer Phelan Green Energy says that it intends to invest $2.5 billion in constructing a green hydrogen and ammonia plant in South Africa's Western Cape province. Phelan subsidiary Solar Capital will oversee the facility, known as the Saldanha Green Hydrogen Project. The complex could begin initial production in early 2026, with a final investment decision in 3Q 2024.

Paschal Phelan, chairman of Phelan Green, stated, "The launch of our Saldanha Green Hydrogen Project is… a testament to our team's unwavering dedication to shaping South Africa's energy future and our commitment to introducing sustainable innovations to the global market."

CHINA

Eurotecnica to license world's largest melamine plant

Melamine technology design and licensing company Eurotecnica, part of the Proman family of companies, a says that it has been awarded a contract for the implementation of the world's largest melamine plant, with a nameplate capacity of 160,000 t/a. Xinjiang Xinlianxin Energy Chemical Co., Ltd. (XLX) has selected Eurotecnica's 5th generation (G5) Euromel® melamine technology for the design and implementation of this project. Once commissioned, this plant will increase XLX's total capacity to 1,000 t/d of melamine, a record for the industry. Eurotecnica says that it has now licensed 28 melamine plants worldwide, with a combined capacity of 1.3 million t/a.

"We are extremely proud of this contract which sets a new standard for the melamine industry reinforcing Euromel's superior features. We are delighted to be working with XLX for the third time and for their trust and confidence in us and our technology. We launched the 5th generation of Euromel this year and it continues to deliver best-in-class energy efficiency," says Alberto De Amicis, Eurotecnica Managing Director.

Stamicarbon licenses low energy urea plant

Shandong Lianmeng Chemical Company has awarded licensing and equipment supply contracts for a grassroots urea melt and prilling plant in China to Stamicarbon, the nitrogen technology licensor of Maire Group. The plant, to be sited in Shouguang, Shandong province, will use Stamicarbon's Ultra-Low Energy design with a highly efficient pool reactor concept and have a capacity of 2,334 t/d. Stamicarbon will provide the license, proprietary equipment, including high-pressure equipment made of super duplex stainless steel and associated services. This grassroots project will be the eighth urea plant worldwide to use Stamicarbon's Ultra-Low Energy design, which allows heat supplied as high-pressure steam to be used three times instead of two, compared to the conventional CO_2 stripping processes. This results in a 35% reduction in steam consumption and a 16% decrease in cooling water use.

"We're excited to launch a project using our Ultra-Low Energy design, which has shown itself to be the top choice for energy efficiency and sustainability in urea production. With this project, we are further expanding our footprint in China, aiming to address the region's growing demand for urea," said Pejman Djavdan, Stamicarbon CEO.

INDIA

Costs rising for coal-based ammonia plant

Rising costs for the Talcher Fertilizers plant in Odisha have necessitated a fresh cash injection by the project partners. State owned companies Coal India Ltd, Gas Association of India Ltd (GAIL), and Rashtriya Chemicals and Fertilizers (RCF), will invest a total of $372 million in the fertiliser joint venture. Each of the three companies has a 31.85% stake in Talcher Fertilizers. The long-delayed project is aimed at building a new coal-fired urea plant with a capacity of 1.27 million t/a to help defray Indian imports of urea.

Deepak selects KBR for Smart Factory project

KBR has been awarded a multi-year service contract by Deepak Fertilisers and Petrochemicals Corp. Ltd for the development of their 'Smart Factory' project. This contract will cover the operations of four nitric acid plants at Dahej and Taloja. KBR will design and deploy real-time monitoring and diagnostics, first-principles modelling, artificial intelligence and machine learning, and advanced process control to optimise plant operations. These digital solutions will deliver decision support and automation, improving energy efficiency and deriving greater value from existing assets.

ROMANIA

Azomures resumes ammonia production

Fertiliser producer Azomures restarted production at its Ammonia III facility in October at 50% capacity. The restart is a result of signing a new natural gas supply contract. Gas prices have forced shutdowns of the plant several times in recent years; in December 2021, and then June 2022 after production had resumed in April. In September 2022 Azomures, which is owned by Swiss agribusiness group Ameropa, laid off 200 staff leaving 960 working at its Targu Mures site, where it has 1.6 million t/a of capacity for ammonium nitrate, CAN and NPK production. Josh Zacharis, CEO of Azomures, said that the company's intention is to maintain ammonia production for "as long as conditions allow".

AUSTRALIA

Engineering work begins on green hydrogen plant

Técnicas Reunidas has agreed with Allied Green Ammonia to begin the basic engineering and design phases of a hydrogen and green ammonia production facility in the country's Northern Territory, a plant that, if financial closure is completed, could be commissioned in 2028. Total investment is estimated at about A$8.5 billion (US$5.4 billion). The plant would produce 165,000 t/a of green hydrogen, which would in turn be used to generate 912,500 t/a of green ammonia. If the negotiations with industrial companies and investment funds that are currently underway confirm the financial closure of the project, the detailed engineering phases and the material execution of the plant would be undertaken through an engineering, procurement and construction management contract.

JORDAN

Feasibility study for green hydrogen project

Jordan's Ministry of Energy and Mineral Resources has signed a memorandum of understanding (MoU) with the Jordan Green Ammonia Company (JGA). The aim is to initiate a year-long preliminary feasibility study, which will lay the groundwork for a green hydrogen project. Should the study yield promising results, the ministry says it will move forward with a formal framework agreement, ultimately culminating in a final investment agreement.

DENMARK

Topsoe to collaborate on nuclear hydrogen production

Topsoe has signed a memorandum of intent with ULC-Energy and Rolls-Royce SMR to jointly investigate the production of hydrogen using Topsoe's solid oxide electrolysis cell (SOEC) technology in conjunction with the electricity and heat produced from a Rolls-Royce small modular reactor (SMR) nuclear power plant. The partners will also prepare a valuation of the operational flexibility of the Rolls-Royce SMR/Topsoe SOEC combination in a future energy market based primarily on renewable energy. Initially, the companies are looking at a conceptual study to demonstrate synergies between SMR and SOEC. Hydrogen produced based on nuclear power has significantly lower carbon intensity compared to conventional hydrogen and can therefore contribute to lowering global greenhouse gas emissions in heavy-industry and long-distance transportation.

Sundus Cordelia Ramli, CCO Power-to-X, at Topsoe said: "We're excited to investigate the potential of hydrogen from nuclear SMR's and our SOEC electrolysis technology together with ULC-Energy and Rolls-Royce SMR. With our SOEC technology, we can produce more hydrogen relative to renewable power when compared to competing electrolysis technologies. To enable net zero by 2050, we need to look into all possible technologies, and we're confident that our electrolysis technology will be one of the key components in the race for net-zero."

Nuclear energy combined with SOEC technology has the potential to produce hydrogen more cheaply than alternative electrolysis processes because: (a) The electrolysis takes place at a high temperature, which means that less electricity is needed to produce hydrogen; (b) the nuclear power plants can produce energy on average up to 95% of the time, significantly higher than alternative variable energy sources; and (c) nuclear energy can supply heat as well as electricity. By using heat directly, energy losses in the steam turbine can be avoided, thus increasing the effective energy capacity of the nuclear power plant above its electric power rating.

The SMR nuclear power plant can also, when required, switch to deliver power to the grid, providing back-up to variable power sources when these sources are not available. This is expected to be a competitive solution compared to alternatives, like long duration energy storage solutions or hydrogen combustion for electricity generation.

Wael Suleiman, CEO of JGA, said that Jordan's strategic geographical location and the abundance of solar energy resources at its disposal were a compelling commercial case. "Today's signing ceremony is a symbol of Jordan's resolute determination to harness its abundant renewable energy resources. Our MoU serves as the blueprint for the collaborative efforts between private sector entities and the government to expand the potential of green hydrogen," he said.

MOROCCO

OCP secures loan for low carbon fertilizer production

State-owned phosphates and fertiliser producer OCP has signed an agreement with the International Finance Corporation (IFC), the World Bank's investment arm, for a $106 million loan to build two solar power plants to increase production of low-carbon fertilizers. The two photovoltaic plants will be located in the mining areas of Khouribga and Benguerir with a combined capacity of 400 MW and a storage capacity of up to 100 MWh, OCP said in a statement. The loan is the second offered by the IFC to OCP within a year after a similar $100 million loan last April to build four plants with a combined capacity of 200 MW in the same mining areas. Last year, OCP announced an investment plan worth $13 billion to fully rely on renewable energies for its fertiliser production by 2027, including investing $7 billion in an ammonia plant using green hydrogen.

NEPAL

Feasibility study on green CAN plant

The Investment Board of Nepal has signed a memorandum of understanding with Malaysian company reNIKOLA Sdn Bhd to prepare a detailed feasibility study on the establishment of a green calcium ammonium nitrate fertiliser plant in Nepal. The proposed project at Abukhaireni, Tanahun is estimated to cost $260 million, and would produce 95,600 t/a of green ammonia and 286,975 t/a of green calcium ammonium nitrate.

INDONESIA

Pusri to build new urea plant

Pupuk Sriwidjaja Palembang (Pusri), a subsidiary of state-owned Pupuk Indonesia, has signed off on funding and agreed the engineering procurement and construction (EPC) contract to build its new Pusri-IIIB ammonia and urea plant at the company's existing site at Palembang, south Sumatra. The plant capacity will be 1,350 t/d (445,000 t/a) of ammonia, and 2,750 t/d (907,500 t/a) of urea, using technology licensed from KBR and Toyo respectively. Wuhuan Engineering and Adhi Karya will perform the construction works, with funding carried out through a syndicate of eight state-owned and private-sector companies. President of Pupuk Indonesia, Rahmad Pribadi, said that Pusri-IIIB will use the latest production technology to increase the reliability of fertilizer production. The plant will replace the existing Pusri 3 and 4 plants, which are less efficient in terms of gas consumption.

ZIMBABWE

Zimbabwe suspends import tax on fertilizer

The government of Zimbabwe has suspended duty on fertilizer imports allowing approved and regulated traders to bring in fertilizer duty-free to ensure adequate supplies locally. Up to 250,000 tonnes of urea and ammonium nitrate will be licensed for import. The Minister for Agriculture has approved a list of fertilizer importers for the purposes of these regulations and licensed the importers so they could then deal with tax authority Zimra. Local producers Sable Chemicals and Chemplex will also be given access to contracts to supply state assisted farming programmes to boost local production and cut imports. Sable Chemicals produces ammonium nitrate using ammonia imported from South Africa and Chemplex produces phosphates using imported sulphuric acid. Zimbabwe has seen a 30% increase in domestic fertilizer prices over the past two years due to high international prices.

AUSTRALIA

Funding boost for green hydrogen hub

The government of New South Wales has signed a $45 million funding agreement to build the Hunter Valley Hydrogen Hub

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on Kooragang Island to assist emissions intensive industries to reduce their reliance on fossil fuels. The project, led by Origin Future Fuels (Origin), will be a regional cornerstone of the hydrogen industry, producing green hydrogen through electrolysis to store energy and as a feedstock in industrial processes. The Hub will initially deliver approximately 55 MW of electrolyser capacity by 2026, with an aim to scale up to over 1 GW of capacity over the next decade.

The hydrogen produced by the Hub will be used by industry, with the majority going to Orica's nearby ammonia plant to help decarbonise its operations. Hydrogen will also be made available to transport customers through onsite and satellite refuelling stations.

BRAZIL

Croatia to import green ammonia from Brazil

Project developer Green Energy Park (GEP) says that it intends to build a renewable ammonia facility in Brazil for export to its planned 10 million t/a import terminal on the Croatian island of Krk. GEP plans a plant that could produce 1 million t/a of ammonia from around 5GW renewable power generation capacity in the northeast Brazilian state of Piaui, in the special economic zone of Luis Correia, where the state's first major port is scheduled to open in December with a view to facilitating exports to European markets. Ammonia from the site would be shipped to the Krk ammonia import terminal, which GEP first announced last month.

MEXICO

Financial closure for large-scale ammonia plant

Proman has achieved financial closure for its planned 2200 t/d ammonia plant in Topolobampo, Sinaloa state. The plant is being financed via German state owned investment and development bank Kreditanstalt für Wiederaufbau (KFW). Proman has engaged thyssenkrupp Uhde to develop the project. Uhde will provide engineering and procurement services in addition to the uhde® ammonia technology license and proprietary equipment.

The project has taken several years to realise due to environmental concerns over the development, and spent two years on hiatus after a Sinaloa court ruling overturned a previous environmental approval in order to allow for consultation with local indigenous communities, although a local referendum showed that there was 76% approval by local residents for the development. However, it has now cleared these hurdles and is moving ahead. Sinaloa is an agricultural state on the western coast of Mexico known as 'Mexico's breadbasket', with considerable demand for fertilizer locally, but domestic ammonia and urea production in Mexico, mostly at Cosoleacaque on the southeast coast, has been idled because of gas pricing and availability. However, the development of new gas fields in the northwest of Mexico has made the Sinaloa plant a realistic possibility.

David Cassidy, Chief Executive of Proman, which owns and operates significant ammonia and methanol capacity, mainly on Trinidad, said: "Proman is excited to be expanding into Mexico. We are already a significant producer of ammonia, and this new plant will increase our annual production capacity to 2.8 million t/a at a time when fertilizers have a critical role to play in the agricultural sector in Mexico and for global food security. We have built strong relationships with local stakeholders and communities and look forward to a long-term future in Mexico."

IVORY COAST

Yara to divest local operations

Yara International has divested its fertilizer import and distribution subsidiary in Ivory Coast. Yara says that the move followed a thorough analysis of its operations, considering market dynamics, the regulatory environment, and strategic growth opportunities. This evaluation has led to the decision to divest its position in Ivory Coast, allowing the reallocation of resources and investments towards other countries in Africa which offer a higher potential for the successful implementation of Yara's 2030 Africa Food Systems Transformation strategy.

Luis Alfredo Pérez, SVP Yara Africa said: "The decision to divest is driven by the acknowledgment that Yara's ambition to become a true leader in the Food Systems Transformation in Africa can only be reached in a phased approach. A necessary first step is to… prioritise those specific crops and regional segments offering the highest opportunity to establish closed-loop partnerships, which will secure a sustainable improvement in the sub-Saharan smallholder farmer's productivity and profitability."

NORWAY

Horisont signs letter of intent for Barents Blue ammonia offtake

Horisont Energi has signed a letter of intent with German energy company VNG Handel & Vertrieb GmbH (VNG) for the offtake of blue ammonia from the Barents Blue project in Hammerfest in Northern Norway – Europe´s largest low carbon ammonia plant project. VNG H&V intends to make the ammonia available to its customers, particularly in the industrial sector, either directly or in the form of hydrogen. The agreement sets out a long-term partnership for clean ammonia supply targeting a quantity of 100,000-300,000 t/a starting from 2028, corresponding to 10%-30% of the capacity at the planned Barents Blue plant.

"The agreement with VNG marks another leap forward in the development of Barents Blue as Europe's largest clean ammonia plant to meet the surging demand for clean ammonia and hydrogen. We are also adding another strong new German partner as we continue to build a clean ammonia value chain and are delighted to have joined forces with a highly competent organization and dedicated team", said Bjørgulf Haukelidsæter Eidesen, CEO Horisont Energi.

"With this agreement, we are strengthening the German-Norwegian partnership in the energy sector. At the same time, we are taking another important step towards driving forward the decarbonisation of Germany. The demand for blue ammonia will multiply in the coming decades, both as a hydrogen carrier and to decarbonise fertilisers, shipping, and other industries," added Ulf Heitmüller, CEO of VNG AG.

Combined with the Polaris CCS project, Barents Blue will offer blue ammonia with a 99% CO_2 capture rate and a correspondingly low carbon footprint compared to conventional production. Horisont Energi targets a final investment decision for the 1.0 million t/a plant in 2024/2025, with estimated production starting in 2028. Horisont has also recently signed a joint development agreement with Spanish fertilizer producer Fertiberia for the Barents Blue project, and announced in September that PIGNiG Upstream Norway intends to join Horisont Energi as an operating partner in the Polaris CCS storage license. The plan is for Polaris to offer the Barents Blue CO_2 storage for its captured carbon.

PHOTO: YARA

Computer rendering of the new ammonia container ship.

Ammonia-fuelled container ship

Yara Clean Ammonia and NorthSea Container Line are establishing a joint venture, NCL Oslofjord, to build a new container ship, which will be the world's first to use pure ammonia as fuel. The Yara Eyde will serve on routes between Oslo and Brevik in Norway and Hamburg and Bremerhaven in Germany from 2026. The project has been awarded $3.6 million from Enova, a Norwegian government enterprise promoting clean energy technologies.

Yara Clean Ammonia will supply the ship with low carbon ammonia. Together with Azane Fuel Solutions, a storage and bunkering network is being developed to make pure ammonia available in Norwegian and eventually Scandinavian ports. The bunkering network can also contribute to achieving Norway's goal of cutting emissions from the offshore sector. Enova and Innovation Norway are also supporting one of the barges planned to supply the Yara Eyde with low-emission fuel in Brevik.

"Ammonia as a fuel does not pollute. When we produce ammonia from renewable energy or with natural gas where up to 95% of the CO_2 emissions are captured and stored permanently, pure ammonia will quickly be a good solution for cutting carbon emissions in the maritime sector," said Magnus Krogh Ankarstrand, head of Yara Clean Ammonia. "Yara Eyde will demonstrate the maturity of ammonia as a maritime fuel."

"We see there is increasing demand from product owners to reduce emissions," said Bente Hetland, CEO of North Sea Container Line. "The ship offers competitive and emission-free logistics to all cargo owners in the Oslofjord and the Greenland region."

Svein Tore Holsether, CEO of Yara International, said, "As a direct continuation of the green logistics with Yara Birkeland, the ammonia-powered ship Yara Eyde will extend the zero-emission value chain from Brevik to ports on the continent. With an emission-free sea journey from Brevik to Europe, Yara scope 3 removes emissions by 11,000 tonnes of CO_2 per year."

BANGLADESH

New urea plant inaugurated

Prime Minister Sheikh Hasina has inaugurated Bangladesh's new Ghorashal-Polash Urea Fertilizer Project. Construction of the ammonia-urea plant started in 2020, conducted by the China National Chemical Engineering & Construction Corporation Seven Ltd., in collaboration with Japanese partner Mitsubishi Heavy Industries (MHI), and was due to have been completed in June 2022, but was delayed by the covid pandemic. The plant, located in Narsingdi district, 51 km northeast of the capital city of Dhaka, has a capacity of 500,000 t/a of ammonia and 800,000 t/a of granular urea, and cost an estimated $1.2 billion. Speaking at the launch ceremony, Hasina said it is Bangladesh's first fertilizer plant capable of capturing carbon dioxide, feeding it back into urea production and boosting the plant's output by 10%.

AFRICA

Proton to develop green ammonia terminal in Western Africa

Dutch ammonia contractor Proton Ventures and Belgian tank specialist Geldof have been awarded a front-end engineering design (FEED) contract for what is said to be the first green ammonia terminal in Western Africa. Proton Ventures said that the project marks a significant step towards exporting green ammonia from Western Africa to the world, noting that the terminal will be located near major shipping trade lanes, making it an ideal spot for the production of renewable energy. Furthermore, it is said to hold potential for competitive green electricity sourcing.

The facility will feature a full containment ammonia storage tank connected to an existing jetty, simplifying the loading and unloading processes and streamlining operations, according to Proton. It will also include dedicated rail and truck-loading facilities, and a refrigeration system designed to swiftly manage the boil-off gas and (un-)load ammonia gas carriers, providing independent operations. High-flow rate pumps and utilities will support ammonia handling processes, while an emergency-only flare system for the safe disposal of gases will guarantee the highest safety measures and lowest emissions.

CHINA

Jiangsu Sailboat starts up CO_2-to-methanol plant

Jiangsu Sailboat Petrochemical has started up a CO_2-to-methanol plant at the Shenghong Petrochemical Industrial Park. The plant was developed in conjunction with Iceland's Carbon Recycling International (CRI), with the plant brought to life in under two years from the initial contract signing. The methanol plant uses CRI's proprietary emissions-to-liquids (ETL) technology, transforming waste carbon dioxide and hydrogen gases into sustainable, commercial-grade methanol. According to CRI, uses 150,000 t/a of carbon dioxide sourced from waste streams at the large petrochemical complex as feedstock, significantly reducing emissions that would have otherwise been released into the atmosphere. The plant has the capacity to produce 100,000 t/a of sustainable methanol, used primarily to supply Jiangsu's methanol to olefins facility to produce chemical derivatives, including sustainable plastics and EVA coatings for solar panels. This is expected to reduce the reliance on fossil-based methanol to drive more sustainable value chains and carbon footprint reduction initiatives across various sectors, such as industrial manufacturing and renewable energy.

Qian Xinhua, Vice President of Shenghong Petrochemical Industry Group, said at the plant opening ceremony: "This green industrial value chain project is a significant step forward. It uses advanced green and low-carbon technology to capture carbon dioxide and turn it into a resource. Further implementation of such technology allows us to combine green hydrogen, renewable energy and more to create new materials, replacing the traditional raw materials used in the chemical industry."

Björk Kristjánsdóttir, CEO of CRI, commented: "This milestone plant not only expands the reach of our technology into new application markets but also showcases the broad versatility and unmatched efficiency of our ETL technology, proving the viability of large-scale sustainable methanol production." ■

GERMANY

Renewable methanol for shipping

Hy2gen, has signed a memorandum of understanding with Japan's Mitsui OSK Lines Ltd to study supplying green methanol for use as a shipping fuel. Hy2Gen is a global project developer, owner, and operator of renewable hydrogen and hydrogen derivative production facilities, while Mitsui OSK is one of the world's largest shipping companies. The fuel will be produced as part of Hy2gen's NAUTILUS project, which is being developed at Friesoythe site, near the c-Port on the Kiel canal. The methanol will be generated using renewable hydrogen and CO_2 from a neighbouring biogas plant. First production at the plant is scheduled for early 2028.

Cyril Dufau-Sansot, CEO of Hy2gen, said: "We are proud to become a close partner and supplier to such a global player in the shipping industry. We are looking forward to supporting MOL with our products. The renewable methanol from Friesoythe will be important for the decarbonisation of the shipping industry worldwide."

Hydrogen tugs for Hamburg

Mabanaft has agreed with Fairplay Towage Group, one of Europe's largest tugboat operators, to supply hydrogen to their new tugs in the Port of Hamburg from 2025. Fairplay Towage intends to add tugboats to its fleet in Hamburg capable of running on hydrogen. Mabanaft Group, a supplier of marine fuels and operator of tank terminals in the Port of Hamburg, intends to supplement its range of marine fuels with hydrogen and to use its tank terminals in Hamburg for this purpose, in order to be able to supply Fairplay Towage with hydrogen. In November 2022, Mabanaft announced its intention to build an ammonia import terminal in the Port of Hamburg, the first step in the development of New Energy Gate, a terminal for sustainable hydrogen products that will make it possible for Hamburg to import large quantities of climate-friendly energy.

ESTONIA

Approval for methanol storage solution on existing ships

A new and space efficient retrofit methanol storage technology developed by Estonia's SRC Group has received Approval in Principle from Lloyd's Register, paving the way for it securing classification approval and regulatory compliance. Methanol Superstorage offers the potential for ships with years of service ahead to be considered for transition to a marine fuel established as a front runner for meeting IMO targets to cut greenhouse gas emissions from ships by at least 20% by 2030 and 70% by 2040 (against a base year of 2008). Clarksons reported that 14% of tonnage on order this year will be methanol-capable, compared to a 22% share for liquefied natural gas. The analyst has estimated that 1,200 ships could be powered by methanol by 2030.

However, while renewably-sourced methanol fits the net-zero framework, and is fairly easy to store and handle, it takes twice as much to generate the same energy as fuel oil. On board ship, this is a major storage issue, especially because low flashpoint fuel tanks conventionally require cofferdams. Although space penalties can be addressed in newbuild ship design, even the youngest existing ships were not built with retrofitting methanol in mind. Methanol Superstorage avoids cofferdams by constructing tank walls using SRC's Sandwich Plate System Technology, boosting the stored methanol volume by up to 85% with minimal impact on the general arrangement.

"Due to long-established use in other industries, availability and performance, methanol is the alternative marine fuel offering the strongest potential to reduce ship GHGs at pace," said Hannes Lilp, CEO, SRC Group. "Methanol Superstorage reinvents methanol storage using the proven SPS Technology system. Instead of a cofferdam which extends – at least - to 600mm, the solution uses a 25mm thick SPS barrier to protect the tank from fire and as a triple barrier against leakage."

EGYPT

Deal to develop green methanol plant

C2X, founded earlier this year by shipping giant Maersk and its parent company AP Moller Holdings, has signed a framework agreement with the Egyptian government to set up a $3bn hydrogen-to-marine-fuel plant in the Suez Canal Economic Zone. C2X will build, own and operate the facility, as well as the upstream wind and solar farms that will power the hydrogen production and methanol synthesis processes. The first phase is expected to produce up to 300,000 t/a of green methanol once it starts up in 2027 or 2028, with subsequent stages eventually scaling up to 1.0 million t/a. Maersk has already launched its first methanol fuelled ship, and ordered another 25 container vessels capable of running on the fuel for delivery early next year. C2X is also reportedly exploring the development of projects in Spain, the US, India and Australia, with the ambition of producing three million tonnes of green methanol a year by 2030. However, Maersk's own annual demand for the fuel will reach five million tonnes by that year.

Methanex's methanol plants, Trinidad

UNITED STATES

Beaumont plant to double green methanol production

OCI Global has announced plans to double its green methanol production capacity to approximately 400,000 t/a in response to the growing demand for green methanol from numerous high emissions industries, including road transport, shipping and industrial. The scale-up plans include entering into supply agreements for renewable natural gas exceeding 15,000 MMBtu/day, as well as securing the waste and development rights from the city of Beaumont to achieve OCI's first upstream RNG production facility with production slated to start in Q1 2025. As well as reducing carbon dioxide emissions, OCI says that obtaining biogas from landfill has the benefit of using methane – which over a 20 year period, has a global warming potential that is 84 times more potent than carbon dioxide – that would otherwise escape and accelerate global warming.

"(This) announcement cements OCI's position as the leading green methanol producer globally," Ahmed El-Hoshy, CEO, OCI Global said. "It also represents another milestone in our decarbonisation journey as a business, and our commitment to driving the energy transition. We are seeing encouraging signs with regulatory support for both ammonia and methanol in shipping, such as the EU's FuelEU maritime regulation and the latest IMO strategy bolstering the value of low carbon and green methanol and ammonia relative to fossil fuels. It is clear that both fuels will need to play an integral role to reach the IMO's revised targets and OCI Global stands ready to supply them. However, these targets must be supported by practical mechanisms to continue to maintain momentum towards meeting global greenhouse gas emissions reduction targets."

"We are seeing increasing pull from road fuel markets due to the delay in EV adoption and charging station build-out and while marine demand has been growing at a very fast pace, we have yet to see the impact of retrofits which should end up being a larger segment than new-builds," added Bashir Lebada, CEO, OCI Methanol/HyFuels. "E-methanol will also be a new product for us and, with the RFNBO mandates in the coming years, will quickly become the blendstock of choice with gasoline to ensure compliance. We are also very excited to announce the expansion of our 13-year partnership with the city of Beaumont. This landfill will bolster our product portfolio with additional green fuels right in our backyard and add to our existing supply portfolio of RNG."

TRINIDAD & TOBAGO

Methanex to switch production from Atlas to Titan

Methanex says that it plans to shut down one of its methanol plants on Trinidad and restart another one that has been idle. Methanex has signed a two-year natural gas agreement with the National Gas Company (NGC) of Trinidad and Tobago to supply its currently idled Titan methanol plant, which has the capacity to produce 875,000 t/a of methanol. With the new gas agreement, Methanex plans to restart the Titan plant in about a year from now, in September 2024. However, due to challenges in securing natural gas in the region, Methanex plans to simultaneously shut down the 1.0 million t/a Atlas plant, in which Methanex has a controlling interest (63%). Methanex says that a 20-year natural gas supply agreement for the Atlas plant expires in September 2024.

"The two-year term of the Titan contract offered by the NGC reflects the challenging near-term gas supply and demand situation in the country," Methanex CEO Rich Sumner said in a news release. "Our decision to restart Titan and cease operations at Atlas was based on economic considerations, including significantly lower capital requirements at Titan compared to Atlas. The new gas price and lower production volume in Trinidad will reduce annual adjusted EBITDA and free cash flow capability, starting in 2025 and compared to 2023, by approximately $80 million and $40 million, respectively, across a range of methanol prices."

Sumner said the company would continue to work with the Republic of Trinidad and Tobago and the NGC to secure natural gas supplies to supply its methanol plants.

SAUDI ARABIA

Contract awarded for green methanol/MTG plant

thyssenkrupp Uhde has been awarded a contract by ENOWA, the energy and water company of the NEOM new technology-based city development on the Red Sea of Saudi Arabia. Uhde's contract is for engineering services and the supply, design and procurement of equipment for a new CO2-to-methanol and methanol-to-gasoline demonstration plant at ENOWA's Hydrogen Innovation and Development Center (HIDC) in Saudi Arabia. The plant is a joint development of ENOWA and Aramco and will use the uhde® green methanol process and ExxonMobil's fluidised bed methanol-to-gasoline process. The plant will produce 12 t/d of methanol and 35 bbl/d of gasoline.

Dr. Cord Landsmann, CEO thyssenkrupp Uhde GmbH said: "We are very proud that NEOM has selected thyssenkrupp Uhde to supply the plant due to its advanced uhde® green methanol process and its expertise. This is clearly another proof of concept for our technology and knowledge being an enabler for the green transformation."

Roland Kaeppner, managing director of Hydrogen and Green Fuels at ENOWA added: "We value the technology cooperation with thyssenkrupp Uhde and their wealth of expertise and technologies in driving a future green fuels economy. The plant will be a key part of our Hydrogen Innovation and Development Center and produce e-methanol and e-gasoline by end of 2025, which will be used for various applications, such as motorsports, off-grid energy and for hydrogen transportation."

SAUDI ARABIA

Aramco to develop e-fuel demonstration plant

Aramco has signed a joint development agreement with ENOWA the energy and water company of the NEOM new city development. The companies will establish a green fuel demonstration plant at ENOWA's Hydrogen Innovation and Development Centre, and aims to demonstrate technical feasibility and commercial viability by producing 35 bbl/d of low-carbon, synthetic gasoline from renewable hydrogen and captured carbon dioxide (CO_2). The fuel has the potential to reduce CO_2 emissions by over 70% on a life cycle basis compared to conventional fuels. Once complete, the integrated facility will generate 12 t/d of synthetic methanol per day from green hydrogen and CO_2, using proprietary technologies developed by thyssenkrupp Uhde. The synthetic methanol will then be converted into low-carbon gasoline using ExxonMobil's fluidised bed methanol to gasoline technology. The Centre will also produce green hydrogen using an on-site 20MW electrolyser powered by renewable energy sources. Through a joint development agreement, NEOM will oversee the construction of the plant, while Aramco and ENOWA will jointly oversee operations and investment in relevant research programs.

Ahmad O. Al Khowaiter, Aramco Executive Vice President of Technology & Innovation, said: "Synthetic fuels can play an important role to accelerate the decarbonization of the global vehicle fleet. We are excited to be working alongside our partners to demonstrate a potential path towards realising this vision."

FRANCE

New green methanol plant

Following the successful completion of a two year feasibility study, Elyse Energy is beginning work on the construction of a new green methanol production plant, called eM-Rhône, at Les Roches-Roussillon chemical platform in the Isère department. The project, being developed with assistance from the European Innovation Fund, is expected to cost around €700 million, and will have a capacity of nearly 150,000 t/a of renewable methanol, which will allow the complex to substitute imported methanol with local production, while avoiding the emission of 200,000 t/a of CO_2 equivalent. The project will use CO_2 captured in Lafarge's plant in Le Teil, and forms part of the partnership initiated in 2022 between Lafarge France and Elyse Energy. Construction is scheduled to start in 2025, with industrial commissioning in early 2028. Hydrogen will be produced by water electrolysis using an electrolyser located on the platform and connected to the electricity transmission network (RTE) at the Gampaloup substation, powered by low-carbon electricity. Carbon dioxide will be captured and used at the OSIRIS site, as well as at the Lafarge plant in Le Teil, Ardèche, a hundred kilometres further south, where liquid CO_2 will be transported by train to the platform.

JAPAN

Partnership for synthetic natural gas

Tree Energy Solutions (TES), a global green energy company and Tokyo Gas Co., Ltd. (Tokyo Gas), a leading Japanese gas utility company, are pleased to announce that they have signed an agreement to explore and develop "e-Natural Gas" (e-NG) – synthetic natural gas based on green hydrogen – as part of efforts to foster the global energy transition and the roll out of e-NG. TES and Tokyo Gas say that they will work together to raise awareness of e-NG globally, encourage the institutional design of an international CO_2 emissions counting system for e-NG and other fuels that contribute to carbon neutrality, and to establish an international supply chain for e-NG. In Japan, natural gas currently accounts for 60% of Japan's total energy demand, and e-NG is seen as a potentially promising option for its decarbonisation. It can use existing city gas infrastructure such as LNG receiving terminals, pipelines, and consumption equipment without modification, for a smoother transition to carbon neutrality and additional social cost containment.

Kentaro Kimoto, Corporate Executive Officer, Vice President and CTO of Tokyo Gas, said: "We are very pleased to conclude this partnership agreement with TES. TES has been promoting studies on the establishment of an e-methane (e-NG) supply chain vigorously and worldwide, and we are extremely encouraged to have TES as a partner as we promote and expand e-methane(e-NG) globally in the future. Based on this collaboration, we will lead to raise global awareness of e-methane(e-NG) and establish an international framework to achieve carbon neutrality."

SPAIN

Contract for green hydrogen plant

thyssenkrupp Uhde has been engaged by Hive Energy Limited to deliver a pre-front end engineering and design (FEED) study to support the development of Hive's first green hydrogen/ammonia production plant in Spain. The pre-FEED was awarded following a comprehensive techno-economic study for the power-to-ammonia facility, which was performed in 2022 using thyssenkrupp Uhde's proprietary RHAMFS® methodology.

The key goal of the pre-FEED is to enhance the technical concept and commence key engineering activities for the plant. thyssenkrupp Uhde will base the pre-FEED on its dynamic uhde® ammonia synthesis technology, which has been specifically developed to tackle the unique challenges of dynamic ammonia production, and will also provide integration engineering for the process facility. The pre-FEED will allow Hive Energy to advance through the subsequent commercial and regulatory phases of the project development.

Hive Energy, headquartered in the UK, was founded in 2010 by Giles Redpath to participate in the significant solar PV expansion across England. The company now operates from over 20 countries globally, and develops and operates large-scale renewable energy projects, including the UK's largest solar park, and has plans to develop 28 GW of renewable energy projects, including one of the world's largest green ammonia plants in South Africa. ■

People

Mangalore Chemicals & Fertilizers Limited has appointed **Vighneshwar G Bhat** as company secretary and compliance officer. Bhat, is an associate member of the Institute of Company Secretaries of India and a Law Graduate and holds master's degree in commerce with more than 20 years of experience in secretarial and legal functions. Prior to joining the company, he was company secretary for Sobha Ltd, and has specialised in corporate secretarial matters including mergers and acquisitions, handling liquidations and SEBI & FEMA compliances.

The Mosaic Company has announced that **Joc O'Rourke** intends to retire and that Mosaic's board has unanimously elected **Bruce Bodine**, currently Senior Vice President, North America, to succeed O'Rourke as the company's Chief Executive Officer on January 1, 2024. O'Rourke relinquished the title of President effective immediately and will resign as CEO and a member of the Mosaic board of directors from December 31st, 2023, after which he will serve as a senior advisor until mid-2024. Bodine has been elected president of the company and a member of the board effective immediately.

"Joc's leadership over the past eight years strengthened Mosaic," said Greg Ebel, Chairman of Mosaic's board. "The company today is larger, more geographically diverse, more resilient and in excellent financial condition. My fellow directors join me in wishing him all the best as he transitions to a well-deserved retirement. The board has full confidence in Bruce and the other members of Mosaic's talented Senior Leadership Team. Together they will build on Joc's legacy of success on behalf of all Mosaic stakeholders."


Bruce Bodine

Bodine has worked for Mosaic and its predecessor company for many years and held a number of executive roles, including Senior Vice President - Potash, Senior Vice President - Phosphates, and Vice President-Supply Chain. In his role as SVP - North America he also led the North American Sales team. Additionally, he led the integration of Mosaic's North America Businesses and currently leads enterprise-wide operations.

"I am grateful for the support of the Mosaic Board of Directors and my extremely talented management team colleagues," Mr. Bodine said. "Joc's leadership made Mosaic stronger. We will continue to meet Mosaic's noble mission-to help the world grow the food it needs-while operating safely and responsibly."

Gerald Marinitsch has become the new CEO of Solex Thermal Science. Gerald joined Solex in 2014 with a background in process engineering, and has led the company's global business development efforts in industrial product lines such as chemicals, metals, minerals and sands. Most recently, he championed Solex's energy portfolio, which included creating tailored and process integrated solutions designed to improve our customers' energy utilisation and efficiencies.

Marinitsch said: "I am excited to be taking on the role of CEO at Solex Thermal Science, effective immediately. My journey with this organisation over the past decade has been extraordinary. Over the years, I have had the privilege of collaborating with a tremendous group of colleagues from around the world, and look forward to our continue this journey. I am deeply grateful for the trust and support I have received from our exceptional team, our partners and our loyal customers during this journey. I look forward to sharing our progress and achievements with you in the coming months and years. Together, we will write the next chapter of Solex's success story."

Calendar 2023/2024

NOVEMBER

27-29
Argus Clean Ammonia Europe Conference
ANTWERP, Belgium
Contact: Argus Media Group
Tel: +44 (0)20 7780 4340
Email: conferences@argusmedia.com
Web: www.argusmedia.com/en/confer ences-events-listing/clean-ammonia-europe

DECEMBER

6-8
IFS 2023 Conference
CAMBRIDGE, UK
Contact: Steve Hallam, International Fertiliser Society
Tel : +44 (0)1206 851819
Email: secretary@fertiliser-society.org

JANUARY

4-6
VI International Conference Fertilizers 2024: Eastern Europe, WARSAW, Poland
Contact: Chem-Courier
Email: conf@chem-courier.com

FEBRUARY 2024

5-7
Fertilizer Latino Americano,
MIAMI, Florida, USA
Contact: Argus Media, Ltd
Tel: +44 (0)20 7780 4340
Email: conferences@argusmedia.com

MARCH

4-6
Nitrogen+Syngas Conference 2023,
GOTHENBURG, Sweden
Contact: Michelle Bingham, CRU
Tel: +44 (0)20 7903 2159
Email: michelle.bingham@crugroup.com

6-7
Green Ammonia Summit
DUSSELDORF, Germany
Contact: Marcin Janecki, ACI Europe
Tel: +48 61 646 7047.
Email: mjanecki@acieu.net

20-24
11th Annual Gasification Summit
GHENT, Belgium
Contact: Mohammed Ahsan, ACI
Tel: +44 203 141 0606
Email: mahsan@acieu.net

MAY

20-22
IFA Annual Conference,
SINGAPORE
Contact: IFA Conference Service, 49 Avenue d'Iena, Paris, F75116, France.
Tel: +33 1 53 93 05 00
Email: ifa@fertilizer.org

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56

Plant Manager+

Problem No. 70 Corrosion at unexpected locations like in dry CO_2 pipelines

It is common knowledge that wet CO_2 is corrosive to carbon steel and "dry" CO_2 is not corrosive to carbon steel. So typically engineers and contractors choose carbon steel for dry CO_2 conditions and stainless steels for wet CO_2 conditions. This can be seen in the CO_2 feed section of almost every older urea plant. But is it true that carbon steel is always the right choice for dry CO_2 and is dry CO_2 really dry under all circumstances?

Le Hoang Viet of PetroVietnam Ca Mau Fertilizer in Vietnam kicks off this round table discussion: CO_2 and NH_3 are raw chemicals that react to produce urea. CO_2 is compressed using a CO_2 compressor. As per the design, carbon steel is used as the material of construction for pipelines that contain hot CO_2 in the discharge of each stage of the compressor. Conversely, stainless steel, usually 304L, is employed for pipelines containing cooled CO_2 downstream of the interstage coolers.

Normally hot CO_2 does not corrode carbon steel. However, in instances of heat loss in pipelines, CO_2 can cause corrosion in carbon steel. Susceptible locations are often vents and drains in these pipelines (as shown in the photo above). This issue arose in our CO_2 piping system and was resolved by upgrading these pipes to 304L stainless steel.

Mark Brouwer of UreaKnowHow.com in the Netherlands responds: In "dry" CO_2 carbon steel is typically applied, and for CO_2 saturated with water stainless steels are typically applied. You are right that in dry CO_2 lines with heat sinks (cold spots) corrosion of carbon steels can and do occur.

Usman Ali Hashmi of Parco in Pakistan adds: The formation of carbonic acid might be the main culprit.

Muhammad Adnan Hanif of Fauji Fertilizer Company in Pakistan shares his experience: In this case, the main culprit is carbonic acid, which is produced by CO_2 in the presence of water, especially at higher pressures (due to the increase of CO_2 solubility in water).

Typically water is present in vapour form at equilibrium conditions in the CO_2 at the inlet of each stage of the mult-stage compressor. This water condenses and forms carbonic acid when the CO_2 gas is compressed in each stage and subsequently cooled in a cooler.

In early designs (1980s), the pipeline material was carbon steel, especially before the intercooler segments, and stainless steel 304 for lines downstream of the intercoolers. However, in new plants all lines are preferably stainless steel 304 to eliminate the corrosion issue as carbonic acid has only a very mild effect on stainless steels in comparison to carbon steels.

Mark comes back with some suggestions: This example shows the need to pay proper attention to all kind of failure modes and that feedback on actual experiences is important. Proper continuous leak detection for CO_2 leaks in the CO_2 feed section of urea plants is also important.

Appearance or morphology of carbonic acid corrosion damage:

Carbonic acid corrosion can manifest in various forms, depending on the specific equipment or infrastructure affected. Some common appearances of carbonic acid corrosion include:

- *Uniform or general corrosion:* This form of corrosion appears as a gradual, overall thinning of the affected material. It occurs when the carbonic acid reacts with the surface, resulting in a relatively even loss of material over a large area. Uniform corrosion may lead to a reduction in the structural integrity of the equipment.
- *Pitting corrosion*: Pitting corrosion appears as localised, small cavities or pits on the surface of the material. Carbonic acid can initiate the formation of pits by attacking localised areas more aggressively. Pitting corrosion is particularly concerning as it can penetrate deep into the material, leading to significant damage and potential failure.

A similar situation of corrosion at unexpected locations can be found in gas pipelines with ammonium carbamate in urea plants. When ammonium carbamate gas condenses at cold spots or heat sinks, the condensed ammonium carbamate liquid contains insufficient oxygen and active corrosion occurs with relatively high corrosion rates. This is also called condensation corrosion. Also here the remedy is to apply proper tracing and insulation to assure a higher temperature than the dew point. Higher alloy materials should be selected and regular corrosion inspections should be performed.

For more background information about carbonic acid corrosion: https://matintegrity.wixsite.com/inspection-corrosion/post/blast-furnace-gas-scrubber-carbonic-acid-corrosion

This series of discussions is compiled from a selection of round table topics discussed on the UreaKnowHow.com website. UreaKnowHow.com promotes the exchange of technical information to improve the performance and safety of urea plants. A wide range of round table discussions take place in the field of process design, operations, mechanical issues, maintenance, inspection, safety, environmental concerns, and product quality for urea, ammonia, nitric acid and other fertilizers.

The merchant ammonia market

Merchant markets for ammonia have faced considerable disruption in recent years due to the covid pandemic and the war in Ukraine.

PHOTO: VIGOR

The Harvest, a refrigerated ammonia barge operated by Mosaic out of the port of Tampa.

Global production of ammonia has risen fairly continuously over the past few decades, though with occasional pauses and plateaus due to major geopolitical events, such as the dip following the breakup of the Soviet Union in the early 1990s. During the 2010s world ammonia production rose from 159 million t/a in 2010 to 186 million t/a in 2020, but again in recent years there has been a dip in production and consumption; the disruption caused by first the covid pandemic and then the cessation of shipments from Ukraine due to the war there saw production drop to 184 million t/a in 2021 and 182 million t/a in 2022. Most of the fall in production in 2020-2022 has come in Europe and the Russian Federation. However, figures for the first six months of 2023 show a rebound; there has been a rise in production of 4% year on year compared to the same period in 2022, which would translate to a full year figure of 189 million t/a if maintained for the rest of the year.

Because it is toxic and must be transported as a liquid cooled to below -33C, most ammonia is instead consumed at the point of production for downstream conversion into urea, nitric acid, ammonium nitrate and other chemicals. The merchant market for ammonia is therefore much smaller than the overall market, and in 2022 stood at 18.1 million t/a, or only about 10% of total production, of which 16.6 million t/a - or over 90% of the merchant market - was moved by ship or barge, and the rest by rail tanker. However, merchant ammonia is particularly important for some consuming segments, such as production of industrial chemicals such as caprolactam (for fibre production), acrylonitrile, adipic acid, and isocyanates (for polyurethane production), where production is often close to centres of demand. Due to the difficulty of transporting explosives over long distances, merchant ammonia is also often used for low density (explosive grade) ammonium nitrate production. And because ammonia has historically been produced where feedstock is cheaper, in major gas producing regions, and because these do not often coincide with sources of phosphate rock, merchant ammonia is also widely used in ammonium phosphate fertilizer manufacture, as ammonia is much lighter to transport than phosphate rock. A small amount of merchant ammonia is also imported by urea and ammonium nitrate producers

Table 1: **World ammonia production, consumption and trade, 2022, million t/a product**

Region	Production	Export	Import	Consumption	Net imports
Western Europe	7.4	1.2	4.7	10.9	3.5
Eastern Europe	3.4	0.2	0.5	3.7	0.3
FSU	22.2	1.7	0.2	23.7	-1.5
North America	21.2	2.0	2.3	21.5	0.3
S/Central America	7.0	3.8	1.3	4.5	-2.5
Africa	11.0	2.0	2.5	11.5	0.5
Middle East	19.9	4.1	1.0	16.8	-3.1
South Asia	21.9	0.0	2.6	24.5	2.6
East Asia	66.6	2.6	2.9	66.9	0.3
Oceania	2.0	0.2	0	1.8	-0.2
Total	**182.6**	**18.1**	**18.1**	**182.6**	

Source: IFA

in regions with relatively high domestic gas costs which makes local ammonia production less economic, such as India and southern Africa.

Merchant ammonia production, conversely, tends to be in low gas cost regions with easy access to ports and overseas shipping. On a regional basis, as shown in Table 1, it can be seen that the major net importing regions continue to be North America (mainly to feed DAP production in Florida, Western Europe (for a variety of uses, often industrial/technical), South Asia (mostly to feed Indian DAP and some urea production) and East Asia (Japan, South Korea, Thailand and Taiwan are all net importers, again often for industrial/technical uses). By nation, the largest importers are the United States (2.6 million t/a in 2021), India (2.3 million t/a), Morocco (1.7 million t/a), South Korea (1.4 million t/a) and Turkey (1.0 million t/a). On the export side, the major volumes come from Russia (4.4 million t/a in 2021) and Trinidad (3.9 million t/a). The Arabian Gulf states (including Iran) add another 2.7 million t/a to that, and North African countries (mainly Algeria and Egypt) another 2.1 million t/a.

Changing patterns of supply and demand

On the demand side, the largest importers continue to be the United States and India. In spite of India building several large ammonia-urea complexes to attempt to reduce the country's dependence on imported urea, there is very little surplus ammonia capacity from these plants, and the impact on ammonia imports for Indian DAP production has been small. Conversely, US imports of ammonia have generally been on a declining trend as lower cost shale gas production leads to more domestic capacity being built or restarted. In 2012, at the peak of its import demand, the US imported 7.8 million t/a of ammonia from overseas. By 2020 this had fallen to below 2.4 million t/a, and although 2021 saw a slight rebound to 2.6 million t/a, this dropped back to 2.3 million t/a in 2022 and is expected to be lower still for 2023.

Morocco

Morocco's imports of ammonia are increasing as state phosphate company OCP continues to build new mono- and di-ammonium phosphate (MAP/DAP) capacity to capture more of the phosphate value chain. Morocco's ammonia imports have gone from 0.5 million t/a in 2010 to 2.2 million ta in 2022; more than four times higher in just 12 years, and the country may soon overtake the US to become the world's second largest ammonia importer. More phosphate capacity is under development, and as Morocco has no gas of its own, this will likely mean more ammonia imports. However, OCP has been looking very seriously at developing 'green' electrolysis based ammonia capacity domestically, using the desert country's abundant sunlight, and in the much longer term this may come to play a factor in Morocco's need for imports.

Europe

Europe's imports of ammonia increased in 2021-22 because of the impact of the war in Ukraine, and a steady reduction in gas flows from Russia. Gas prices skyrocketed in the winter of 2021 leading to widespread shutdown of European ammonia capacity. European ammonia production dropped by over 5 million t/a from 2020-2022. However, imports rose only by a few hundred thousand tonnes to 5.2 million t/a over the same period, as high ammonia prices in Europe led to demand destruction in downstream industries. At the peak of the shutdowns, 70% of European ammonia and urea capacity was shut down, and 50% of nitrate capacity. Production has reopened during 2023, but is still down on its pre-war/pandemic value.

Exports – Russia and Ukraine

While patterns of imports have changed significantly, undoubtedly the largest impact of the war in Ukraine has been on ammonia exports, particularly from Russia and Ukraine. Prior to the war, Russia had been ramping up its export-oriented ammonia capacity, including the start-up of an 890,000 t/a plant for Eurochem at Kingisepp in northwest Russia. Cheap gas and rising domestic demand for fertilizer had been leading to something of a boom for Russian nitrogen production. However, the war closed the ammonia export pipeline across Ukraine to Odessa, and effectively ended all Black Sea exports of ammonia. While urea was rerouted to the Baltic Sea, Russian ammonia exports dropped from

PHOTO: BRUNSBUTTEL PORTS

LNG tankers tied up at Brunsbuttel, Germany. European gas markets continue to hold the key to ammonia pricing.

4.4 million t/a in 2021 to 0.8 million t/a in 2022. Exports for 2023 are expected to be up, but a resumption to ammonia exports which had been one of the Russian government's conditions for allowing Ukrainian grain exports to continue, did not eventually materialise. In the meantime, Russia has approved the construction and operation of an export terminal in Taman, to be owned and operated by TogliattiAzot. The first phase, which is due to be operational by the end of 2023, will have a capacity of 2 million t/a, and a second phase with 3.5 million t/a of capacity is due for completion in 2025.

Meanwhile, Ukraine was likewise also once a major exporter of ammonia, but much of its domestic capacity had already been shut down by the conflict in the Donbas region in east of the country from 2016, while high gas prices closed most of the remainder of the country's production. The export-oriented Odessa Port Plant (OPZ) was operating only intermittently because of unpaid gas debts, and has closed down since the conflict began.

Middle East

The Middle East has only around 11% of global ammonia capacity, but much of that is export oriented, and in 2022 it exported 4.2 million t/a of ammonia, a 50% increase on the 2.8 million t/a exported in 2021. Most of that production (2.6 million t/a or 62%) came from Saudi Arabia, which has added new capacity at Ma'aden III. Qatar exported 0.5 million t/a, and Iran just under 0.6 million t/a. As capacity in Russia and Ukraine has become constrained, so Middle Eastern countries have increased production and managed to gain a greater share of the global merchant ammonia market. In 2022 Saudi Arabia became the second largest ammonia exporter in the world after Trinidad.

Trinidad

In the 1980s and 90s, Trinidad developed an ammonia economy based on supplying the merchant market with cheap ammonia using natural gas feedstock from its offshore gas fields. But government controls on gas prices disincentivised gas producers from exploring and developing new production, and so as the gas fields have matured and production has begun to fall, so Trinidad has faced problems with maintaining ammonia production. Thus although it remains the second largest exporter of ammonia in the world, Trinidad has seen its ammonia exports fall due to gas supply constraints, from 5.3 million t/a in 2010 to 3.6 million t/a in 2022. At the same time, its main market, the continental United States, has been importing less and less ammonia, and so Trinidadian producers have had to look further afield for customers. Europe's gas difficulties in 2022 were an unexpected bonus for Trinidad as it provided a ready market for what ammonia Trinidad was able to produce. Until more gas fields can be opened up, Trinidadian production is likely to remain constrained, and new production will have a much higher cost base for its gas feedstock.

New merchant capacity

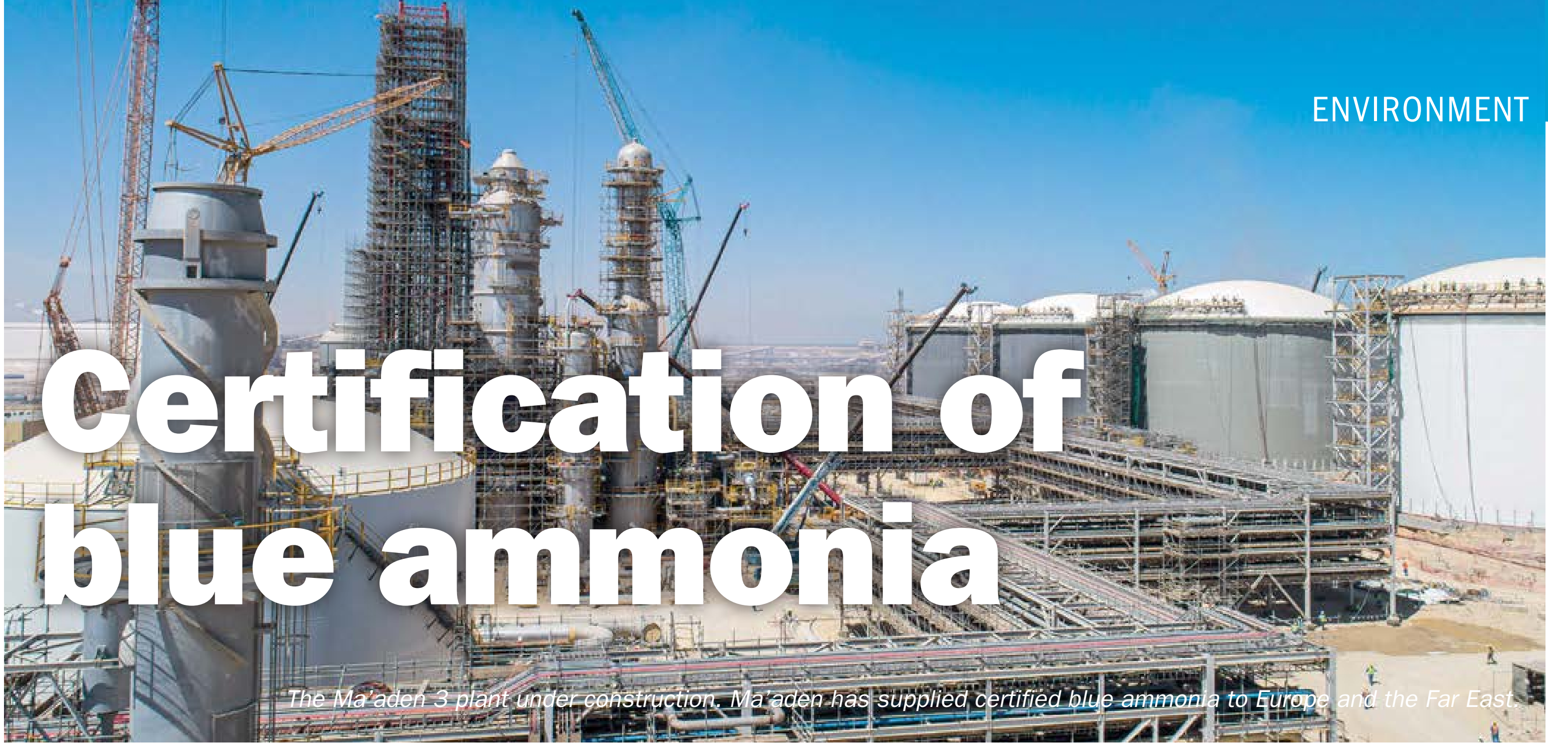
There have been a number of additions to merchant ammonia capacity in the past 18 months, including Ma'aden III, commissioned in March 2022, which added 1.1 million t/a of capacity over and above that required for DAP production. Not far away, Salalah Methanol in Oman started up an ammonia plant in September 2022 with an additional 330,000 t/a of capacity. But the largest concentration of new capacity seems to be occurring in the US Gulf Coast, where there are several projects competing to develop 'blue' ammonia capacity using carbon capture and storage for enhanced oil recovery in the oil fields of the region, boosted by US government subsidies under the Inflation Reduction Act. OCI has already begun construction of a 1.1 million t/a plant at Beaumont, Texas which is due to be completed in 2025. CF Industries has also committed $285 million to enable existing plants in Louisiana and Mississippi to capture and sequester carbon and together with Mitsui is considering construction of a new blue ammonia plant in Louisiana. Yara, in partnership with Enbridge, is also approaching a final investment decision on a $2.9 billion blue ammonia plant in Texas with a capacity of around 1.3 million t/a. Both of these projects could be onstream in 2027-28, and Yara is also partnering BASF on a second blue ammonia project with a tentative date of 2028-29. Finally, Nutrien is evaluating a site at Geismar, Louisiana, where it already has a facility, to produce 1.2 t/a of blue ammonia with a provisional onstream date of 2027.

Many of these developments are predicated on tightening environmental regulations, such as Europe's upcoming Carbon Border Adjustment Mechanism, as discussed in our other articles in this issue. There are hopes in some quarters that low carbon ammonia may achieve a degree of take-up as a marine fuel, though at the moment these projects are still at a developmental stage, or as a power plant fuel in Japan, which is looking to import several million t/a of blue ammonia to lower its carbon emissions at existing power plants.

A year of oversupply

A glance at the graphs in the markets pages of this issue will show just how volatile ammonia prices have been over the past three years. By far the largest disruptions have come from gas shortages and high ammonia prices in Europe leading to shutdowns of both ammonia and downstream capacity, and the closure of the Black Sea to ammonia exports. US and Middle East exports have risen as a result, while India is importing more. A factor in supply of ammonia is the relative price differential between ammonia and urea prices. When ammonia prices are significantly above those for urea, producers who are capable of doing so are encouraged to shut down the urea section of their plant and sell ammonia instead. But the run of high ammonia prices that incentivised ammonia production is over now, and prices have fallen back to relatively low levels. Indeed, thanks to the demand destruction in Europe and the startup of new capacity the ammonia market has spent much of 2023 oversupplied, Only towards the end of the year have prices seen an uptick as some demand begins to return.

But European gas prices could still be a major factor in the ammonia market this winter. Europe has made a remarkable turnaround in the way it sources gas after having the pipelines from Russia turned off, with new LNG import capacity supplementing existing imports and an increasing switch to renewables. There has been a conscious attempt to fill storage during summer, as there was last year, and at the start of November 2023, going into winter, gas storage levels were reported to be 99% across the continent. But Europe is still likely to consume more gas than it can import over winter, and while last year was a relatively mild one, prolonged cold weather could see gas prices rise rapidly and a return of ammonia shutdowns. There are also continuing worries about the conflict in Gaza, with the potential for it to spread and affect the wider region. The ammonia market continues to be extremely volatile, and 2024 is looking difficult to predict. ■



Certification of blue ammonia

PHOTOL: MA'ADEN

The Ma'aden 3 plant under construction. Ma'aden has supplied certified blue ammonia to Europe and the Far East.

While producing ammonia with hydrogen from electrolysis remains expensive, large scale lower carbon ammonia has focused on carbon capture and storage from existing plants, so-called 'blue' ammonia. But exactly how green is blue?

In August 2022, Saudi state fertilizer producer Sabic Agri-Nutrients delivered the first accredited cargo of blue ammonia; 37,800 tonnes produced at Jubail. The accreditation was provided by German testing, inspection and certification agency TÜV. Sabic has delivered several blue accredited cargoes over the succeeding year, to clients in South Korea, India, China and Taiwan. A cargo of certified blue ammonia from Ma'aden also arrived in Varna, Bulgaria in June 2023 for Bulgarian fertilizer producer Agropolychim, marking the first commercial-scale delivery to Europe, and Ma'aden has also supplied to Taiwan. But as these deliveries become more frequent and more widespread, there is a looming question of who will certify these cargoes and upon what basis. Those financing blue ammonia projects will wish to be assured of offtake by customers, and those customers in turn will want some measure of certainty of what they are buying. Fertilizers Europe has put it like this: "The development of a coherent and science-based certification process will be key to developing this market."

Carbon intensity

To certify ammonia and hydrogen as 'blue', a significant part of the CO_2 associated with the manufacturing process needs to be captured and permanently sequestered or used in downstream applications. But the devil is in the details, particularly the word "significant". Different ammonia technologies are amenable to carbon capture, utilisation and/or storage (CCUS) to different degrees. For example, most ammonia capacity today is based on steam methane reforming (SMR). Carbon dioxide generated during the partial oxidation of natural gas in the process can be fairly readily captured as it already forms part of the process stream. In this way around 50-70% of CO_2 generated in the process can be captured for utilisation or storage. However, carbon dioxide generated from the gas burned to heat the reformer ends up instead in flue gas, and represents the other 30-50% of CO_2 generation. There is a very low partial pressure of CO_2 in the flue gas, making its recovery more expensive. Conversely, autothermal reforming (ATR) uses an oxygen blown reformer which entrains around 90-95% of the CO_2 in the process stream. While it is a more capital intensive process than SMR, ATR therefore offers advantages in terms of carbon dioxide recovery.

There are also other potential carbon savings in production, for example using renewable electricity to run plant power demands and power pumps etc which can all have a bearing on the carbon intensity of the final ammonia.

End uses

Life cycle carbon costs can also be a factor. For carbon capture and use, this depends upon what the end product is. If the CO2 is being used to make urea, methanol or olefins, for example, these products may end up releasing the CO_2 again when they are used, especially if low carbon methanol continues to make inroads into the market for shipping fuels.

At the moment, most carbon dioxide that is captured and pumped back into the ground goes into oil producing wells to maintain well pressure and hence output, so-called Enhanced Oil Recovery (EOR). While at the moment these projects are able to claim that they are 'blue' production, there is considerable debate as to exactly how 'low carbon' it is to be generating additional oil output. EOR is attractive as an end use for captured carbon because the additional oil has a monetary value, and hence so does the CO_2 that is being supplied, offsetting to at least some extent the cost of CCUS.

Proponents would argue that as long as oil is being produced and consumed, where and how it is produced is largely irrelevant, as it is a fungible commodity, and the carbon impact of oil production and consumption is being tackled separately via taxes on consumption and on emissions from refineries etc. Production of oil generates about 100 kg CO_2e per barrel according to the International Energy Agency, and burning it another 400 kg CO_2e/bbl. Enhanced oil recovery can sequester between 300-600 kg CO_2e/barrel, in theory potentially generating carbon neutral or even carbon negative oil, though of course it is important to avoid double counting – one shouldn't get credits for both low carbon ammonia and low carbon oil using the same sequestered CO_2.

However, were, for example, the EU decide that CO_2 being used for EOR no longer qualifies for 'blue' ammonia certification, or that it qualifies at a reduced rate, it would shut off a large market for the product.

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56

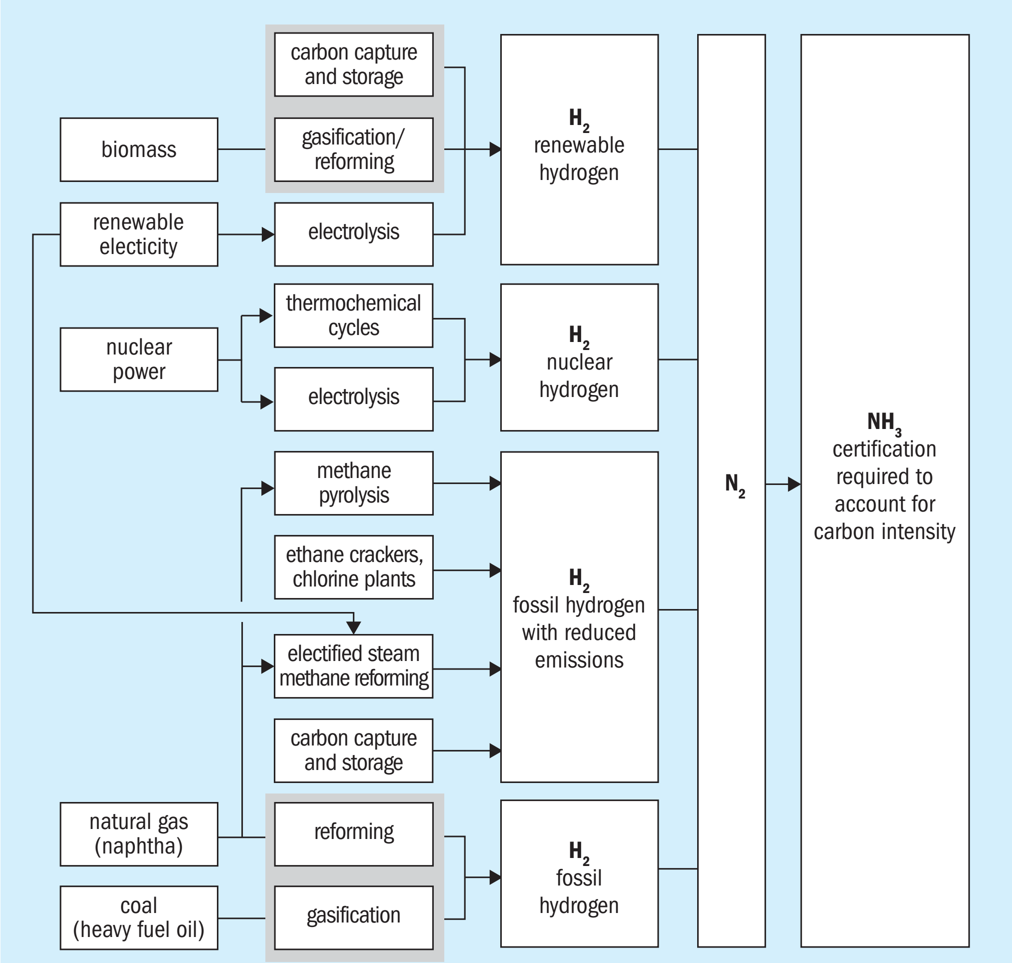
The US already takes this into account with its Inflation Reduction Act (IRA), in section 45Q, where CO_2 used for EOR receives a carbon credit of $35/t, compared to $50/t for CO_2 which is permanently sequestered. It remains to be seen how far such a two tier system might spread. Even so, there are four ammonia plants in the US currently receiving $35/t tax credits for producing ammonia using CCUS.

Carbon credits

Blue ammonia certificates will also need to interface with existing emissions reduction regulatory frameworks. Various nations and grouping of nations already operate such schemes. For example, the European Union operates its ETS emissions trading scheme, a cap and trade scheme based on trading emissions permits above a floor level. The aim is to put a cost on CO_2 and CO_2 equivalent gases above a certain limit and encourage the use of abatement technologies such as carbon capture and storage. However, from 2026 it will be augmented by the EU's Carbon Border Adjustment Mechanism (CBAM), which aims to prevent 'carbon leakage' – the shutdown of domestic industries which have made expensive investments to reduce carbon output, and their replacement with imported ammonia or urea from overseas which may have been made in a more carbon intensive manner. In effect it will place a carbon tax on any imports, meaning that in order to produce, European producers are going to have to be tackling their CO_2 emissions in some way, and in order to compete and supply the European market, overseas producers will need to be able to produce certification to prove how low carbon their own production is.

The US IRA has been a major driver of new project activity, with the carbon credits available from blue ammonia production driving a number of new projects which collectively represent around 80% of announced new blue ammonia capacity. However, while much of the impetus for development of blue ammonia has come from a regulatory push from governments, there are also the signs of a pull from customers who are looking to improve their own environmental credentials. Consumers of ammonia and other downstream products who are trying to move towards net zero will need to look at ammonia as a primary way of reducing their lifecycle CO_2 emissions. The Japanese government has been a major factor in this, as it plans to co-fire low carbon ammonia in coal-fired power stations in order to reduce their carbon intensity and extend their working life. But many companies who are working towards net zero carbon reductions wish to be able to demonstrate to their customers that they are producing low carbon products and

Fig. 1: **Pathways to low carbon ammonia**



Source: IRENA/AEA

Who will certify?

There is also the question of who will certify the ammonia, and perhaps even a question of who certifies the certifiers. Multiple certification schemes for low carbon hydrogen and/or ammonia are already offered by the Green Hydrogen Organisation, the Smart Energy Council, TUV SÜD, CertifHy, Bureau Veritas etc, with schemes also under development by industry bodies such as Fertilizers Europe and The Fertilizer Institute. The Australian Government is working on a Guarantee of Origin scheme which would certify the carbon reduction on lower carbon hydrogen production for ammonia which it hopes to have up and running next year.

The schemes differ. Bureau Veritas says that carbon intensity of the ammonia produced must be below 0.5 kg CO_2e per kg ammonia, for example, while the EU is pushing for a definition of 'renewable' hydrogen/ammonia of a 70% reduction in carbon intensity, with less than 70% being defined as 'low carbon' hydrogen. At present around 10 plants worldwide are producing blue ammonia of one hue or another, but the average carbon reduction is around 50%, as they are based on steam reforming plants, as discussed earlier.

Ideally there would be a single widely recognised unified reporting standard worldwide, but at the moment the situation is analogous to the current carbon credit reporting system, with a methodology which varies between jurisdictions. At its most extreme it even raises the possibility of a kind of two or more tier blue ammonia certification system, where some jurisdictions like the US and EU are stricter on the criteria for qualification than other parts of the world.

Over the past couple of years, the Ammonia Energy Association has been trying to draw together the various stakeholders to achieve a globally harmonised certification scheme for low carbon ammonia. In 2021 it published a discussion paper on the subject and solicited comments from interested parties for its own proposed certification scheme. This aims to support the adoption of a globally harmonised framework for the accounting, reporting, and verification of the carbon intensity of ammonia ($tCO_2e/tNH3$) as the basis for certification of emission reductions associated with the implementation of low-carbon ammonia initiatives, via:

- registration of ammonia projects under the certification scheme, against approved project design, accounting, monitoring, reporting and verification methodologies; and
- the issuance of low-carbon ammonia certificates for verified emission reductions arising from the implementation of low carbon ammonia projects registered under the scheme.

It aims to quantify an absolute carbon intensity for ammonia produced at a specific site, as well as other metrics, such as origin, inputs, co-products, technology pathway, and date of manufacture.

As far as life cycle costs go, the AEA has concentrated on well-to-factory gate emissions (Scopes 1, 2, and upstream Scope 3) as a basis for certification, with the option of additional well-to-tank or well-to-wheel/wake certification on top. Well to gate is regarded as a minimum standard which could be more widely applicable across multiple customer types (producers, traders, retailers, end users) in different and possibly conflicting sectors or jurisdictions. The EU however seems to be moving towards a life cycle cost analysis.

Computer rendering of the planned Barents Blue ammonia project in Norway.

Pricing

Will blue ammonia develop a price premium over conventional 'grey' ammonia? At the moment, none of the buyers or sellers of the certified blue shipments mentioned at the start of the article have said whether or not they were bought at a premium to normal ammonia prices. Platts, which, in common with several other market consultancies tracks assessed prices for grey, blue and green ammonia plants, says that the current premium for blue ammonia over conventional production in the US Gulf Coast was estimated at around $24/tonne in September 2023. But establishing the production cost of blue ammonia is not quite as straightforward as for green ammonia produced using electrolysis, depending on how the CCUS is financed and installed. Often there is a collaboration with the oil or gas producer who runs the reservoir where the CO_2 is being sequestered, and as previously mentioned, where CO_2 is being sold for enhanced oil recovery it may actually be a credit for production. CRU estimates that carbon capture and storage will increase grey ammonia costs by between \$20/t NH_3 and \$44/t NH_3.

It is possible, if the market becomes more sophisticated, that in the longer term it may be possible to trade blends of grey/green/blue ammonia based on their overall carbon reduction, but this will need much greater harmonisation of certification than is presently the case. There are also other factors to consider, such as ammonia 'cracking', allowing users to import ammonia to generate hydrogen.

However, at the moment, the prime factor in determining investment decisions for blue or green ammonia seems to be not pricing but rather a requirement for commitment from buyers for long-term offtake agreements. ■

Constraints on renewable production

With low carbon ammonia and methanol being considered not just for their chemical and fertilizer uses, but as fuels, can we make enough of them to fill our energy needs?

Low carbon hydrogen is increasingly being seen as a route to lower carbon production of the fuels and chemicals that our civilisation depends upon. And the most prominent among the routes to these low carbon fuels and chemical feedstocks rely upon the two main current uses for hydrogen; ammonia and methanol production. The global ammonia market currently stands at around 180 million t/a, representing 30 million t/a of hydrogen production by weight, and the global methanol market is around 100 million t/a, representing another 12.5 million t/a of hydrogen. While these figures are certainly impressive, however, fuels markets in particular are of an order of magnitude larger. There is therefore a question as to whether it will be sustainable to base fuel and chemical production upon low carbon ammonia and methanol, and whether sufficient renewable energy resources can be tapped to generate them.

Biofuel storage tanks at Drax power station, UK

Ammonia

At the moment, ammonia is mostly (ca 80%) used as a feedstock for fertilizer production, with most of the rest going to produce various industrial chemicals such as melamine, caprolactam, etc. It is unlikely that these markets will increase drastically over the coming years, with growth tending to be incremental. In the field of nitrogen fertilizers, there are attempts to correct overapplication and leaching into water courses and to reuse nutrient bearing material flows which may indeed reduce consumption in the longer term, or at least balance increased consumption in regions such as Africa which currently under-apply fertilizer.

However, new uses for ammonia have the potential to dramatically increase consumption over the next 20-30 years. There is serious consideration being given to ammonia use as a maritime fuel in order to meet upcoming International Maritime Organisation rules on carbon emissions. Maritime engine manufacturers are actively developing and aim to soon commercialise ammonia-fuelled two-stroke and four-stroke engines in the next few years for both new builds and retrofits, and believe that they can

deliver commercial performance within existing regulatory limits for nitrogen oxides. There is also consideration being given to ammonia as a fuel for stationary power, particularly in Japan, where there is interest in burning low carbon ammonia in coal-fired power stations to lower emissions. JERA is demonstrating co-combustion of 20% ammonia and 80% coal in a 1 GW power plant, and the Japanese government roadmap targets the use of 30 million t/a of fuel ammonia by 2050, starting with co-combustion technologies and eventually moving to 100% ammonia combustion.

Ammonia is also proposed as a hydrogen carrier, to overcome the storage and distribution challenges of hydrogen, producing ammonia using low carbon hydrogen in regions where abundant solar or wind energy is available, and then 'cracking' it back to hydrogen and nitrogen where it is required.

The International Renewable Energy Agency (IRENA) has suggested in a recent report that global ammonia demand could increases from 183 million t/a in 2020 to 688 million t/a in 2050, including 230 million t/a of ammonia as fuel and 130 million t/a of ammonia as a hydrogen carrier.

Methanol

Methanol has already to some extent made the transition from a purely chemical feedstock to being used in fuel derivatives and even as a way to produce plastic precursor chemicals. Of the approximately 100 million t/a of methanol produced globally, around half is used as a feedstock for traditional chemicals production, including formaldehyde, acetic acid, methyl methacrylate etc. Another 20% is used to make olefins (MTO), mainly in China. And the remaining 30% goes to various fuel end uses, including direct blending into gasoline, direct conversion of methanol to gasoline (MTG), esters which are used as gasoline additives, esterification of vegetable oils for biodiesel production, and manufacture of dimethyl ether (DME) which is used as a blendstock in LPG.

However, as with ammonia, there is considerable interest in using low carbon methanol as a maritime fuel. Methanol has something of a head start on ammonia in that methanol marine engines have already been developed, and there are far fewer concerns in the shipping industry around safety as regards using methanol as a bunker fuel – ammonia by contrast is still viewed with some suspicion because of its toxic nature. Low carbon methanol has also been suggested for static power applications, and because of its versatile chemical nature could be used for production of low carbon plastics, gasoline etc. IRENA's report on methanol, developed in conjunction with the Methanol Institute, suggested that by 2050, global methanol demand could have reached 500 million t/a.

Low carbon feedstocks

These figures; 688 million t/a of ammonia and 500 million t/a of methanol equate to 115 million t/a and 62 million t/a of low carbon hydrogen respectively. But how to generate that much low carbon hydrogen at scale is the question that must be answered before these projections can become a reality, especially when it is considered that they must be developed in parallel with a wholesale switch over from electricity generation via burning oil, gas and coal to renewables, itself taking place at the same time that electric vehicles are demanding more and more power from the grid. Is there enough renewable power available?

Carbon capture

Carbon capture and use/storage (CCUS) – so-called 'blue' ammonia or methanol – has been a favoured route for producing lower carbon production at scale, because it is able to make use of well proven technologies at relatively modest additional cost, at least compared to fully green production using electrolysis. The International Energy Agency (IEA) estimates that 15% of carbon reduction achieved by 2050 will need to use CCUS. However, development of CCUS has not been as fast as anticipated. Over the period 2009-2021, of dozens of planned projects, only 26 came to fruition, and all but six are used for enhanced oil recovery, where the oil revenues can balance the cost of implementation. Around 25 million t/a of CO_2 is captured from these projects. It is estimated that on the basis of currently announced projects this could rise to 700 million t/a by 2050, but this is still far short of the 36 billion t/a of carbon dioxide that is currently being released to atmosphere each year, and only a fraction of the 6-7 billion t/a which the IEA projection says will therefore be required to be captured using CCUS in order to reach net zero. There is no shortage of available space in underground oil and gas formations, what is lacking is the financial incentive to press ahead with projects, though the US IRA has helped kickstart a number of new projects there by guaranteeing subsidies.

Nevertheless, a recent McKinsey report is more optimistic on the prospects for CCUS. It estimates that – given sufficient international cooperation and the availability of enough investment money – the development of 400 CCUS 'hubs' near large point source emitters (cement, power, steel, and chemicals such as ammonia and methanol) would be close enough to existing underground geological structures suitable for use in CCUS, and could capture a total of 9-10 billion t/a of CO_2 at an average cost of $100/t, and could capture 4.2 billion t/a just using 110 hubs at an average cost of $85/t. Capture costs are lowest where carbon streams are already concentrated, and ammonia and methanol are particularly suited for this as they produce concentrated CO_2 in process streams. It is also possible to use captured CO_2 as a feedstock in renewable methanol production.

Biomass

Another route to low carbon production is to use biomass as a feedstock, usually waste from forestry or pulp and paper production, though municipal solid waste is now also lumped in with these. Conversion is via gasification. The issue for biomass is cost and scale. Gathering sufficient biomass to operate a large scale plant is a difficult and hence expensive task, and most plants that have operated have been based on small scale modular production. IRENA estimates the cost of ammonia production via biomass gasification to run from $450-2,000/tonne of ammonia, making it just about viable at the lower end of scale, but in its Renewable Ammonia Innovation Outlook, IRENA says that "biomass is not expected to play a major role in decarbonising ammonia production".

Renewable electricity

Renewable electricity generation has been increasing rapidly, with 320 GW of capacity added in 2022 alone. High fossil fuel prices, the disruption to Europe's energy supply caused by the war in Ukraine, and government policies such as REPowerEU in Europe and the IRA in the US have all played a part in the current surge in renewable installations. Total capacity is expected to reach 4,500 GW next year, equivalent to the combined generation capacities of the US and China, and 6,000 GW by 2027. Most of the growth is from solar and wind; suitable sites for new hydro-electric power are few and often contentious in terms of the land that is flooded.

Around 50-90 GW of the renewable electricity used by 2027 is earmarked for generation of green hydrogen, mostly for green ammonia and methanol production. This represents only around 2-4% of new renewable capacity. However, generating the 170 million t/a of clean hydrogen we discussed earlier will require 3,600 GW of renewable electricity capacity by 2050 at average solar/wind generation rates. While this will be well within the anticipated 20,000 GW of renewable capacity forecast to be installed by that time, it also requires the same amount of electrolyser capacity, which currently stands at just 0.6 GW worldwide. Capacity must therefore increase 6,000 times – an unprecedented, perhaps even impossible number. It is worth bearing in mind that installed solar power capacity has increased by a comparable amount over the past 25 years, but even so, this looks like a tall order, barring some technological breakthrough in the technology.

And of course costs will determine the rate of uptake, and here the news is less good. Although renewable power costs have come down dramatically, and electrolyser costs have fallen significantly, CRU estimates a current cost for green ammonia of $650-900/t, more than double that for blue ammonia. Carbon pricing and government subsidies can bridge some of that gap, and costs will continue to fall, but for the time being, that looks very expensive as something to be burned as a fuel; probably four times that of a liquid fossil fuel on an energy equivalent basis. The cost of green methanol is higher still, at around $750-1,200/t, though again blue methanol is much more comparable to existing bunker fuel costs. The conclusion for the ammonia and methanol industries would seem to be that blue is the way forward, at least for now. ■

Ammonia oxidation catalyst replacement

Sumit Rao of Hindustan Platinum Private Ltd describes two recent start-up issues with catalyst gauze packs at a nitric acid plant, and their remediation to allow production to continue.

Fig. 1: Gauze pack damaged due to mechanical failure in the light-up assembly.

Mechanical failures in the catalyst pack converter are observed only infrequently, so this article describes a unique situation which deserves to be shared from the perspective of good corrective planning and implementation. Two failure occurrences were experienced one after another within 48 hours involving two different catalyst packs, but the plant restarted production within less than 36 hours of the second failure occurrence. The first failure was a result of a mechanical failure, while the second one was caused by a variance from the correct start-up procedure, resulting in catastrophic damage to the catalyst surface, rendering both packs inoperative. With no spare catalyst at hand, new catalyst supply at the site being at least two weeks away, and acid demand at its peak, a remedial measure was performed to get one of the catalyst packs up and running. We detail below the two failure scenarios and how plant production operations were restored within 36 hours of the second catalyst pack failure through teamwork and innovative restoration countermeasures.

Fig. 2: a) & b) Observations of contamination on the gauze surface from the sight glass during the running of the plant. c) Observations of contamination on the gauze surface after removal of the burner hood.

First failure

After operating the plant for about 90% of its anticipated production run, a mechanical failure in the light-up assembly caused damage and a tear to the gauze pack (Figure 1). The plant was stopped and an inspection carried out.

Second failure

The plant was restarted after replacing the damaged gauzes with a fresh set of catalyst gauze pack.

After the start-up of the newly installed catalyst pack, the plant team observed contaminants through the sight glass (Figure 2). The plant had to be stopped again due to the large scale contamination visible via the sight glass. After the removal of the burner hood, the degree of contamination was clearly visible, making the decision to shut down the plant a prudent one.

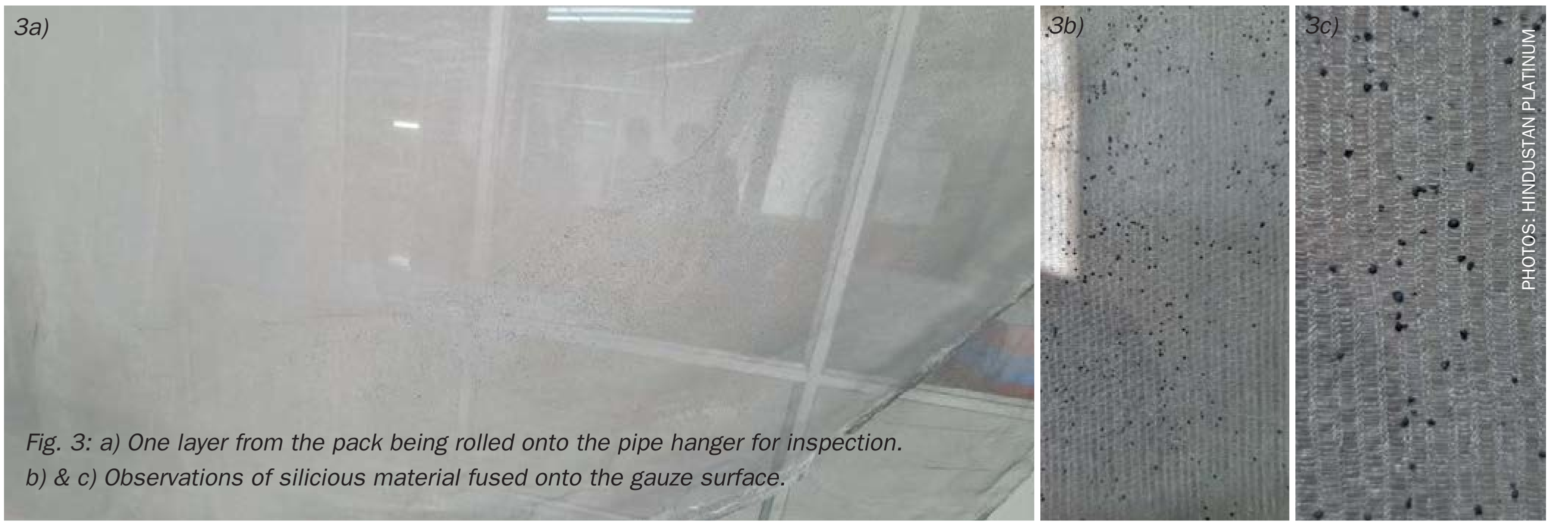


Fig. 3: a) One layer from the pack being rolled onto the pipe hanger for inspection. b) & c) Observations of silicious material fused onto the gauze surface.

Root cause analysis

The contaminated gauze pack was transported to our Hindustan Platinum (HP) facility for inspection and assessment of the gauze surface. The bulk of the contamination was removed from the gauze surface by employing suitable mechanical operations. The gauze layers were separated from the pack and rolled onto the pipe hangers for inspection purposes (Figure 3-a). Fusion of the contaminants on the gauze surface was determined to be silicious and had coverage across the entire pack (Figures 3-b and 3-c).

The surface impurities resembled the material employed during upstream piping treatment and sand blasting operations. Insufficient blowing operations after sand blasting may likely have caused the retention of these contaminants in the u-bend piping, which eventually entered the convertor during the start-up process.

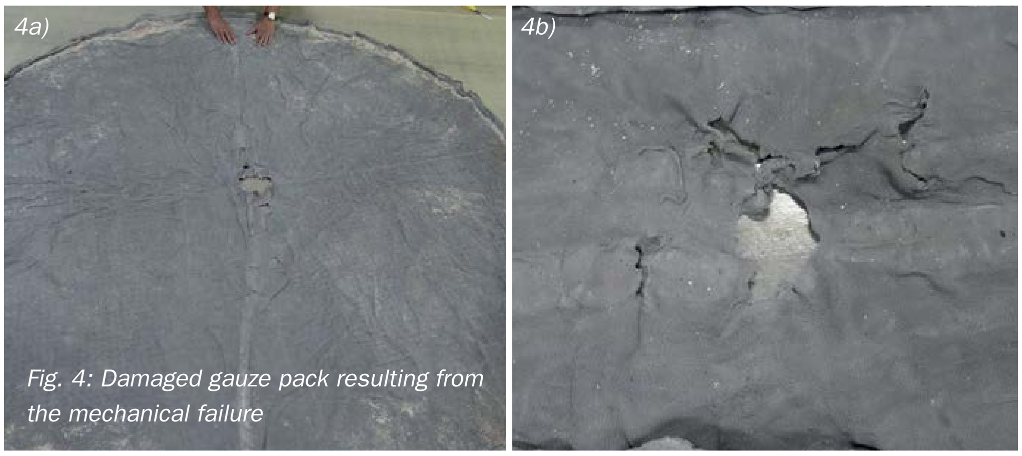


Fig. 4: Damaged gauze pack resulting from the mechanical failure

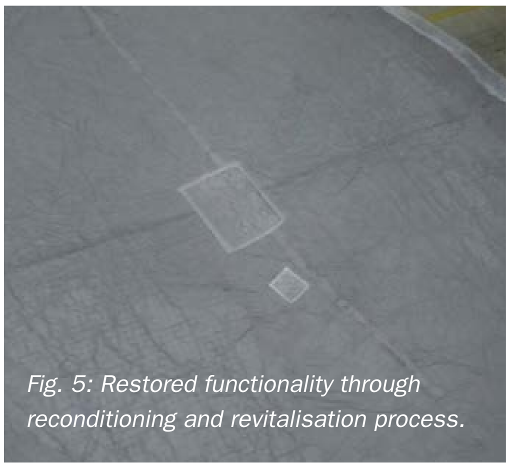


Fig. 5: Restored functionality through reconditioning and revitalisation process.

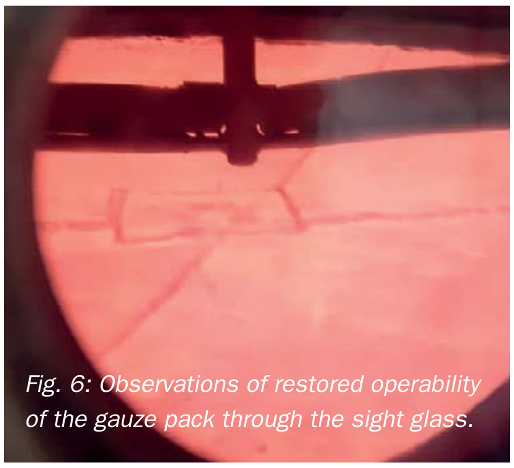


Fig. 6: Observations of restored operability of the gauze pack through the sight glass.

Remediation

Several checks and tests were carried out and the fused deposits could not be separated from the gauze surface, neither physically nor chemically, rendering the gauze ineffective for reuse. After joint brainstorming sessions between both the organisations' plant production, manufacturing, technical services, and product management teams, it was jointly agreed to instead repair the damaged gauze pack from to the first shutdown.

The damaged pack (90% used) from the first failure was taken up for restoration (Figure 4). The motivation to take up this kind of solution arose based on past feedback from customers to safeguard critical production loss. While ideally it would be recommended to replace the pack, this is a temporary solution emphasising that the reconditioned product must be operated under strict supervision and regular monitoring to ensure safe operation.

After several hours of deliberations and relentless efforts for the best outcome in the surface structure to enable continuity in the process for at least a month, a reconditioning process was taken up to revitalise the damaged catalyst pack by the production team at Hindustan Platinum, to restore each layer for operability and performance (Figure 5). The damage was: across the pack, through the centre, at the periphery, etc. It was a considerable feat to manage to bring back to life this damaged gauze pack.

Restored operability and performance

The renewed gauze pack was transported back to the plant site and installed within the catalyst basket. The plant was successfully restarted as per the normal procedure and normal observations were made in terms of its operability and performance (Figure 6).

The plant successfully restarted and operated for just under two weeks. Regular monitoring and evaluations were done during these two weeks' timeframe to ensure that the gauze performance was within the normal and safe operating criteria, until a new supply of the fresh catalyst gauze pack arrived at the plant site and was installed. ■

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56

Ammonia plant hybridisation

The ammonia industry is expected to change drastically in the coming years to meet sustainability goals and to face the problem of climate change. New low carbon ammonia plants as well as fully green facilities are expected to be commissioned to meet the target of climate neutral production.

The integration of an existing ammonia facility with green hydrogen to supplement or replace the grey ammonia production with green ammonia represents a low-risk solution to meet the requirement for running clean ammonia plants and offers the most competitive green ammonia production cost in the short term.

In this article **Sergio Panza** and **Marco M. Carlucci** of Casale paper present different scenarios based on energy availability at battery limits.

The energy transition is pushing industries toward a more sustainable model where old plants are upgraded, or converted with new technologies and processes, to reduce their environmental impact.

Increasingly stringent emissions regulations and ambitious zero-carbon energy goals are also moving existing players of the fertilizer industry as well as new investors of the ammonia industry to design new plants to meet the goals set by the energy transition model.

New plants alone cannot meet the targeted climate neutral production of goods in the timescale required and so a strategy must be developed for the approximately 600 fossil fuel based existing ammonia plants which need to be upgraded in order to satisfy new climate requirements.

Carbon border tax mechanisms are also going to play a crucial role for export-oriented producers in order to provide a more competitive product on the market. The demand for low carbon ammonia will be facilitated by end users driven by a carbon reduction strategy to demonstrate their compliance with a societal demand toward a zero-carbon goal.

Plant revamping to reduce the specific energy consumption and the CO_2 emission in general is one possible route towards this goal. Another option is plant conversion to a blue configuration with carbon capture and utilisation (CCU) or carbon capture and sequestration (CCS).

Another interesting route to update existing plants to a configuration with a lower environmental impact is the so-called hybridisation route, where green hydrogen produced by electrolysers is integrated in the existing facility with the target to decrease the CO_2 footprint and potentially to increase the plant ammonia production. Renewable energy can be utilised to promote such green hydrogen production allowing the partial (or complete) production of a premium product (green ammonia).

Planning for the continued hybridisation of existing plants should be done and will require investments enabling the transition from grey to green ammonia production.

The European renewable energy directives are pushing producers to the hybrid revamp of their existing ammonia plants, in order to reduce the carbon taxation and possibly fetch a premium price for the low ammonia carbon production.

In hybrid plants the green ammonia production cost will be quite competitive, as the capex is greatly reduced by the utilisation of many of the existing sections such as the ammonia synthesis capacity, and existing utilities.

Depending on the type of energy supply to the electrolysers (steady or erratic mode), and depending on the extent of plant hybridisation (percent of green ammonia production compared to the overall one), different outcomes are expected for the existing ammonia plant.

Casale solutions are tailored to client requests and consider such revamping boundary conditions.

Degree of hybridisation

Depending on the extent of green hydrogen integration in the existing plant and the type of green hydrogen supply (steady or erratic), different outcomes and modifications could be required to implement the new hybrid arrangement.

In general, green hydrogen is injected at the suction of the syngas compressor machine even if other locations are also possible (e.g., upstream of the methanator or directly inside the synthesis loop).

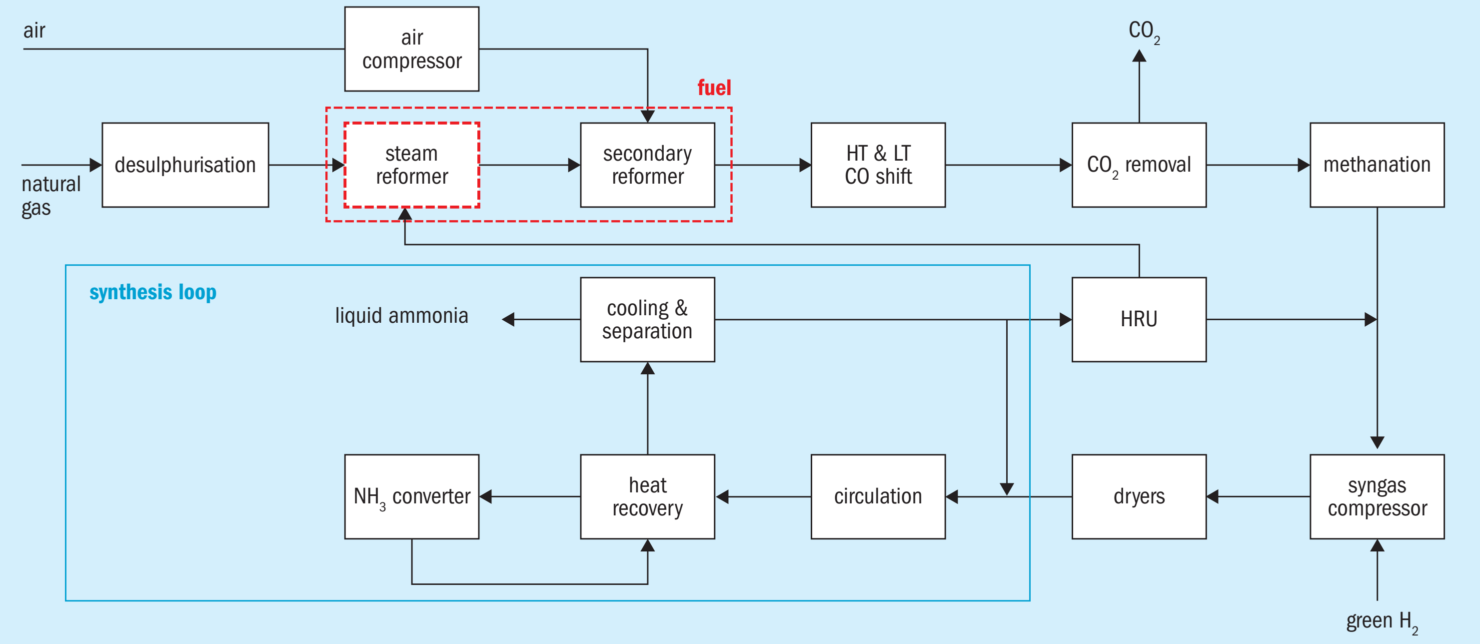
In case green hydrogen supply contains potential poisons for the ammonia converter catalyst (e.g., oxygenated compounds, sulphur compounds, halogens, olefins), adequate pre-treatment must be foreseen before integrating it into the existing plants.

For a low degree of hybridisation (say green hydrogen represents less than 5-10% of the total hydrogen fed to the ammonia synthesis), it is reasonably expected that no (or minor) modifications are necessary to the existing ammonia plant, regardless of the type of green hydrogen supply (steady or erratic).

Steady power supply

If the renewable source is always available at constant value (e.g., from hydroelectric or geothermal power), a high degree of hybridisation of the existing plant can be reached with few modifications.

Fig. 1: **Existing plant main areas affected by typical plant hybridisation**



Source: Casale

Low plant hybridisation (typically up to 10%) with steady green hydrogen supply can be accommodated without any major modification.

Total hydrogen supply at the syngas compressor suction must deal with existing machine limitations, so it is necessary to reduce the front-end load to accommodate the extra gH_2.

Since part of the hydrogen is supplied at the syngas compressor suction, bypassing the plant front-end, a change in the operating conditions of the reforming section is expected. In particular, the air to feed gas ratio in the secondary reforming section needs to be increased to compensate for the extra hydrogen and to supply the required nitrogen.

To control the secondary reformer outlet temperature and avoid jeopardising the downstream waste heat boiler, the primary reformer outlet temperature is decreased. The methane slip of the reforming section is controlled as duty is shifted from primary to secondary reforming.

The impacts on the primary reformer convection coils should be evaluated, but typically at 10% hybridisation they are minor and no modification to the convective section is required.

Changes in the steam balance are also expected due to the different boiler production at the new operating conditions.

The synthesis loop and in particular the ammonia converter operating conditions could benefit from green hydrogen integration thanks to the lower inert content of the new makeup gas: gH_2 stream from electrolysers is inert-free, allowing for more room in the plant back end.

The lower inert content requires a careful check of the outlet temperature from the ammonia converter, to avoid any operation of the converter and the downstream equipment beyond their temperature limits.

Plant hybridisation will potentially reduce the CO_2 production in the process line, however in case of a CO_2 requirement for downstream production (e.g., for a urea plant), the process gas flow through the reforming section can be kept unchanged, recycling part of the synthesis gas downstream of the CO_2 removal section to the fuel gas system.

In this way a pre-combustion strategy for carbon capture can be integrated with green hydrogen injection into the plant.

Another revamping option, in case of the availability of an oxygen stream from electrolysers and steady state integration, is the injection of the oxygen stream into the process air going to the secondary reformer to enhance the methane conversion in the secondary reformer.

Since the load of the primary reformer radiant box is further reduced, the amount of flue gas going to the convection section is also decreased, allowing for additional plant CO_2 emissions reduction.

The primary reformer convective section should be verified since the operation of the convection coils and steam superheating in particular will also be affected.

As previously indicated, a low degree of green hydrogen integration is not going to require any change to the plant configuration; conversely, a larger integration would involve a deeper check of the existing plant and likely involve some modifications. However, such plant upgrading can be treated as a "standard" revamping project, due to the stability of green hydrogen feed.

If a mild or high degree of hydrogen integration is required (up to 30-40% and above) an external nitrogen source is necessary. The primary reformer operating temperature would be decreased too much to accommodate the required air to gas ratio, leading to fuel maldistribution in the radiant box.

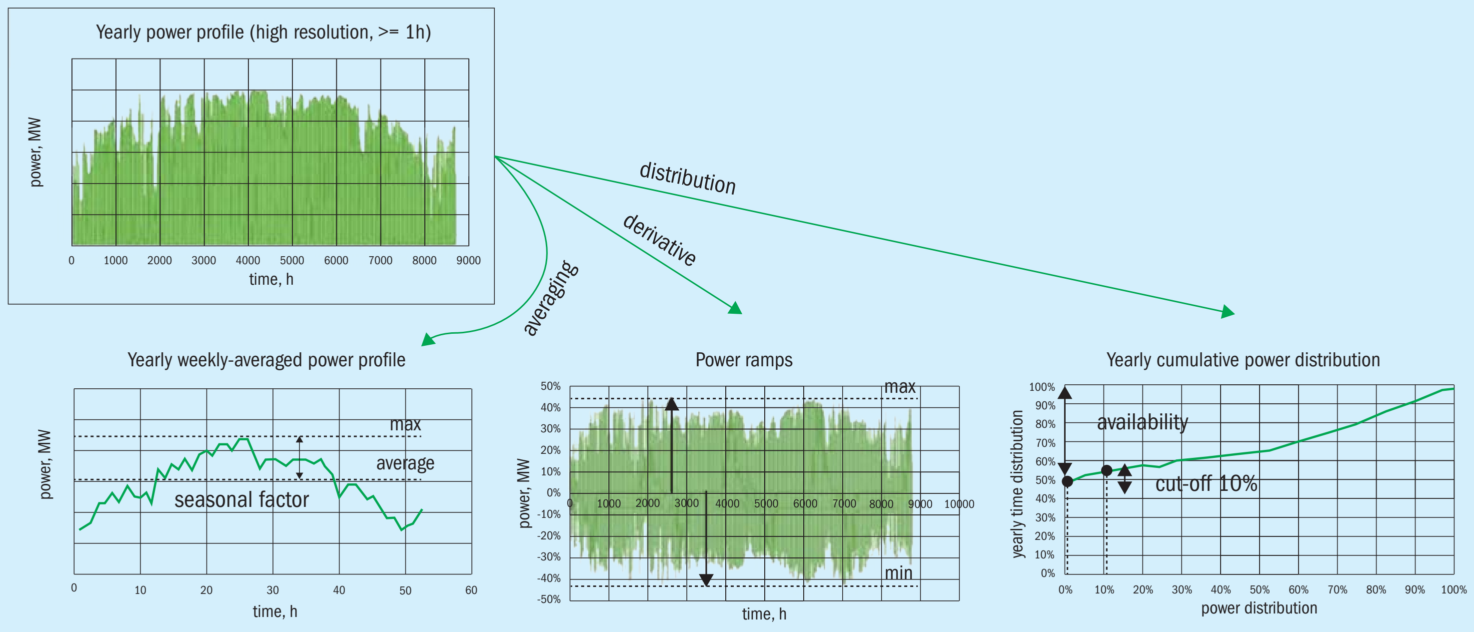
Extra nitrogen feed, if not already available at plant battery limits, can be provided by a new PSA or ASU.

With enough extra-nitrogen and steady gH_2 supply, a complete plant conversion to green ammonia production is achievable (i.e. 100% hybridisation). In such a case the plant front-end should be idled and ammonia production will rely entirely on gH_2 and gN_2.

Full hybridisation of a plant can be reached with a step-by-step approach, taking advantage of the increasing level of CO_2 taxation to improve project economics.

In case of fluctuating power supply, and therefore erratic green hydrogen feed flow to the synthesis loop, a different approach is required to avoid cyclic

Fig. 2: **Typical power profile analysis**



Source: Casale

plant operation that would lead to fatigue issues, which could severely impact the mechanical integrity of equipment and therefore require costly upgrading interventions.

Erratic power supply

Per definition, renewable energy is often tied up with erratic power generation. Green hydrogen and green ammonia production need to be able to cope with such feed flows.

The intermittency of renewable power requires a higher flexibility of the ammonia process and presents challenges due to the intrinsic operational discontinuities.

Efficient utilisation of the available renewable power affects the project capital investment cost. The licensor goal is to minimise any impact on the capex, maximise the renewable power utilisation and ensure safe plant operation avoiding any damage due to fatigue issues.

Power profile analysis

The power profile from renewables (used to feed the electrolysers) features specific parameters that affect the design of the green ammonia plant. These parameters are:

- **Capacity factor**, defined as the ratio between the average production and installed capacity, which gives a benchmark for the generation over the year.
- **Seasonal factor**, defined as the ratio between the average of the daily average power and the maximum daily average peak. This parameter provides a better understanding of how big the fluctuations are between different seasons.
- **Ramp up/down**, defined as the load variation in one hour with respect to the average capacity, which gives an indication of the stability of the renewable sources.
- **Availability**, defined as how long a certain percentage of the installed capacity is available.
- **Cut-off**, defined as the renewable power that cannot be used or stored. This parameter must be minimised in order to reduce inefficiencies.

The power profile variability and fluctuation can give a preliminary idea of the economic feasibility for the project, since high variation and low availability lead to increased hydrogen storage requirements (when its use is foreseen) with detrimental effects on the capex.

As previously mentioned, a low degree of plant hybridisation (typically up to 5-10%) is not going to require major plant modifications even if the gH_2 supply is erratic.

However, mild plant hybridisation (up to 25-30% gH_2) can be carried out if an additional nitrogen source is available. The extra nitrogen can be used to compensate for fluctuations in the hydrogen feed, avoiding modification of the air to gas ratio in the front-end.

Extra nitrogen feed, if not already available at plant battery limits, can be provided by a new PSA or ASU.

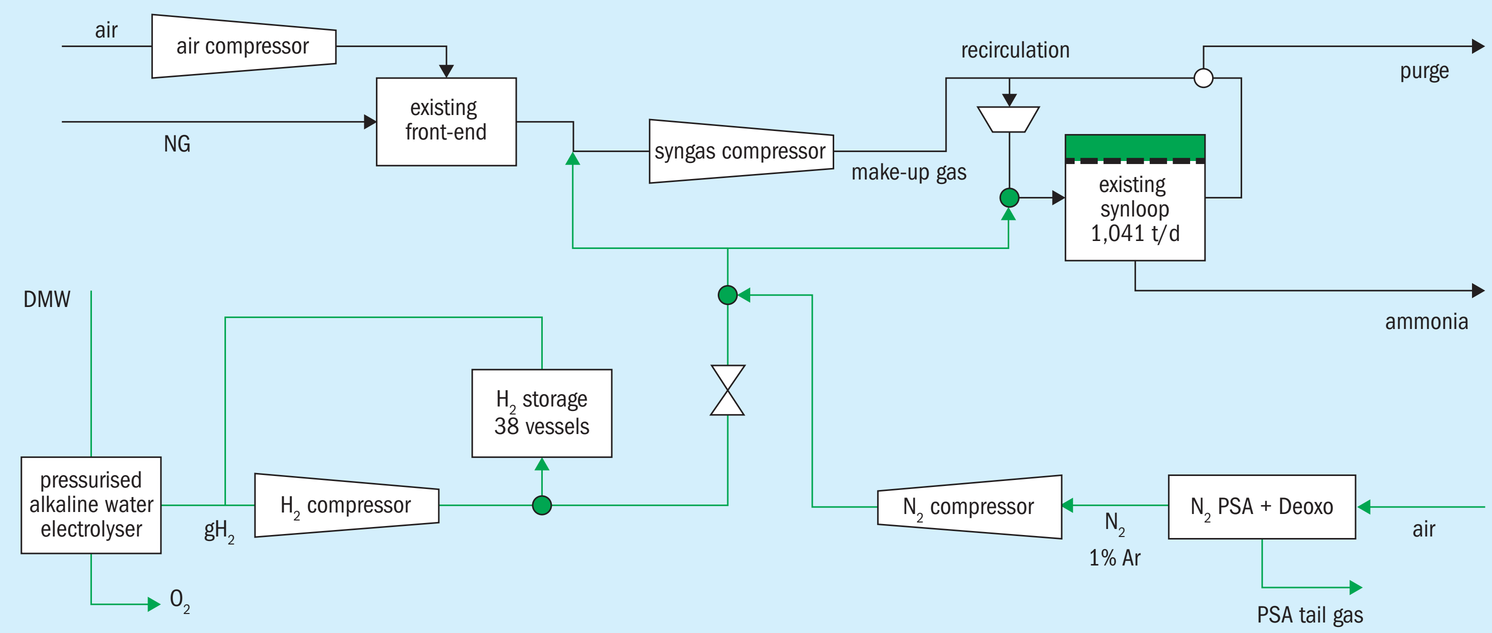
In case of no extra nitrogen availability, it is still possible to target a low degree of hybridisation, but a careful check on front-end equipment must be carried out to ensure that no fatigue issues are encountered, or alternatively the plant should be adequately upgraded to cope with such operating conditions.

For a high degree of plant hybridisation (say above 30%), the use of hydrogen storage to optimise the feed profile is typically necessary to avoid costly power cut-offs and ensure the economic profitability of the project.

Hybridisation degree achievable with erratic power supply, as well as project economics, are strongly dependent on the power supply profile: in general, high capacity factor profiles will allow a higher hybridisation degree with a lower capital investment cost.

In case of erratic power supply, oxygen from the electrolysers cannot be used in the secondary reformer to promote NG reforming as it would entail a significant change to the front-end operating conditions, creating the conditions for cyclic operation of the plant, thus fatigue issues which are costly to deal with.

Fig. 3: **Process scheme for high hybridisation with erratic green power supply and no extra nitrogen available at plant battery limits**



Source: Casale

Hydrogen storage

As the electrolyser dynamic is much faster than the ammonia plant dynamic, when the amount of erratic green hydrogen supply becomes comparable to the grey hydrogen produced by plant the front-end (hybridisation degree 30% and higher), it is convenient to foresee a hydrogen buffer.

The hydrogen storage system should be designed to cope with the unpredictability of some power profiles and to increase the daily trend gH_2 supply (e.g. wind and solar systems).

Operation based on so-called "hot stand-by" mode is also possible but is considered less profitable for the plant economics and is not discussed further here.

The installation of a hydrogen storage system is meant to stabilise the green hydrogen supply to the ammonia synthesis loop, maximising the gH_2 intake and minimising green power cut-off.

Casale solution for hybrid plant fed by erratic power supply

Casale hybridisation of existing ammonia plants follows the below principles:

- minimise changes to the existing plant, minimise/avoid H_2 storage installation;
- minimise operator engagement for daily control of plant based on input of renewables;
- minimise upset to the existing plant front-end due to the fluctuating hydrogen supply.

In case of erratic power supply: ammonia plants can typically accept 5-10% hybridisation without any major intervention. A higher degree of hybridisation (higher than 10%), as a general rule, requires some independent extra nitrogen to balance the green hydrogen.

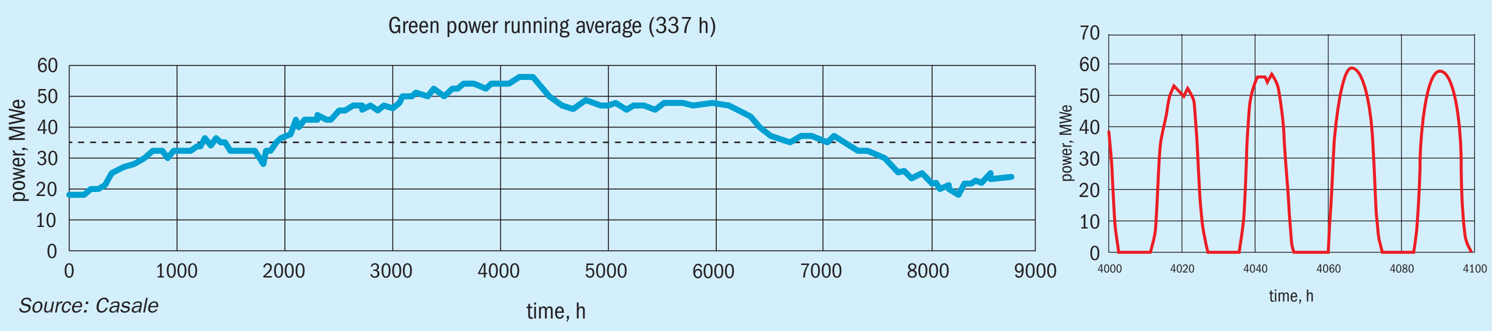
The typical arrangement for a high degree of hybridisation (higher than 30%), erratic green energy supply and no extra N_2 availability at plant battery limits is reported here, for reference.

As shown in Fig. 3 the gH_2 injection can be conveniently located at the syngas compressor suction or directly inside the synthesis loop; the presence of a small hydrogen storage supply would guarantee continuous green ammonia production even when green power is not available at battery limits. The hydrogen storage would also minimise fluctuation in the hourly ammonia production.

If desired, the plant can be configured without hydrogen storage, but a small hydrogen buffer is in any case suggested to smooth green hydrogen upsets.

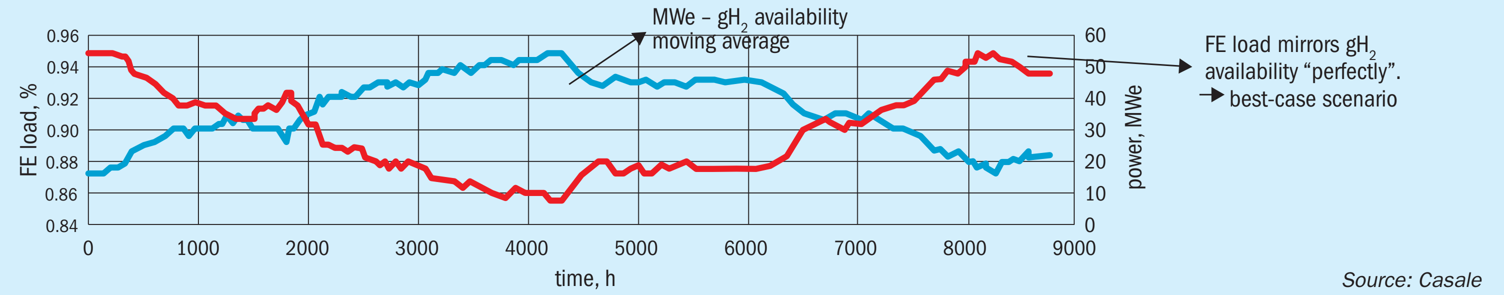
To minimise green power cut-off, the idea developed by Casale is to produce more grey ammonia when minimum green hydrogen is available in winter and more green ammonia in summer where maximum hydrogen production is expected.

Fig. 4: **Averaged power profile for a full PV system with 30% capacity factor**



Source: Casale

Fig. 5: **Front-end load profile according to power supply curve**



Since total hydrogen supply at the syngas compressor suction must deal with existing machine limitations, to introduce the extra gH_2 it is necessary to reduce the front-end load. The final target is to achieve ammonia plant decarbonisation and potentially also a capacity increase, made possible thanks to the reduction of synloop inerts or by exploiting the room available in the existing machinery and equipment.

Considering a reference power profile such as the one in Fig. 4, the above statement can be translated in an existing front-end (FE) operation that is mirroring the green power (green hydrogen) supply (see Fig. 5).

A continuous change of the FE load following the average renewable power supply should be avoided, since this would require costly equipment upgrades to ensure their mechanical integrity due to cyclic operation of the system triggering fatigue issues.

To solve this issue, the front-end load would be modified according to a "stepped" strategy: namely the front-end load is chosen, for instance, on a weekly basis or every two weeks to avoid continuous adjustment of the operating parameters.

The back-end of the plant would be vice versa operated according to continuous and flexible adjustment of the operating parameters, according to the same philosophy applied for the Casale flexible green ammonia plant solution.

The ammonia converter would be operated keeping the synloop operating pressure and temperatures almost constant. This is achieved thanks to a properly designed control philosophy that would allow the synthesis loop to be operated over a wide range of operating load.

In Casale new green ammonia plants, for instance, such a control philosophy allows the plant to operate with a capacity range of 10-110% and according to quick ramp-up and ramp-down parameters (3%/min).

In case of power supply with a low capacity factor (i.e. low average output with respect to installed capacity) or when a high degree of hybridisation is required, the installation of a hydrogen storage system together with the aforementioned FE stepped solution becomes interesting, since it helps to maximise the green energy intake and minimise green energy cut-off.

In case no hydrogen storage is foreseen, higher back-end load variation is expected following the erratic power supply trend, in addition to higher green energy cut-off or (alternatively) lower average ammonia production.

The solution developed by Casale is based on a historical power trend, however weather forecasts can be integrated to adjust the trend to the current plant environmental conditions.

The proposed FE stepped solution offers the following benefits:

- the overall decarbonisation is almost proportional to the gH_2 integration;
- FE cyclic operation is avoided;
- LCOA with this solution is lower compared to a parallel green Haber Bosch loop as well as with other solutions expecting either the use of green hydrogen as fuel or the installation of a big hydrogen storage system;
- proposed solution minimises H_2 storage;
- solutions are under patenting phase (pending);
- synloop operation under erratic power supply is managed as per usual Casale green ammonia solutions (load can ramp-up and ramp-down according to Casale technology).

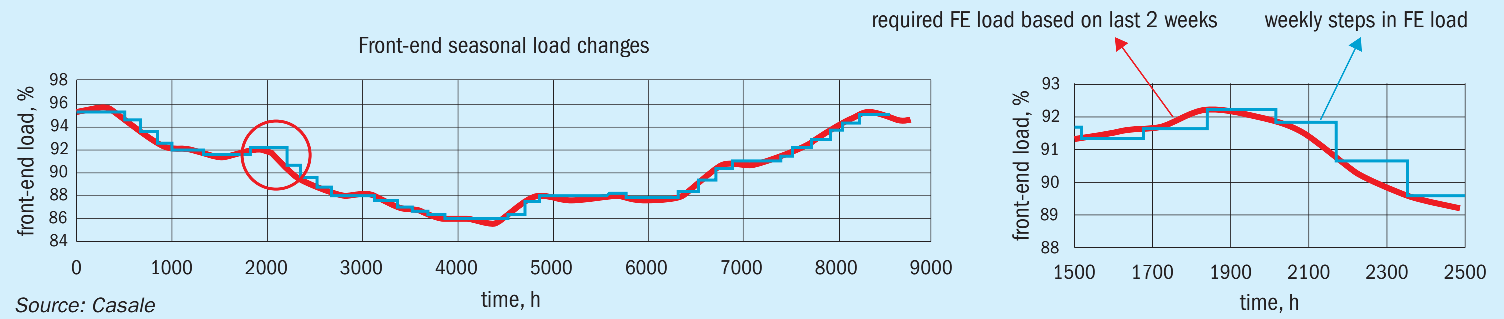
Hybridisation case study

To better understand the concept behind the Casale solution an example for a 1,000 t/d existing ammonia plant is presented. The selected operating case is expecting an averaged yearly green ammonia production of 10% through a plant hybrid revamp; this example can be extended to a higher degree of hybridisation providing similar outcomes.

The power generation unit is based on a full PV system as per Fig. 4, while FE load is chosen on a weekly basis as per Fig. 6.

The following example has been developed assuming to limit the plant hourly

Fig. 6: **Stepped front-end load**



1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56

Table 1: **Ammonia plant loads in typical summer and winter days**

Operating condition	Front-end load	Synloop load	H_2 from electrolysis (kg/h)	H_2 to storage (kg/h)	H_2 directly to loop (kg/h)	H_2 from storage to loop (kg/h)	Syngas from front-end (kg/h)
Baseline	100%	100%					
High FE load (winter) Daytime	95.30%	102.50%	1,698	1,161	537	0	42,981
High FE load (winter) Nighttime	95.30%	97.50%	0	0	0	183	42,981
High FE load (summer) Daytime	85.70%	102.50%	2,390	1,149	1,241	0	38,661
High FE load (summer) Nighttime	85.70%	97.50%	0	0	0	876	38,661

Source: Casale

production variation within 5% between the maximum and the minimum achievable by the hybrid plant and according to the available power profile; such boundary conditions have been kept throughout the year of operation and for this reason a small hydrogen storage unit has been required.

Table 1 summarises the achievable front-end and synloop performances during a typical winter and summer day.

As can be noted during the winter day the FE load is kept constant (a fixed FE load is preliminarily selected for such a week), while the synloop load can move within the allowance (5%) provided as boundary conditions.

Being the green portion of the plant based on full PV power generation system, during daytime the hydrogen produced by the electrolysers is partially fed to the ammonia synthesis loop, while the balance is fed to hydrogen storage, this stored hydrogen will be used to enable the night operation of the green portion of the hybrid plant.

During a typical summer day, the FE capacity is kept constant and, as expected, at lower load compared with the typical winter day, because of the higher renewable power availability that would allow higher green hydrogen production from the electrolyser; during daytime this hydrogen is partially routed to the synthesis loop and partially to the hydrogen storage unit. During night-time stored green hydrogen is supplied to the synthesis loop.

From Table 1 it can be seen that:

- plant capacity is always kept between 97.5% and 102.5% compared to the baseline production;
- only the synloop must be able to change load quickly;
- summer balances are the furthest conditions from baseline (most green H_2 + N_2 input). Summer day-night transitions are therefore the largest jumps in operating conditions.

Turning the focus of the analysis to the ammonia synthesis converter, it can be easily assessed that Casale proprietary solutions for flexible Haber Bosch loops provide a constant synloop operating pressure as well as almost constant converter operating temperature. The purge gas in Table 2 was slightly changed however this is not a requirement of Casale's proprietary solution for loop control.

As shown in Fig. 7 and for the selected example, the major factor affecting capex and opex, due to plant hybridisation is the cost of electricity and the electrolysers.

The hydrogen storage capex can be further reduced by allowing a final hourly production variation of higher than the assumed 5% (initial boundary conditions selected for the presented hybrid revamp example).

Conclusions

Fertilizer producers have a window of opportunity to adapt the operation of their existing plant as well as to develop new facilities to help reduce the disruption that climate change will ultimately bring.

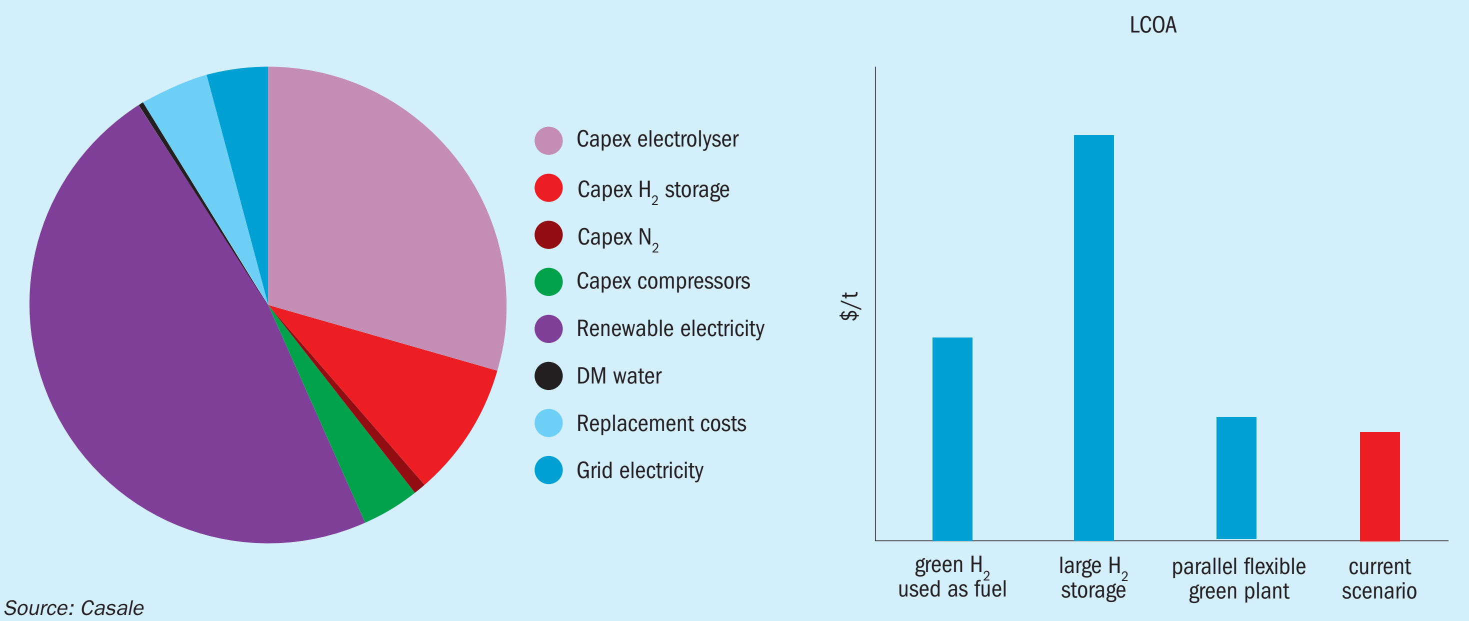
New challenges towards sustainable power and chemical production to minimise

Table 2: **Ammonia converter and loop pressure in a typical summer day**

Operating condition	FE load	Synloop load	Purge flow (kmol/h)	Recycle ratio	Tout (°C) Bed 1	Tout (°C) Bed 2	Tout (°C) Bed 3	P (bar) @ mixing point
Baseline	100%	100%	383	2.91	483.4	442.5	420.9	135.7
Low FE load (summer) Daytime	85.7%	102.50%	355	2.90	484.7	444.1	420.7	135.7
Low FE load (summer) Nighttime	85.7%	97.50%	340	2.88	482.3	442.3	419.4	135.7

Source: Casale

Fig. 7: **LCOA comparison, opex and capex**



Source: Casale

the environmental impacts and carbon footprint are on-going and plant hybridisation of existing units provides significant advantages thanks to the availability of the existing plant sections, which minimise the capex investment required.

Casale has provided solutions focused on updating existing facilities by the integration of green hydrogen, in particular a new concept has been proposed for plant hybridisation involving erratic power supply without affecting the mechanical integrity of the existing plant.

The new proposed scheme provides an efficient arrangement targeted at reducing the carbon footprint and allows premium production in the most reliable and simple way.

Reducing the carbon footprint of ammonia plants

With the current focus on decarbonising ammonia production, **Tom Davison** of Johnson Matthey explains the important role of high activity ammonia synthesis catalyst in the production of green ammonia.

In the transition to a low carbon economy there is an ever increasing need to develop technology to decarbonise the chemicals, fuel and energy sectors. Along with decarbonising ammonia production for the existing markets of fertilizer and speciality chemical production, ammonia is also seen as a key part of the future energy strategy as an effective hydrogen transport vector. In countries with emissions trading schemes there is an extra incentive to reduce a plant's carbon footprint, especially in Europe where carbon prices have risen considerably in early 2022. The volatile and high gas prices being seen in a lot of regions over the last couple of years are also an effective driver to increase plant efficiency in order to drive down opex costs. For new plant designs the focus on green and blue ammonia flowsheets as an effective way of addressing these issues and these technologies are key to achieving GHG reduction targets, whereas for existing conventional plants the transition is more difficult and will be more gradual, with revamps or replacement over time to low carbon alternatives.

Away from the established markets for ammonia in fertilizers and chemical production, which will continue to grow, there is also projected to be a large emerging market for ammonia as a hydrogen transport vector. A lot of developmental focus was initially going into green hydrogen production as a source of fuel or energy vector/storage medium, but hydrogen itself is not the best choice, having a low energy density and being difficult to store and transport. Looking at other potential choices, ammonia is currently considered a front-runner as a hydrogen transport vector due to a high hydrogen density (120 kg H_2 per m^3 at -33°C, 1 atm)[1] and existing infrastructure for storage and transportation associated with the mature fertilizer and chemicals industry. Ammonia can also be used as a fuel itself, either as pure ammonia or partially decomposed ammonia along with the option to fully decompose to hydrogen for use in fuel cells or energy generation. Whilst ammonia does not contain carbon, so there isn't the potential issue of CO_2 generation at point of use or decomposition, care does need to be taken in the design of ammonia crackers or when using ammonia as a fuel to minimise/abate NOx emissions and N_2O, which is in itself a potent greenhouse gas. Plants to service this market will be blue or green ammonia designs and are projected to make up the majority of the new ammonia plants being built in the mid to long term.

Clean ammonia production

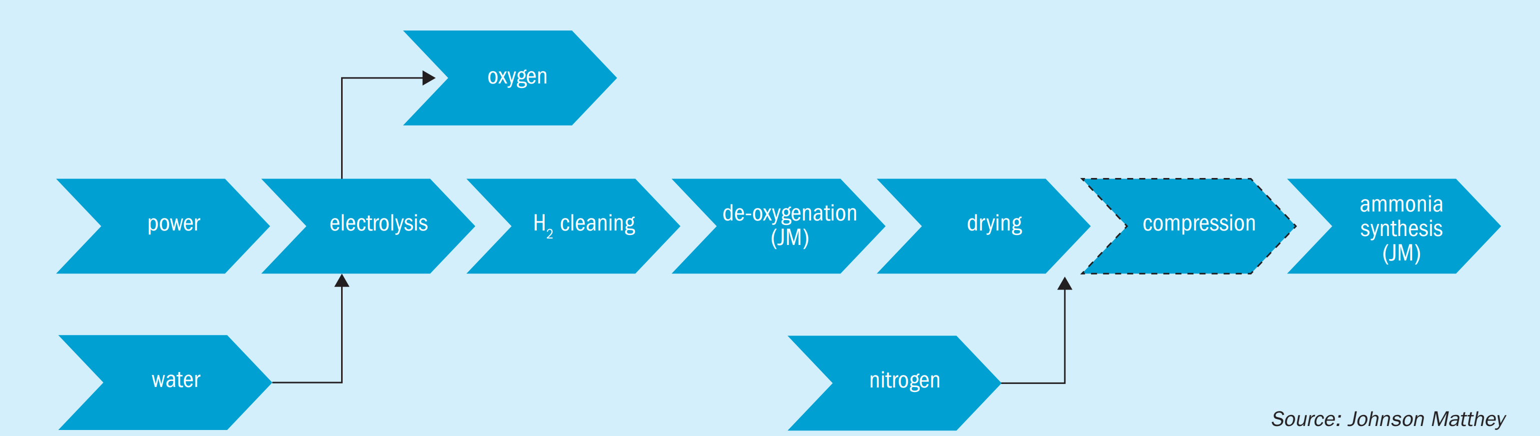
Blue ammonia

Blue ammonia will be a key technology in the drive to low carbon ammonia and energy, whilst carbon dioxide is still produced by the process, it is produced in a form which can be captured and sequestered. This technology is closer to a conventional "grey" ammonia plant and as such in the short term is more viable for the bulk of the large-scale new ammonia plants, whereas green ammonia technology at this scale will likely become more prominent in the mid to long term. The major differences between existing "grey" ammonia plants and blue ammonia flowsheets are around the reforming section, with auto-thermal reforming (ATR) technologies such as Low Carbon Hydrogen LCH™ being used to generate hydrogen as this means that up to 99% of CO_2 can be captured within the process. The conditions within the synthesis loop will be within the bounds of currently operating plants. Both KATALCO™ 35 series and the high activity KATALCO 74 series catalysts have proven strong performance at these conditions – in particular the KATALCO 74 series catalysts can be used to maximise activity within the ammonia synthesis reactor and optimise loop performance.

Green ammonia

In the longer term, and particularly for ammonia production for the energy market, green ammonia production is in the best position to become the dominant technology. Reductions in renewable energy costs, improvements in electrolyser technology, higher natural gas prices recently in much of the world and the drive to reduce carbon emissions mean that green ammonia is looking increasingly favourable as a viable alternative to traditional ammonia production technologies. The majority of projects in development are based on updated AWE (alkaline water electrolysis) or PEM (proton exchange membrane) type electrolysers, with a flowsheet similar to that shown in Fig. 1, a process schematic showing the building blocks of a typical green ammonia process.

Fig. 1: **Typical schematic of a green ammonia process**



Source: Johnson Matthey

One of the big considerations for these plants is how best to match the input power to the desired ammonia production rates. To effectively decarbonise the system the power generated must come from renewable or decarbonised energy production, but most renewable energy production methods have large fluctuations in output, for example wind and solar energy both fluctuate greatly depending on the weather. There are various methods in development to mitigate these effects, but despite this there will be more fluctuation in the flow of syngas to the synthesis loop compared to a conventional "grey" ammonia plant, so this will need to be factored into the design of the equipment in the loop to ensure that it is robust and adaptable to these conditions.

The green ammonia technologies in development fall into two major categories – designs with high pressure synthesis loops and those that have low pressure ammonia synthesis at the electrolyser operating pressure. The low-pressure plants tend to be at a smaller scale or modular in design, with multiple modules to achieve the desired capacity. The high-pressure plants may also have a modular approach in terms of the electrolysis section, with the potential to add more capacity over time but they have a large ammonia synthesis loop operating at high pressures (from 130 to over 300 barg). Some of the projects focussing on the smaller/modular plants are designing for ammonia production at the operating pressure of the PEM electrolyser to reduce the need for compression. These projects are looking at ammonia synthesis at significantly lower pressures than existing large scale ammonia production, from some as low as 20 barg to around 45 barg, with relatively low conversion per pass of ammonia in the synthesis reactor due to the less favourable equilibrium conditions.

A study carried out by the University of Cambridge looked into the potential for using integrated reaction and absorption in a single vessel for green ammonia synthesis production and separation, with the absorbent to remove product ammonia and reduce the impact of equilibrium on the ammonia production rate[2]. As part of this work, various catalysts were tested at low temperatures and pressures (220-400°C, 20 barg) to look at the operating conditions that may be seen on small scale green ammonia units. At these conditions it was found that, on a volumetric basis, KATALCO 74-1 showed comparable reaction rates to the ruthenium-based catalyst they were testing and actually exceeded the ruthenium catalyst at lower temperatures.

For the high synthesis pressure type designs the conditions within the loop are similar to conventional ammonia plants or with even higher pressures so the reaction equilibrium is relatively good and conventional catalysts are suitable for this duty, with KATALCO 74-1 GREEN a superior choice to deliver high performance in the centralised synthesis loops.

In the UK as part of National Net-Zero Project a Green Ammonia Demonstrator was designed, built and commissioned at the Science & Technology Facilities Council (STFC) Rutherford Appleton Laboratory in Oxfordshire in 2018. This unit was loaded with JM's high activity KATALCO 74-1 GREEN ammonia synthesis catalyst. The aim of the project was to be a small-scale demonstrator for the world's first roundtrip application of green ammonia for energy storage (power-to-ammonia-to-power). The project was part of the Siemens-led Decoupled Green Energy project and is now entirely operated by STFC.

ASPIRE, a UK government funded project headed by STFC in collaboration with The University of Bath, Johnson Matthey and Frazer Nash Consultancy, is a project to build a 150 kW green ammonia demonstration plant (also to be located at the Rutherford Appleton Laboratory), powered by a combination of solar PV panels and a wind turbine. Due to the nature of the renewable energy generation the power input to the plant will vary considerably with changing wind and sun conditions and it is being designed for flexible generation. The unit comprises a PEM electrolyser and PSA nitrogen generator feeding into an ammonia synthesis loop with a three-bed, quench-cooled reactor, installed with KATALCO 74-1 GREEN catalyst. There is a Smart battery in the flowsheet, but it is

Fig. 2: Green ammonia demonstrator plant installed with KATALCO 74-1 catalyst

PHOTO: JOHNSON MATTHEY

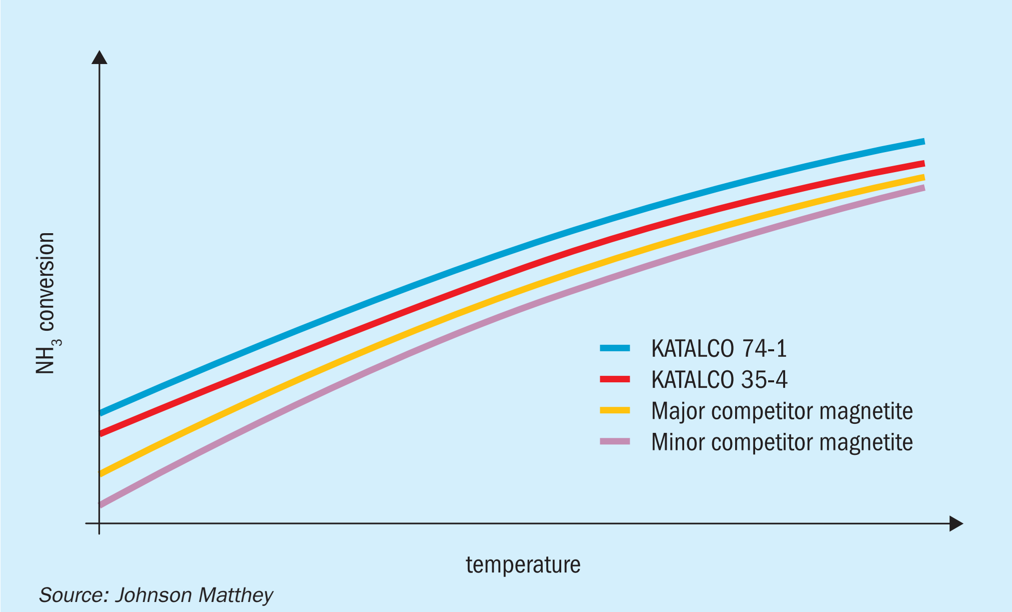
relatively modest in scale and the plant is being designed for high turn down rates and transient operation such that the ammonia generation tracks the intermittent renewable power. Unlike many of the other smaller scale plants the ammonia synthesis reactor within this unit is designed to operate at more conventional operating pressures of approximately 100 bar.

To assess the viability of ammonia synthesis at the low pressures associated with many of the small, modular green ammonia units in development, testing of KATALCO 74-1 GREEN catalyst was undertaken down to pressures of 25 barg. This testing and associated modelling confirmed that KATALCO 74-1 GREEN still shows high activity at these low pressures and Johnson Matthey's in house models provide a good measure of the reaction dynamics even in this operating envelope. Due to the low pressures the equilibrium conversion is significantly lower than in conventional ammonia synthesis reactors so the outlet ammonia concentration from the reactor is lower (likely <10 mol-% NH_3) and a higher recycle rate would be necessary compared to the higher pressure loops.

High activity KATALCO 74-1 catalyst

KATALCO 74 series high activity catalysts were initially developed for used in the AMV and LCA processes, as the low pressure (80 bar) synthesis benefitted from a more active catalyst. As this increased activity compared to conventional magnetite catalysts is applicable over the whole range of ammonia synthesis converter pressures however, more recently it has been adopted for high pressure synthesis loops along with the lower pressure applications. This increase in activity, illustrated in Fig. 3, and an increased ease of

Fig. 3: **Comparison of magnetite catalyst performance**



Source: Johnson Matthey

reduction are achieved by incorporation of cobalt oxide as a promoter and differing re-optimised levels of the other structural and electronic promoters compared to standard magnetite catalysts. The cobalt has the effect of increasing the rates of nitrogen adsorption and ammonia desorption from the surface of the catalyst, hence increasing the rate of the overall synthesis reaction.

A number of studies[3-6] into the location of cobalt in ammonia synthesis catalysts have looked at the reasons for the positive effect on catalyst reduction and activity. In these studies, cobalt oxide is found as a solid solution dissolved in the magnetite phase. The incorporation of cobalt into the iron lattice distorts the structure of the fused iron catalyst, generating layers of cobalt spinels which typically produce smaller iron crystallites on reduction, as shown in Fig. 4, benefitting the catalyst activity.

This catalyst is robust and stable, with the high activities relative to conventional magnetite catalysts sustained over long catalyst lifetimes. Johnson Matthey has a long list of references for these KATALCO 74 series catalysts, all showing high activities maintained for long lifetimes with a number of plants operating for over 20 years on the same charge. LCA plants were designed to have a more flexible loop than conventional ammonia plants, so whilst not as variable as some of the new green ammonia plants are designed to be the catalyst within these LCA plants has coped with more transient operation in terms of temperatures and pressures than in more conventional loop designs and proved stable.

Revamps of existing plants

The scope for low carbon solutions via revamps is dependent on the final product manufactured on the site – if the ammonia

PHOTOS: JOHNSON MATTHEY

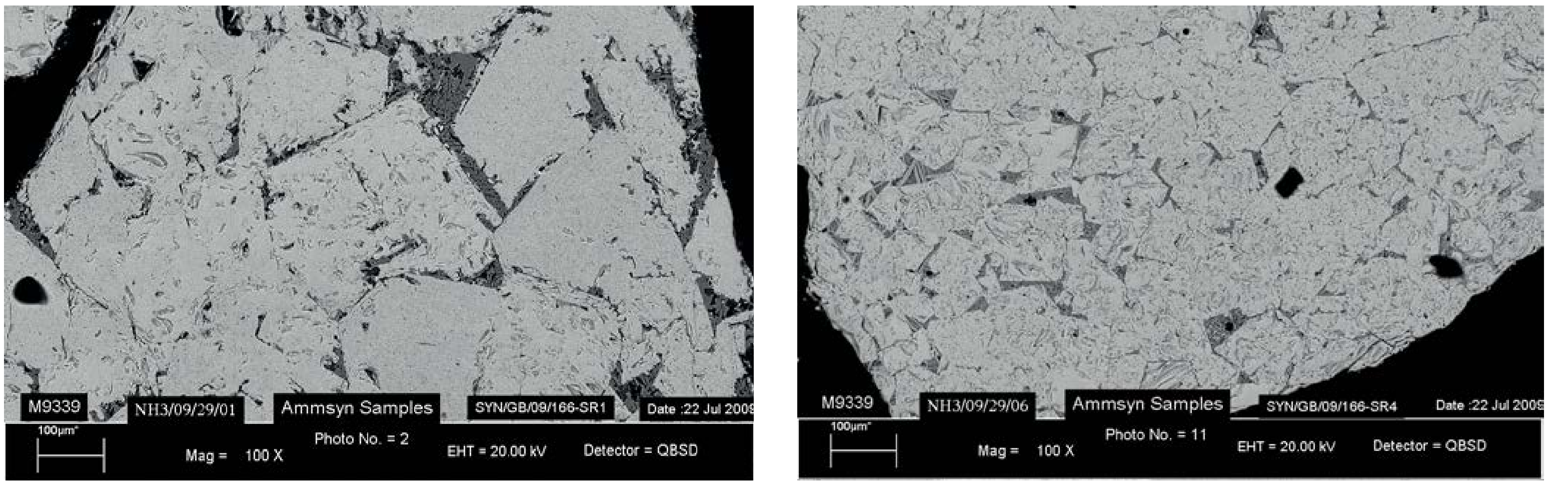


Fig 4: Microscopy images of standard and cobalt promoted magnetite.

is fed to a urea plant then the majority of the carbon dioxide recovered in the CO_2 removal stage will be used as feedstock for urea production. In this case there is potential for carbon capture and storage (CCS) only from the flue gas exit the primary reformer and any surplus CO_2 not required for urea production. If the plant is producing merchant ammonia or the site is manufacturing ammonium nitrate, etc. then more of the carbon can be captured and sequestered with potential CCS on both the flue gas from the primary reformer and the CO_2 stream from the CO_2 removal stage. Concurrently with installing CCS technology many plants will look to make other improvements during a revamp project including debottlenecking and opex reductions, where a high activity ammonia synthesis catalyst such as KATALCO 74-1 can be utilised in conjunction with other upgrades to get the most out of the plant. Some plants have also added additional capacity by installing an electrolyser to feed clean hydrogen into the front end of an ammonia plant, to partially reduce the emissions from the plant and enable the producers to charge more for this proportion of green ammonia. More substantial increases in capacity in this way are likely to require further alterations/uprates to the rest of the plant to enable effective operation.

Summary

Reducing the carbon footprint of ammonia plants is not without its challenges, but the increased focus on the development of green and blue ammonia flowsheets and technology, along with changes in the market and legislation have made these plants increasingly commercially viable. Whilst blue ammonia plants are more viable in the short term for large scale production for fertilizer production the choice of end product can affect the scope for carbon footprint reduction. For green ammonia, whilst the development of this technology has decreased the production cost, the majority of the scope for this cost reduction is around the design and intensification of the electrolysers. However, use of the high activity KATALCO 74-1 GREEN catalyst in these flowsheets can aid in optimisation of the loop and subsequently bring operating costs down. For the green ammonia flowsheets with low pressure loops, KATALCO 74-1 GREEN catalyst has been tested down to 25 bar internally and even lower still in the University of Cambridge study and it still shows reasonable activity even at these low pressures. The ASPIRE project is developing a green ammonia demonstration unit, feeding power from local renewable energy generation to show that generation of ammonia from a variable renewable power source is achievable. ■

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Pioneering green ammonia – start small, think big

Distributed and carbon-free ammonia production with Stami Green Ammonia technology offers a highly competitive alternative to conventional grey processes, paving the way for scaling up and sustaining local communities with renewable energy sources.

Rolf Postma, Mahal Patel, and Deepak Shetty (Stamicarbon)

As the world shifts toward sustainable solutions, it has become clear that traditional ammonia production methods, which depend on non-renewable resources and contribute to global GHG emissions, must be redefined. However, with approximately half of the global population relying on artificial fertilizers for their food supply, the production of ammonia and its derivatives must keep growing. Additionally, ammonia is expected to play an important role as an energy carrier in the transition to clean energy. To meet sustainability objectives while addressing rising demand, ammonia production must increase, but it's imperative that it's sourced from renewable sources.

More ammonia, less carbon

The Haber Bosch process, developed in the early 1900s, revolutionised high-pressure ammonia synthesis. It directly combines nitrogen from the air with hydrogen under high pressure and moderately high temperature. The invention resulted in the wide availability of ammonia-based fertilizers that rapidly increased agricultural yields in a short time span.

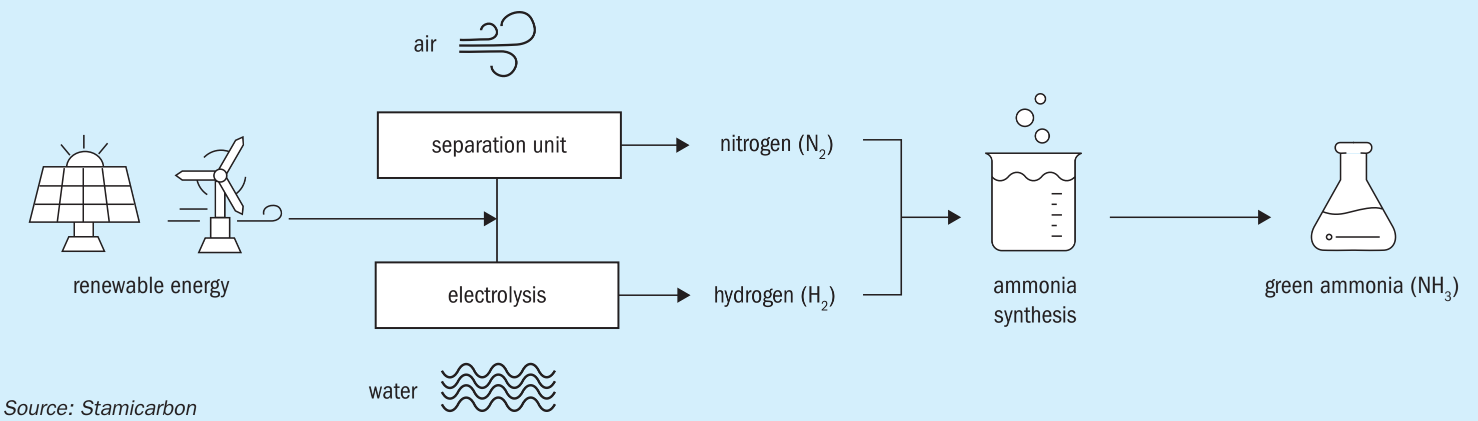
Today, most ammonia facilities are using hydrogen from steam reforming of natural gas or coal gasification. While hydrogen continues further into the synthesis, carbon dioxide, having no other role, is mainly released into the atmosphere. Fortunately, the Haber Bosch process can use hydrogen from any source. When renewable electricity with an electrolyser is utilised to produce hydrogen, combined with the atmospheric nitrogen down the line (see Fig. 1), the resulting ammonia is referred to as "green."

The economy of smaller scale

Historically, the process industry aimed to increase production and capitalise on economies of scale. As we transition to green energy to power and sustain the world, this approach remains relevant. However, the limited availability of renewable electricity and production capacities of electrolysers – essential for transitioning to green hydrogen and subsequently to green ammonia – are slowing the deployment of large-scale non-fossil projects. Given today's challenges and opportunities, starting with smaller-scale, modular, and scalable green ammonia production can be a smart step toward a carbon-free journey.

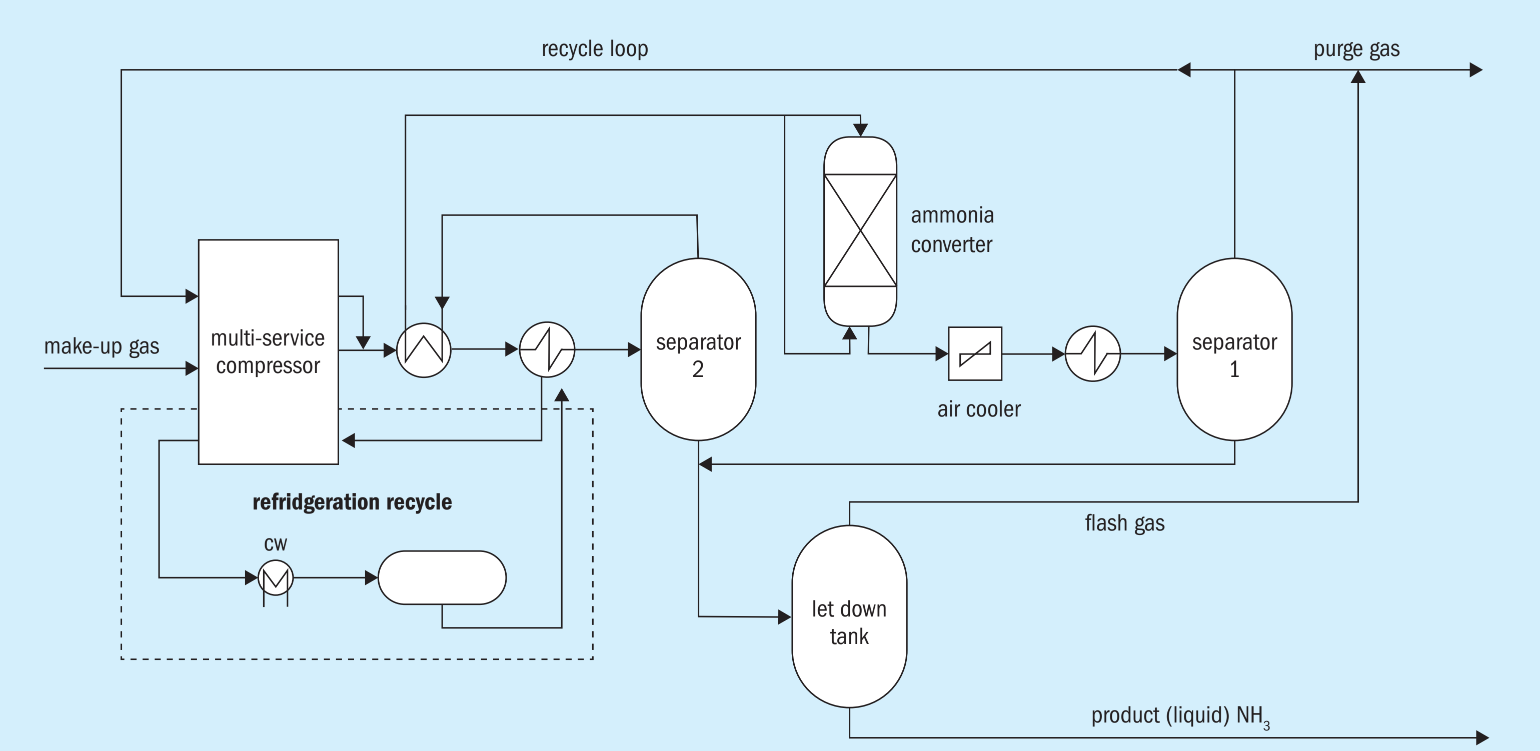
Stamicarbon, the nitrogen licensor of the MAIRE Group, recognises the urgency to pursue sustainable, carbon-neutral

Fig 1: **Green ammonia production process**



Source: Stamicarbon

Fig 2: **Stami Green Ammonia process diagram**



Source: Stamicarbon

ammonia production technologies, as well as the new opportunities that have arisen. To address the sustainability challenge effectively, Stamicarbon developed its high-pressure green ammonia technology with a capacity of up to 500 t/d. By enabling ammonia production from renewable energy sources, Stami Green Ammonia offers a path to a carbon-free future, enabling a more environmentally friendly approach to producing nitrogen-based fertilizers or converting renewable energy to a valuable commodity with multiple ways of further monetisation.

Features of Stami Green Ammonia technology

Central to Stamicarbon's technology is a high-pressure ammonia synthesis loop tailored to provide optimal efficiency in smaller to medium-sized plants using renewable energy as a feedstock. A major benefit of this high pressure is that it enables ammonia to condense in a single stage using cooling water. This efficiency reduces the need for multiple pieces of equipment, resulting in capex savings of around 25-30%. This is a notable advantage of smaller applications. Additionally, the high pressure means that the synthesis requires only a minimal reactor size and smaller catalyst volume. An illustrative process flow diagram can be found in Fig. 2.

The chemical process to produce ammonia is most efficient under low temperatures and high pressures due to the exothermicity of the reaction. Stami Green Ammonia technology operates at a higher synthesis loop pressure of 300 bar, distinguishing it from other technologies that typically operate between 80-150 bar.

The Stami Green Ammonia process capitalises on the proven designs from established natural gas-based technologies and its modular approach makes it suitable for decentralised, small-scale production. The plant, due to its scale and design, can efficiently handle the sporadic nature of renewable energy sources. Customised plant capacities ranging from 50 to 500 t/d ammonia are possible. Due to its streamlined design, a 500 t/d ammonia plant covers an area of roughly 50 x 45 metres (see Fig. 3). Depending on the project site, available space, and various local factors, either a stick-built or a fully modular design may be employed.

As seen from multiple studies developed by Stamicarbon for its customers worldwide, local green ammonia production can be feasible in many regions. The high availability of solar energy resources enables the production of green hydrogen and ammonia in Africa, the Middle East, South America, and Oceania. Furthermore, other regions have access to various renewable energy sources, like wind and hydropower, enabling the local production of sustainable fertilizers and driving the energy transition in other industries. Establishing local, distributed production facilities offers more than just high-added-value products. Local fertilizer production would have an impact on the affordability and availability of fertilizers for farmers. Local communities would benefit from developmental projects undertaken as part of the corporate social responsibility of the fertilizer plants. Plant construction would create employment and educational opportunities and boost the development of infrastructure.

Case: Carbon-free fertilizer for America's Corn Belt

One of the industry's pioneers, the Meadowlark project, announced in May 2023, promises to bring substantial benefits to the agricultural sector in Gothenburg, Nebraska. This innovative renewable-energy-based liquid fertilizer plant will be based on the Stami Green Ammonia technology and is expected to start up in 2026. Stamicarbon will develop a basic engineering design package for a 450 t/d green ammonia plant that will be used to produce

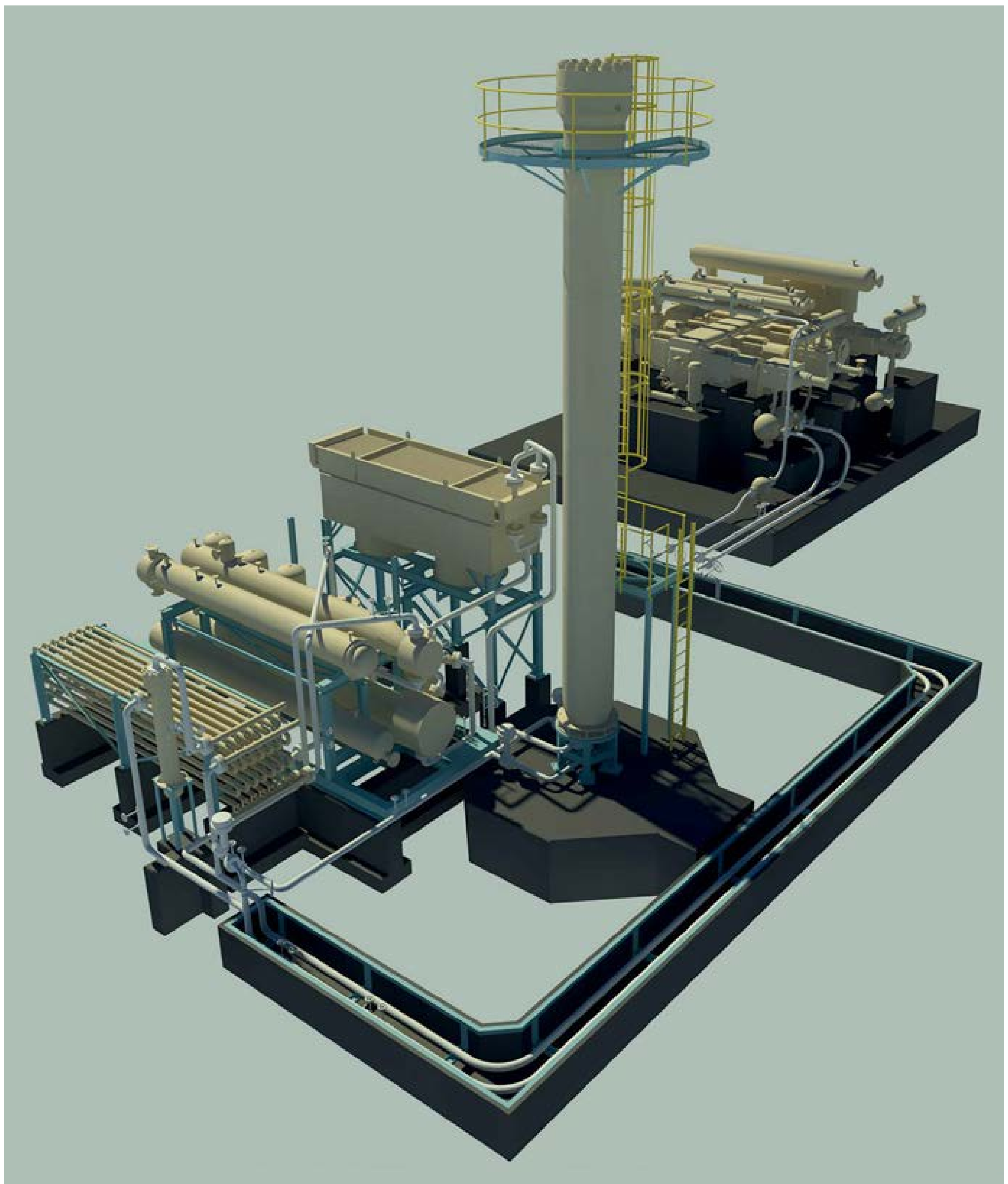


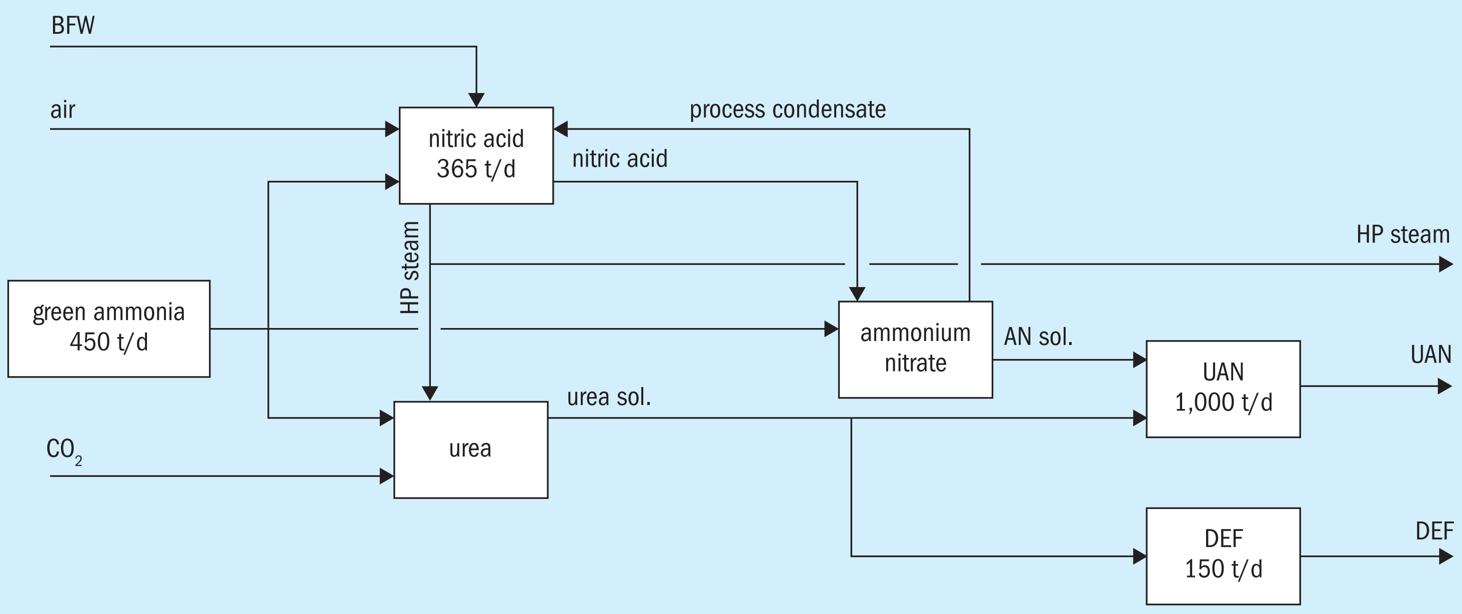
Fig 3: Typical 3D model of a plant based on Stami Green Ammonia technology

nitrogen-based fertilizers (Fig. 4). Leveraging locally produced renewable energy, the facility is projected to produce impressive outputs: 365,000 t of urea ammonium nitrate (UAN), 146,000 t of ammonium thiosulphate (ATS), and 20 million gallons of diesel exhaust fluid (DEF) annually. Strategically located, Project Meadowlark aims to cater to an agricultural area spanning approximately 150 miles around Gothenburg.

Paving the way for a sustainable future

Fossil-fuelled ammonia plants are traditionally located at places rich in available natural gas or coal. This leads to an uneven distribution of fertilizer production worldwide and adds to transportation costs and emissions. To address these challenges and promote sustainability, there is a growing need for alternative production methods that utilise renewable resources and decrease the overall carbon footprint of ammonia production. Green ammonia production not only has zero CO_2 emissions but is also less tied to a specific location, provided sufficient renewable energy is available in different locations across the world. This gives many countries the opportunity to become self-sufficient in fertilizer production, thereby reducing issues related to supply chain disruptions and unexpected price fluctuations.

Fig 4: **Stamicarbon full scope to be implemented in Gothenburg, USA**



Source: Stamicarbon

Application of CFD for optimisation of waste heat boilers

Steinmüller Engineering shares its experiences of applying CFD to re-design the waste heat boiler downstream of the secondary reformer to successfully achieve the desired uniform cross flow across the tube bundle.

Svenja Blechmann, Dr. Ralph Ernst, Waldemar Hoffmann, Benedikt Tressner, Thomas Will (Steinmüller Engineering)

The waste heat boiler (WHB) downstream of the secondary reformer is one of the most critical heat exchangers in ammonia and methanol plants. Typical reformer outlet gas temperature is in the range 900 to 1,050°C while pressure varies between 25 and 35 bar. Due to these gas conditions and the demand for rapid cooling down the WHB has to cope with a high specific heat flux density > 500 kW/m². Flow imbalances and undesired bypasses affect efficiency and may even lead to local overheating. In order to achieve a high thermal efficiency, as well as to prevent severe damage, sophisticated process know-how is required to understand and to optimise the WHB.

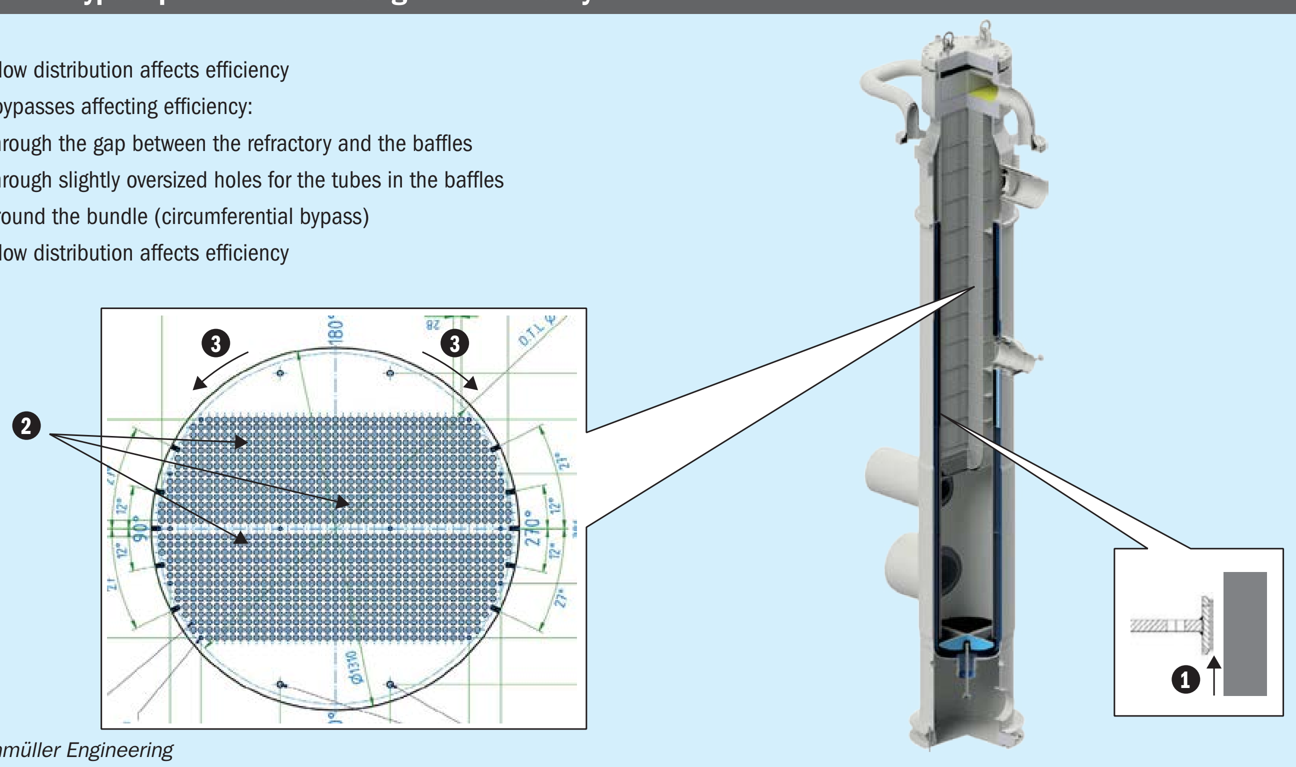
Thermodynamic software tools for heat exchanger design require input with respect to the efficiency of the heating surfaces as well as for any proportion of the gas flow bypassing the tubes. To include those effects in the thermal design even for complex geometries the design engineer needs additional tools.

In the last decade computational fluid dynamics (CFD) has been established in many fields of application to investigate physical phenomena and to optimise process related components.

Coupling results from CFD simulations to thermodynamic design enables the process engineer to further optimise critical static equipment by science-based analytical tools.

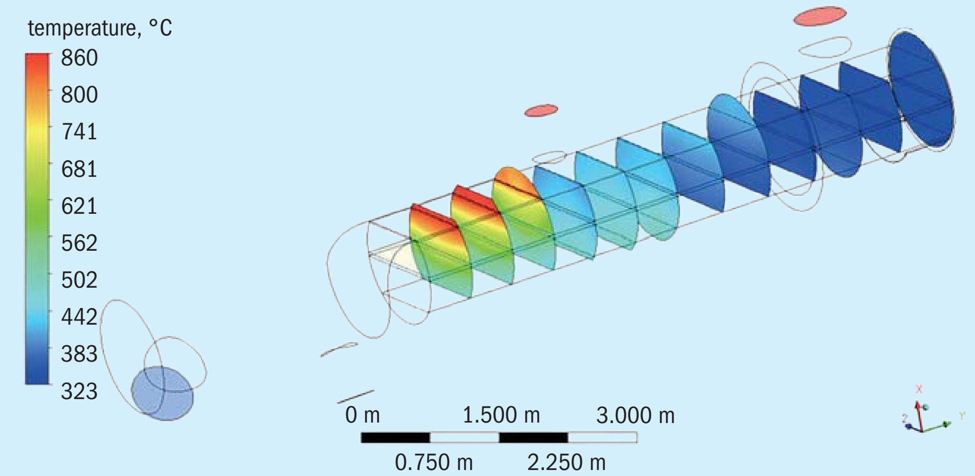
Fig. 1: **Flow and bypass phenomena affecting WHB efficiency**

- Gas flow distribution affects efficiency
- Gas bypasses affecting efficiency:
  1. Through the gap between the refractory and the baffles
  2. Through slightly oversized holes for the tubes in the baffles
  3. Around the bundle (circumferential bypass)
- Gas flow distribution affects efficiency



Source: Steinmüller Engineering

Fig. 2: **Material temperature of baffles**



Source: Steinmüller Engineering

Thermal design challenges

Fig. 1 shows areas in which bypasses occur on a typical U-bundle WHB. In addition, the gas flow distribution in the bundle itself also affects the thermal efficiency. While thermodynamic software calculates on the pre-assumption of an ideal cross flow, the situation is more complex.

CFD simulations

Standard CFD simulations cover the fluid flow only. Solid material is typically modelled as a dimensionless wall (s = 0 mm) with defined thermal boundary conditions to include heat transfer from fluid to the wall. For the purpose of optimising the WHB design the solid material of the baffles has to be part of the model in order to allow a prediction of the temperature profile to derive the thermal expansion.

The WHB was simulated by Steinmüller Engineering in a 3D CFD model using porous media properties to model the flow resistance and the heat transfer inside the tube bundle. The complete bundle was split into 20 sections with individual heat take up, derived from a first thermodynamic model.

The model delivers patterns of gas flow velocities, pressure drop and also temperature profiles. However, many design details cannot be included in a global model because a proper mesh geometry with a reasonable number of cells is required.

To investigate areas where a detailed geometrical model is required, smaller sub models were developed.

Results and solutions derived from CFD simulations

As a counter measure to the type 1 bypass between baffle plates and refractory, a CFD simulation assists in evaluating the order of magnitude of the bypass. In addition, the effective baffle material temperatures can be estimated (Fig. 2) and so the thermal expansion can be calculated for each individual section. With these data the remaining gap can be minimised.

In order to prevent type 3 bypasses a set of sealing strips was implemented. The efficiency of those strips was modelled by a 2D simulation of the tube bundle area.

The optimisation of the velocity profiles is the most important focus of the CFD simulation. The upper part of Fig. 3 shows the velocity profile for a non-optimised WHB. Due to the conservation of momentum the hot gas tends to flow almost in parallel along the first pass of the WHB unless the first baffle plate forces a 90° turn. In large areas of the tube bundle there are significant swirls and low flow, whereas the last section has to cope with very high velocities bearing a very high heat flux.

The poor velocity distribution affects the efficiency of the WHB and is either balanced by a high fouling factor or an additional degradation factor.

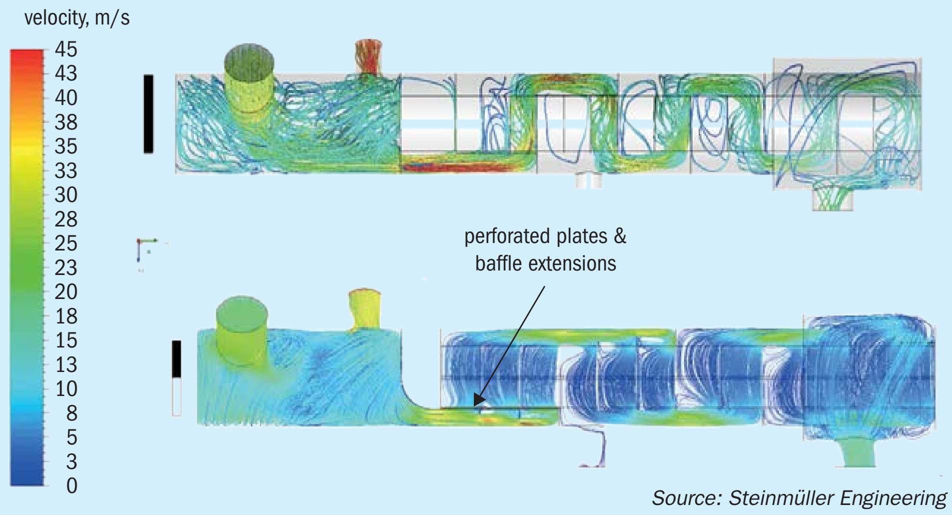
Steinmüller Engineering's experience of applying CFD to correct flow patterns in the power industry was used to correct the flow behaviour. The baffles were extended in a manner to guide a gas proportion towards the bundle. In addition, a set of perforated plates was installed upfront of the tube bundle to balance the flow and to establish an almost perfect cross flow.

Conclusion

A conventional design for waste heat boilers is based on empirical heat transfer correlations, derived from experiments providing ideal flow conditions. In addition, due to the significant change of gas properties in the WHB, the ordinary correlations to estimate bypass impacts are not sufficiently precise.

The lessons learnt from applying CFD in various industries were used to optimise one of the most challenging heat exchangers in the synthesis gas process. The simulations allowed the engineer to judge the efficiency of counter measures for bypasses and enabled the desired uniform cross flow across the tube bundle to be achieved. ■

Fig. 3: **WHB velocity profile before and after optimisation**



Source: Steinmüller Engineering

Enhancing granulation technologies

TOYO has a long history in urea granulation technologies and has recently added two new technologies to its product line-up.

PHOTO: TOYO

Granulation unit at IEFCL urea plant (4,000 t/d) in Nigeria

Since its establishment in 1961, TOYO Engineering Corporation (TOYO) has been a leader in the urea industry as a urea process licensor. TOYO has designed, engineered, constructed, and commissioned 26 urea granulation plants based on TOYO's Spout-Fluid Bed Urea Granulation Process, ranging in scale from 50 t/d to 4,000 t/d production capacity in a single train. The photo (below left) shows a urea granulation unit based on TOYO technology at Indorama Eleme Fertilizer & Chemicals Limited (IEFCL) in Nigeria, the world's largest single train urea granulation plant.

TOYO has been continuously responding to market requirements and developing its product line-up. Fig. 1 shows the history of TOYO's urea granulation and associated technologies.

Most recently, TOYO has added two new technologies in the line-up, (1) a new mixed granule production process with acid scrubbing and (2) a novel low PM emission process which integrates a wet electrostatic precipitator (WESP) with TOYO's low pressure drop scrubber.

TOYO's urea granulation technology

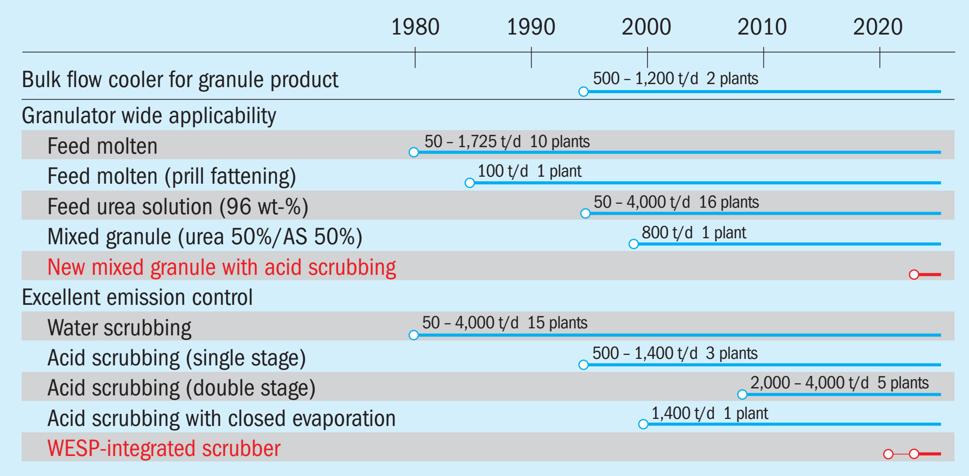
TOYO started developing a urea granulation process based on a spouted bed type urea granulator back in the 1980s. In the 1990s, TOYO further improved its granulation technology by applying spout-fluid beds in the granulator.

Fig. 2 illustrates the process flow of TOYO's granulation process. The urea solution or molten urea is sprayed onto spouting urea seeds to enlarge the recycle particles (seeds) in the granulator. Water in the feed urea solution evaporates in the spouted beds and fluidised beds. The enlarged granules are cooled to a suitable temperature in the fluidised beds in the granulator.

Coarse urea granules exiting the granulator are separated into product size granules, oversize and undersize granules by a screen. Small size granules are recycled back to the granulator as seed and oversize granules are crushed by a crusher to be recycled to the granulator together with the undesize granules as seeds. Product size granules are further cooled to be sent to bulk storage and/or bagging unit as final product.

Exhaust air from the granulator and the cooler is scrubbed in a wet type dust scrubber to recover the urea dust. Recovered urea dust is recycled back to the urea plant as an aqueous urea solution.

Fig.1 History of granulation technology development



Source: TOYO

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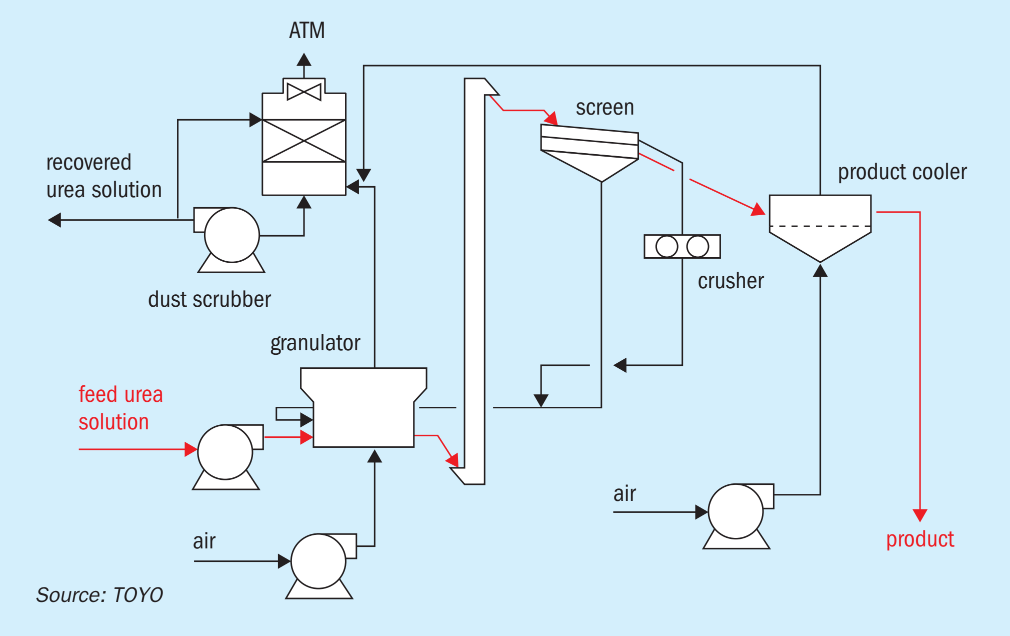
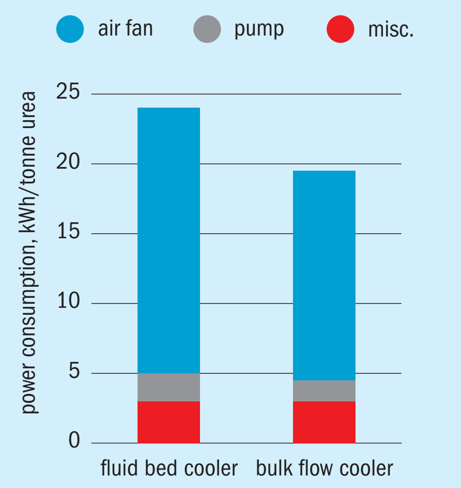
Fig. 2: **TOYO granulation process**



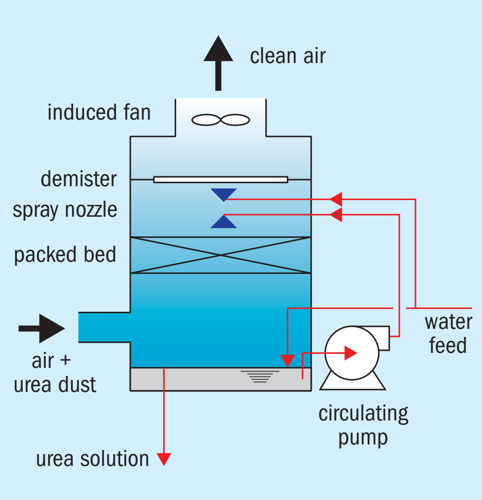
Source: TOYO

Fig. 3: **Typical power consumption in a TOYO granulation plant**



Source: TOYO

Fig.4: **Dust scrubber (water scrubbing type)**



Source: TOYO

Bulk flow cooler for product cooling

A bulk flow cooler can be applied as a product cooler instead of a fluid-bed cooler. In 1995, TOYO was the first in the world to apply a bulk flow cooler for product cooling in a granulation plant. The application of a bulk flow cooler has successfully lowered power consumption by 4 kWh/t compared to a fluid-bed cooler, as shown in Fig.3.

Wide applicability of TOYO's granulator

Through pilot tests and operation of industrial scale plants, TOYO has accumulated huge expertise and know-how in urea granulation. TOYO's granulator can be designed to produce granules with various compositions using a wide range of feed concentrations.

Feed concentration (96 wt-% urea solution to molten urea)

TOYO's granulator can be designed to receive feed urea concentration from 96 wt-% to 99.7 wt-% molten urea. Thanks to the excellent drying function of TOYO's granulator, product with a moisture content of 0.3% or less can be obtained even with 96% urea solution feed. The lower concentration of urea solution feed contributes to lower biuret product and less utility requirement in the granulation plant than the molten urea feeding case.

Expansion of product line (including prill fattening)

The applicability of molten urea provides options to apply the granulation process for the revamp or expansion of existing urea plants with a prilling tower. For example, the TOYO urea granulation process can be installed to produce granular urea in parallel with prilled urea from a common urea synthesis unit. In addition, prilled urea can be supplied from the existing prilling tower as seed for the granulator (prill-fattening). In this case a crusher is not required and the granulation unit can be smaller. TOYO designed and constructed a prill fattening plant based on TOYO technology in 1983.

Urea-AS (ammonium sulphate) mixed granulation

Sulphur or sulphate maybe required as a fertilizer depending on soil requirements. In 1998, in close collaboration with a plant owner, TOYO responded to this need by designing and constructing a 50:50 urea-AS mixed granulation plant. The urea granulation plant is capable of producing mono-urea granules and urea-AS mixed granules up to 50:50.

New mixed granulation with acid scrubbing

As part of its latest development, TOYO has invented a simpler (lower facility cost) and more energy-efficient urea-ammonium salt mixed fertilizer process than the process shown in Fig. 6, which eliminates ammonium salt by-products by introducing a new concept to the urea concentration, granulation and exhaust scrubbing system. Further details of this novel technology will be presented at the Nitrogen+Syngas 2024 Conference in Gothenburg.

Excellent emission control

Urea dust and ammonia are major emissions which need to be controlled in a urea plant. TOYO owns various unique and well proven technologies and processes to treat exhaust air containing urea dust and ammonia:

- **Water scrubbing** with random packing and a demister as internal parts is the simplest option (see Fig. 4). This type of system can reduce urea dust in exhaust air to less than 30 mg/Nm³, but does not address the ammonia emission.
- **Acid scrubbing** can reduce the ammonia emission in exhaust air to less than 30 mg/Nm³. TOYO first applied acid scrubbing in 1995 and successfully reduced ammonia emissions to less than 30 mg/Nm³. Either sulphuric acid or nitric acid can be used with the

Fig. 5: **Single / double-stage acid scrubber**

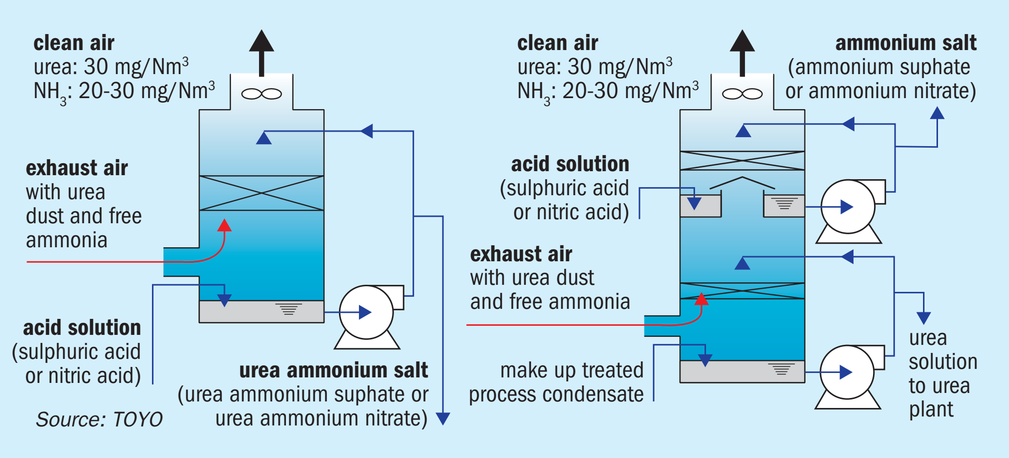


Fig. 6: **Acid scrubber with closed evaporation system**

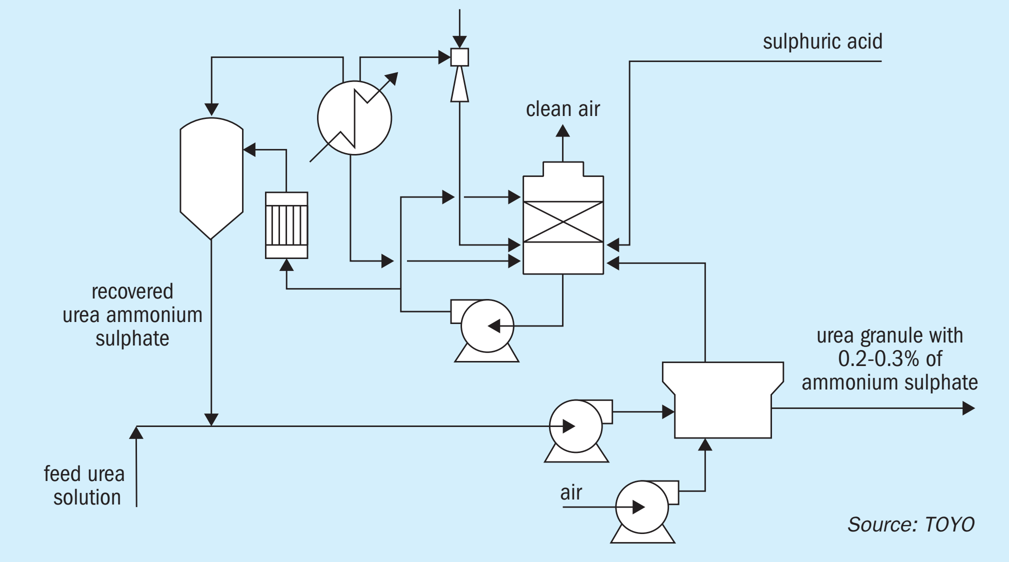


Table 1: **Scrubbing technologies**

	Water scrubbing	Single-stage acid scrubbing	Double-stage, acid scrubbing	Acid scrubbing with closed evaporation
TOYO experience	45 plants *	3 plants	5 plants	1 plant
Acid required (98% H_2SO_4)	none	1 kg/t urea	1 kg/t urea	1 kg/t urea
By-product	none	45% urea ammonium salt solution: 90 kg/t urea	40% ammonium salt solution: 5 kg/t urea	none
Urea product	urea	urea	urea	urea + ammonium salt (0.2 wt-%)
Recovery of urea dust	as urea product	as by-product	as urea product	as urea product
Recovery of ammonia	none	as by-product	as by-product	as urea product
Urea dust emission	< 30 mg/Nm³	< 30 mg/Nm³	< 30 mg/Nm³	< 30 mg/Nm³
Ammonia emission	ammonia in urea melt is emitted	< 30 mg/Nm³	< 30 mg/Nm³	< 30 mg/Nm³

Source: TOYO **Number of scrubbers for prilling tower with same design philosophy is included.*

appropriate material selection. A single or double-stage acid scrubbing system can be applied considering the type of by-product formation from the acid scrubbing process.

- Single-stage acid scrubbing: As urea is absorbed into the acidic solution together with the chemical absorption of ammonia, urea ammonium sulphate (UAS) or urea ammonium nitrate (UAN) is produced as by-product (see Fig. 5).
- Double-stage acid scrubbing: Since only urea is absorbed into water in the first stage, ammonium sulphate (AS) or ammonium nitrate (AN) is produced as by-product. The quantity of by-product is reduced compared to the single-stage option (see Fig. 5).
- Acid scrubbing with closed evaporation system: When the production of by-products needs to be avoided due to market conditions, incorporating UAS into the urea granule product is a suitable option. In this case, UAS solution coming from the acid scrubbing system is concentrated in the dedicated evaporation stage, and then fed with the urea solution to the granulator (see Fig. 6). In this scheme, the final urea product contains 0.2–0.3 wt-% of AS which is applicable for fertilizer use.

Water scrubbing and all three acid scrubbing systems can be applied to the urea granulation plant for emission control. These options are summarised and compared in Table 1.

New technology for emission control

Further, in responding to a social demand for the elimination of fine particle (PM) emissions from industrial activities, TOYO has developed a novel PM elimination technology for urea granulation, integrating WESP and TOYO's well-proven scrubbing technology. TOYO has conducted WESP pilot test with actual emitted air from a TOYO granulator. The pilot plant has stably achieved PM2.5 contents of less than 5mg/Nm³ after treatment in the WESP and has demonstrated that the same or better performance is assured at industrial scale. The design of an industrial scale plant has been completed. This technology will also be presented at the Nitrogen+Syngas 2024 Conference in Gothenburg. ■

Improving nutrient use efficiency with methylene urea

Ballestra is taking a new approach to improving nutrient use efficiency by moving methylene-urea production to the fertilizer industry. **Massimo Gori** and **Svet Valkov** of Ballestra discuss the technology and benefits of having a slow-release fertilizer that uses a product from within the fertilizer industry.

The fertilizer industry as we know it is set for a change. Arable land is limited, and world population continues to grow, but it is no longer acceptable to simply pour more fertilizer per hectare to feed more people. The capability of crops to absorb nutrients is limited and any surplus nutrients are leached away by rain and end up in rivers and seas as ammonia, nitrates, phosphates and potassium.

Improving fertilizer efficiency and increasing product value without changing existing plants and renewing investment has become the new focus of the fertilizer industry. Many different solutions have come to market that provide crops time to absorb the nutrients, avoid or reduce leaching by rain or irrigation and ultimately maximise the efficiency of fertilizers.

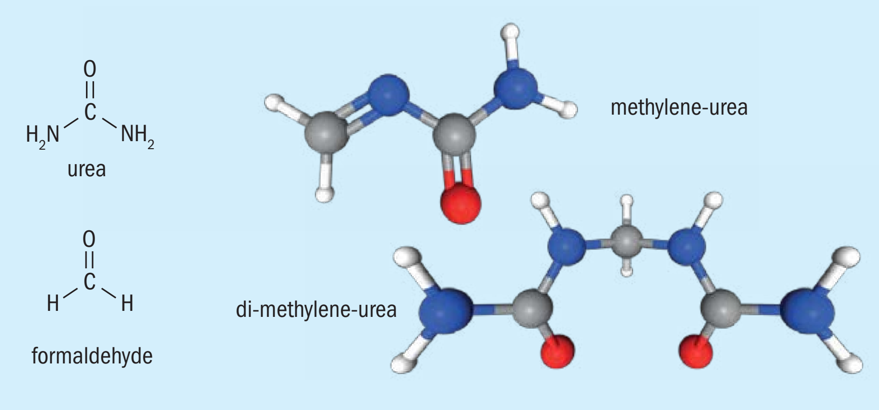
For nitrogen fertilizers, the main strategies that have emerged are:

- urease inhibitors which block or slow down the decomposition of urea into NH_4^+;
- nitrification inhibitors which block or slow down the conversion from NH_4^+ to nitrate;
- coatings which cover the entire surface of a fertilizer granule with a substance that delays contact with water;
- formulations, same as above, with substances intimately mixed with the mass of the fertilizer granule.

These solutions are made possible by substances like polylactic acid, polyurethane, N-(n-butyl) thiophosphoric triamide, dicyandiamide, sulphur, 2-chloro-6 (trichloromethyl) pyridine, 2-chloro-6 (trichloromethyl) pyridine, malic+ itaconic acid copolymer, etc., none of which are a product of the fertilizer industry. As a result, the fertilizer industry has to pay a third-party fee to achieve fertilizer efficiency that erodes, sometimes significantly, the margin from the added value of controlled and slow-release fertilizers.

Taking a different approach, what if the means of delivering a step change in nutrient use efficiency was a product, methylene-urea, already available to the fertilizer industry? Currently, the production of this compound is limited by the small size of the resin industry that supplies it. Ballestra is therefore working to scale up methylene-urea manufacturing technology to allow the large-scale production of this slow-release fertilizer within the fertilizer industry.

Fig. 1: **The chemical structures of methylene-urea and di-methylene-urea**



Source: Ballestra

Methylene-urea chain compounds

Methylene-urea (Me-urea) is obtained by condensing together one molecule of urea with one molecule of formaldehyde. If condensation continues, more molecules join together to form di-methylene-urea (Fig. 1). Proceeding further with polymerisation increases the chain length and a compound known as ureaform is then formed. The ultimate end product of this polymerisation process is a urea-formaldehyde (UF) resin made up of long reticulated molecular chains.

These types of compounds are already well known within the nitrogen industry. Urea-formaldehyde concentrate (UFC), for example, is an essential additive used to impart mechanical resistance and hardness to urea granules. There is also good awareness of formaldehyde as a product of the partial oxidation of methanol, a major basic chemical and close relative of ammonia.

Valuable slow-release properties

Urea is very soluble in water while UF resins are completely insoluble. The various methylene-urea chain compounds (Me-urea, di-methylene urea and ureaform) sit somewhere in between these two extremes and are partly soluble. Generally, these compounds become more insoluble as their polymer chain length increases.

Urea, Me-urea, di-methylene urea, ureaform and UF resins are all excellent nitrogen carriers and can therefore be used as fertilizers. The slow-release properties of methylene-urea chains can be precisely engineered to dissolve and make nitrogen available within days, weeks, or months, according to the requirements of a particular crop. These compounds will resist water leaching depending on their polymer chain length, starting from urea (very soluble) and arriving at UF resins (insoluble).

Me-urea and longer chain ureaform (UF) fertilizers are available in both liquid and granular form and are considered safe for both humans and the environment. These slow-release nitrogen fertilizers, when applied as a foliar liquid, have been shown to be 4-5 times more efficient than conventional nitrogen fertilization, i.e. 4-5 kg of urea are needed to deliver the same yield as 1 kg of Me-urea. Granular Me-urea offers similar efficiency advantages and is widely applied in turf (e.g., golf courses) and ornamental markets as well as in agriculture. Both liquid and granular products do not result in crop burn as they have a low salinity and no nitrate content.

Low volumes, high prices

The valuable fertilization properties of Me-urea compounds are said to have been discovered when grass surrounding a ureaform tank grew greener and taller because of a leak. In reality, Me-urea is a well studied and well known product that has been sold and used for decades. It is a proven slow-release fertilizer that is attractive in the wider world market and can therefore command premium prices.

Currently, Me-urea is manufactured by the UF resin industry, a much smaller industrial sector compared to the fertilizer industry, with installed capacity limited to a few hundred thousand tonnes per year.

Interestingly, though, this compound is made from chemicals already found in fertilizer production processes. That opens up the possibility that the fertilizer industry itself could begin to produce Me-urea, rather than sourcing this externally. This would allow fertilizer producers themselves to deliver the necessary step change in nutrient use efficiency – without sharing added value and margins with third parties. Indeed, in this article, we explain how Me-urea manufacturing can be moved from the UF resin sector to the fertilizer industry where it belongs.

Methylene-urea production

Ballestra's Me-urea production system (Fig. 2) closely follows the approach already taken by the UF resin industry. The process design guarantees a fully automated, safe and durable production system, with no volatile organic compounds emissions. Operators, by adding the recipe to the control system, are ready to go.

The core know-how behind Me-urea production is the process recipe. The use of a batch reactor allows this to be changed easily to deliver different product grades. UFC or formaldehyde are loaded with solid urea or urea solution into the reactor. Polymerisation via acid or basic catalysis is performed in closely controlled cycles with the conditions varied to obtain a specific polymer length (or mix of polymer lengths).

The product obtained can be stored as liquid nitrogen fertilizer or mixed with other nutrients and micronutrients to obtain a precisely formulated liquid NPK fertilizer. Both of these product types can also be sent for further finishing in a drum granulator.

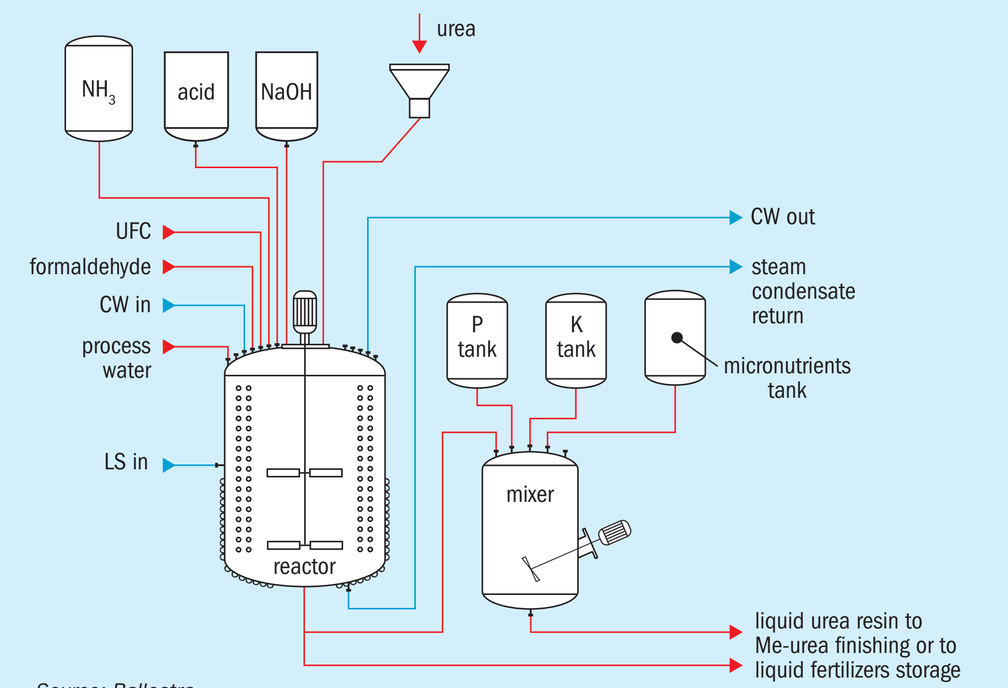
Product finishing

Although Me-urea production technology is well defined, the finishing stage is where most existing plants fall short. This is also the reason why the production capacity of a single Me-urea line is generally limited.

Me-urea is actually a family of different products, not a single product based on well-defined commercial specification. Because of this, each individual process recipe will require a specific set of finishing parameters for the Me-urea product obtained. However, most available granulation technologies do not have the flexibility to cope with full the range of Me-urea product grades.

This is where Ballestra's fluid drum granulator excels. Essentially, it consists of a rotating drum with a fixed table inside made of a perforated metal sheet (Fig. 3). The rotation of the drum lifts the granules onto the table, where they are kept in fluid bed conditions by air flowing through holes in the metal sheet. The perforated table is slightly inclined to one side. This allows dry granules from the fluid bed to fall back to the lower part of the rotating drum. While doing so, they pass through an incoming spray of fresh Me-urea, which creates a further layer of material.

Fig. 2: **The methylene-urea reaction section**



Source: Ballestra

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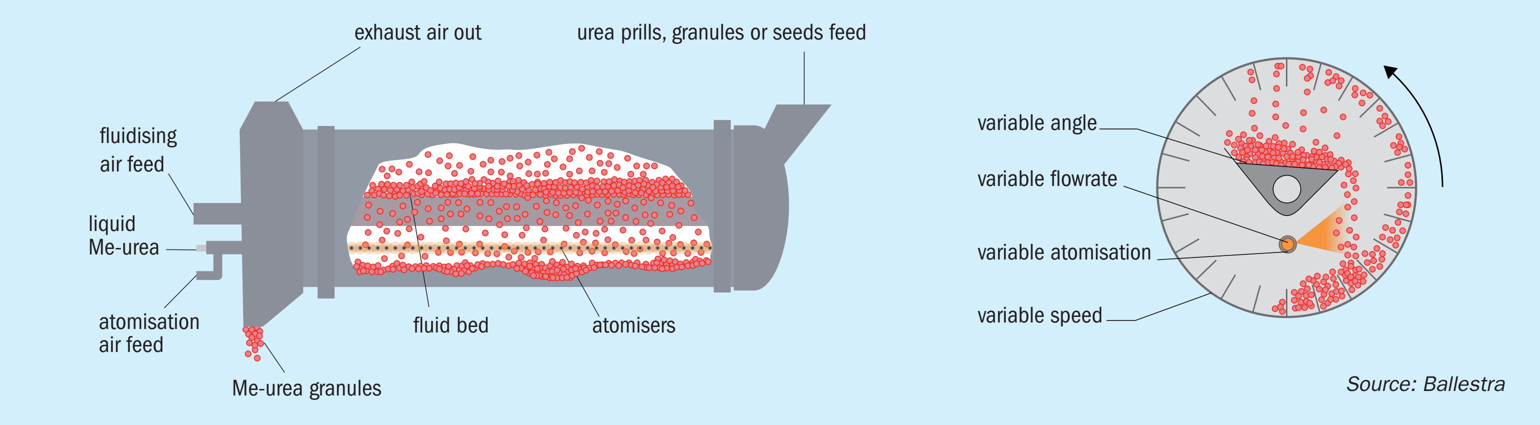
Fig. 3: **Schematic of Ballestra's fluid drum granulator**



Source: Ballestra

Everything in the design is about flexibility. The following parameters can all be carefully regulated:

- drum rotation speed;
- inclination of the fluid bed table;
- temperature and flow of the fluidising air;
- temperature of the freshly sprayed liquid.

Once the proper parameters for each recipe are defined, the result is granules with a solid, onion-like, layered structure and a hardness and mechanical resistance far greater than those of standard urea granules. A notable feature of Ballestra's fluid drum granulator is that the fresh solution is sprayed into an area away from the fluidising air flow. This limits droplet entrainment, compared to a standard urea granulation process, and therefore reduces the duty on the downstream air cleaning section.

Setting aside these differences, the overall finishing scheme for Me-urea (Fig. 4) resembles a simplified urea fluid bed granulation process.

More products from the same plant

The finishing process described here is not limited to just Me-urea and ureaform production. Its flexibility also enables the production of other, more complex types of slow-release fertilizers.

Prior to finishing, Me-urea and ureaform, which are basically UF resins with shorter polymer chains, behave like a glue. Other nutrients can therefore be added as feed particles to the Ballestra fluid drum granulator and become evenly embedded within the solid and hard matrix of Me-urea granules. The resulting NPK and multi-nutrient granules have the same slow-release properties as standard Me-urea granules. This holds true even when the granule is broken as the added nutrients are still firmly fixed within the Me-urea matrix.

The fluid drum granulator can also be used as a quick and economical way of modifying the physical behaviour of urea granules and prills by, for example, improving their slow-release properties, surface resistance and bulk flowability. This is achieved by coated or fattening urea prills and granules fed to the Ballestra fluid drum granulator with a layer of Me-urea.

The resulting granules have a core of pure urea surrounded by an Me-urea coating. The release of the urea core to the soil can be carefully timed by regulating the thickness of the outer Me-urea coating.

Applying Me-urea coated urea granules to soils alongside seeds, for example, could provide a fertilization boost exactly when growing crops need it. Furthermore, supplying mixed granules with coatings of different thicknesses can provide a series of fertilization boosts at specific times. The end result is precision engineered fertilizer granules designed to deliver nutrients at specific times to closely match crop requirements.

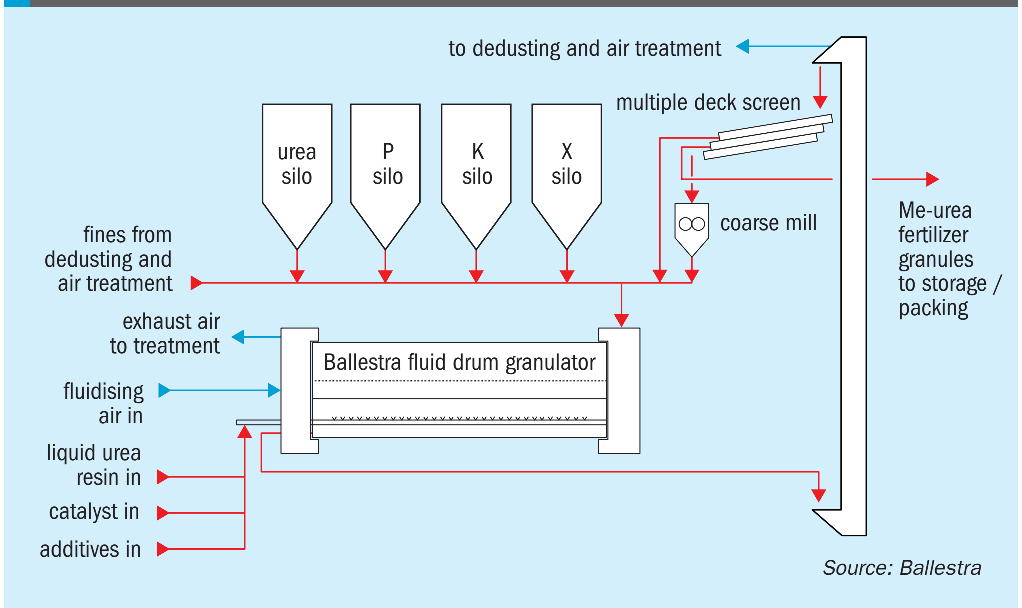
Partners on a common journey

Ballestra invites partners to help them shift methylene-urea production away from the UF resin and laminates industry and embed production within the fertilizer industry where it can make a significant contribution to fertilizer industry sustainability and improve nutrient use efficiency.

As a company, Ballestra offers robust and scalable process and finishing technologies, as well as agronomic, marketing, and regulatory support, plus the expertise to deliver new fertilizer product recipes. By combining these strengths with industry partners who have the necessary feedstock availability, marketing push and innovative spirit, methylene-urea technology could be scaled up to meet actual market demand.

New products, intellectual property (IP) and applications could also be jointly developed. Achieving reductions in natural gas consumption during fertilizer production would be another worthwhile objective. ■

Fig. 4: **The methylene-urea finishing section**



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