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Ammonia as a marine fuel

Urea markets

New nitrogen fertilizer production technologies

Upgrading the CO_2 removal section

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NUMBER 378
JULY | AUGUST 2022

Cover: Industrial hydrogen gas cylinders. Chanon Naprom/Shutterstock.com

20

Ammonia shipping

Safety and handling concerns over ammonia as a marine fuel.

44

CO_2 removal

Upgrading an ammonia plant CO_2 removal section

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Published by: BCInsight

CONTENTS

20 Barriers to ammonia's adoption as a fuel
Green ammonia is increasingly being looked to as a low carbon fuel for maritime vessels, but this will require it to overcome concerns over availability, toxicity, safety and handling.

24 A shock to urea markets
The Russian invasion of Ukraine has presented urea markets with a major shock, but there are signs that this may now be easing.

28 New value chains for sustainable chemistry
A report on some of the actions Clariant Catalysts is taking and focussing on in research and development to enable its customers to reach their sustainability targets.

32 New technologies for nitrogen fertilizer production
Casale, thyssenkrupp Industrial Solutions, Toyo Engineering Corporation and Stamicarbon discuss some of their latest technology developments for solid nitrogen fertilizer production.

44 Upgrading the ammonia plant CO_2 removal section
Casale and Giammarco-Vetrocoke discuss different strategies to revamp the CO_2 removal section in ammonia plants for improved efficiency and capacity increase.

50 CO_2 footprint reduction in ammonia production
BD Heat Recovery and Petrokemija show how digital twin modelling and simulation concepts can be combined with proven methods such as pinch analysis and heat exchanger networks to identify and optimise the main bottlenecks in primary reformer furnaces with the main goal of finding the best possible retrofit options for fuel savings and related CO_2 reduction.

REGULARS

4 Editorial
Prolonging the agony

6 Price Trends

7 Market Outlook

8 Nitrogen Industry News

14 Syngas News

16 People/Calendar

18 Plant Manager+
Handling leaks in urea plants: part 2

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

Prolonging the agony

Like a stone thrown into a pond, the ripples from Russia's February attack on Ukraine continue to widen as they propagate outwards. Fertilizer and energy markets were first to be hit, but there are now increasing concerns over the impact on grain and other food markets, and the long term effects of high fertilizer prices on food production. The closure of Black Sea ports has affected grain exports from Ukraine and Russia, which between them represented 24% of global wheat exports, 57% of sunflower seed oil exports and 14% of corn exports over the past five years, according to UN data, while the UN World Food Programme (WFP) says that 51 million tonnes of grain passed through Ukrainian ports in the eight months before the February invasion. The halt in Ukrainian exports has pushed the UN Food and Agriculture Organization's (FAO) food price index to its highest point since records began in 1990. At the same time, numerous food exporting countries are restricting exports to protect domestic consumers. Indonesia has banned palm oil exports and Argentina soybean oil exports. Rapidly rising prices for food around the world have already fuelled protests in Argentina, Indonesia, Greece and Iran.

> **"If the war continues into the winter... the 2023 cropping season in the northern hemisphere might be affected by shortages of nitrogen."**

Fertilizer production, distribution and application for the northern hemisphere is already mostly complete, and at the moment it looks as though India has been able to secure sufficient fertilizer for its key kharif monsoon application season, but Brazil, which imports nearly all of its fertilizer requirements, is judged to be at risk, especially from the loss of potash from Belarus and Russia. Brazil's soybean harvest next year could be badly hit by the lack of nutrient availability.

The nitrogen fertilizer market has been less badly affected than the potash market, where production is concentrated in only a few countries. There is potentially also some spare capacity for e.g. urea, though mainly in China, where the government has tried to crack down on carbon emissions by restricting coal-fired ammonia production, and limited urea exports to make sure that the domestic market is insulated from the international storms. But high gas prices could continue to curtail nitrogen production in Europe and India, both of which import much of their gas requirements. The worry, if the war continues into the winter, is that the 2023 cropping season in the northern hemisphere might be affected by shortages of nitrogen, especially ammonium nitrate. And while farmers can reduce phosphate and potash applications for a year with fewer ill effects, nitrogen remains the key nutrient for grain fertilization. Particularly in countries in regions such as Africa, farmers may not be able to afford fertilizers at the kind of prices we have seen, and as a result may see their production decrease.

Speaking to the Berlin conference on food security in late June, UN Secretary General Antonio Guterres said that the war in Ukraine has added to the disruptions caused by climate change, the coronavirus pandemic and inequality to produce an "unprecedented global hunger crisis", with the potential that "multiple famines will be declared in 2022… and 2023 could be even worse." The UN FAO and WFP recently issued a 'Hunger Hotspots' report warning of multiple, looming food crises. WFP Executive Director David Beasley said that conditions were now "much worse than during the Arab Spring in 2011 and 2007-2008 food price crisis, when 48 countries were rocked by political unrest, riots and protests." Ethiopia, Nigeria, South Sudan and Yemen are at the most risk, as well as Afghanistan and Somalia, with up to 750,000 people facing starvation and death.

In his speech, Guterres argued that the solution to this impending crisis was firstly to arrange a deal to allow Ukraine to export the grain already sitting in its warehouses, and then to achieve an agreement that will let Russia and Ukraine export their fertilizer production without restrictions, in particular the payment restrictions which complicate purchases from Russia. This will also mean opening Black Sea ports such as Odessa, currently blockaded by the Russian navy. Whether such a deal can be done, and whether it can be done before the situation becomes even more serious, remains very much open to question, however.

Richard Hands, Editor

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Price Trends

NITROGEN

High gas prices, especially in Europe, and lack of availability from Russia kept ammonia prices high in April, but as May began there were signs of demand destruction as record ammonia prices kept buyers away. Industrial users in particular seemed to be staying out of the market. The trend was also exacerbated by poor weather in the US which delayed planting and led to US ammonia buyers delaying purchases of direct application ammonia. All of this led to considerable pressure on prices. Yara and Mosaic dropped North American prices by $200/t from April to May. In southeast Asia, a sales offer from Kaltim was left untouched at $1,125/t f.o.b. The downwards correction accelerated at the end of May, with the Tampa June ammonia contract price falling $425/t to exactly $1,000/t c.fr; around $100/t lower than expected.

Gas prices remain volatile and have been creeping up in the US, and freight rates remain high, setting a limit to how far sellers are willing to drop prices. Russian gas flows into Europe continue to tighten, with flows through the Nordstream pipeline down 40% and concerns that Europe will not meet gas storage targets for the coming winter. Several European producers are shut down and more may follow.

Meanwhile, with buyers thin on the ground, and no ammonia coming from the Black Sea, the traditional benchmark for ammonia prices, price offers and expectations varied widely, with OCP in Morocco heard to be offering the best prices at up to $990/t. Further price corrections were anticipated by the market heading into July, with Asian export offers expected to sink towards Chinese domestic price levels.

Urea prices also appeared to peak at around the start of May and began to fall thereafter in most regions on relatively thin trading. There was comfortable supply available from Russia, which continues to ship urea to the Americas, especially Brazil, and from the Middle East, Egypt and Nigeria. Supply disruption from Russia now appears to be compensated for in the market.

The market looked to India for direction; after largely staying out of the market during April and early May, there was considerable interest in the major RCF tender on May 11th, which eventually led to the purchase of a total of 1.65 million tonnes of urea (against offers of up to 2.6 million tonnes) at prices between $716 and $721/tonne c.fr. The Middle East supplied around 650,000 tonnes of this, as well as Indonesia and Vietnam, and some Chinese cargoes in spite of export controls.

As with ammonia, poor weather in the US has led to falling urea prices, though NOLA rates were volatile and relatively lower than international prices, leading to some arbitrage by traders. Asian demand is relatively weak, and although there is ongoing demand from Brazil, prices continued to fall there to $570/t in June, and in general expectations of further price falls is leading to short selling by traders. ■

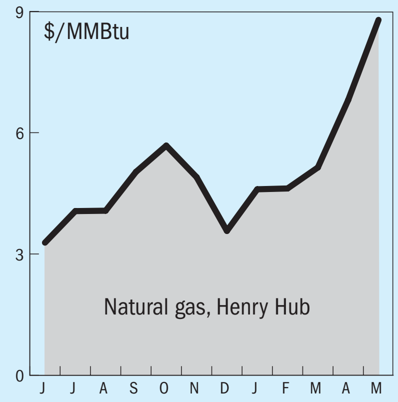
Table 1: **Price indications**

Cash equivalent	**mid-Jun**	**mid-Apr**	**mid-Feb**	**mid-Dec**
Ammonia ($/t)				
f.o.b. Black Sea	n.m.	n.m.	1,115-1,140	950-1,055
f.o.b. Caribbean	925-950	1,350-1,550	1,020-1,075	875-1,000
f.o.b. Arab Gulf	880-970	975-1,150	860-985	850-1,000
c.fr N.W. Europe	1,000-1,085	1,400-1,490	1,150-1,180	1,020-1,120
Urea ($/t)				
f.o.b. bulk Black Sea	n.m.	n.m.	518-620	800-905
f.o.b. bulk Arab Gulf*	535-650	700-850	750-825	810-910
f.o.b. NOLA barge (metric tonnes)	570-595	935-970	570-580	770-780
f.o.b. bagged China	525-625	690-820	560-700	830-920
DAP ($/t)				
f.o.b. bulk US Gulf	822-888	1,001-1,066	785-849	814-825
UAN (€/tonne)				
f.o.t. ex-tank Rouen, 30%N	583	837-859	680-740	680-740

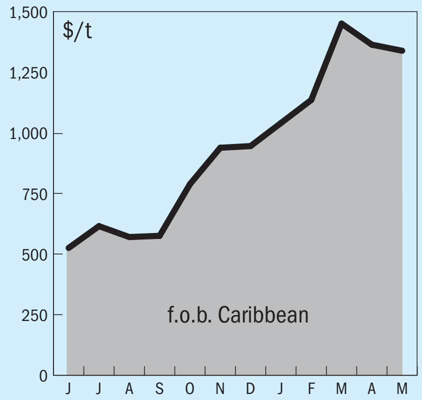
*Notes: n.a. price not available at time of going to press. n.m. no market. * high-end granular.*

END OF MONTH SPOT PRICES

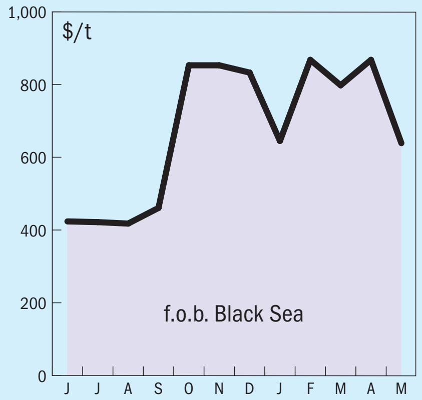
natural gas



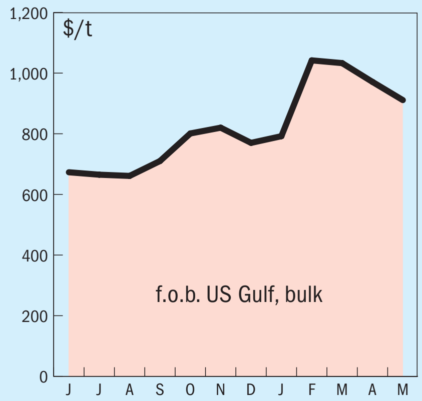
ammonia



urea

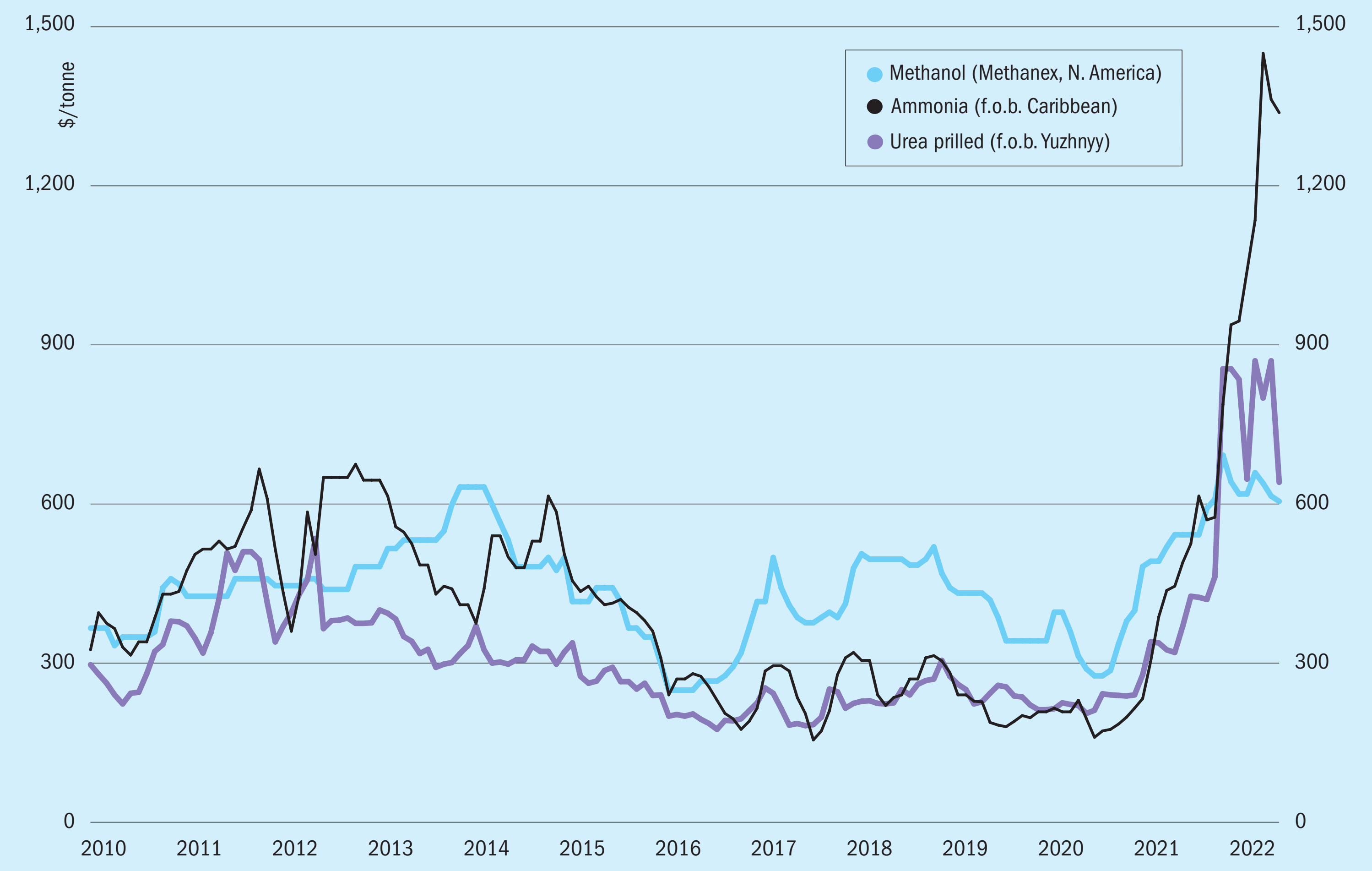


diammonium phosphate



Market Outlook

Historical price trends $/tonne



Source: BCInsight

AMMONIA

- High gas prices continue to keep ammonia prices elevated, but the lack of interest from buyers for some of the quoted rates has led to prices collapsing back towards slightly more rational levels. Even so, ammonia prices are 80% up on the same time last year.
- Indian DAP producers have been priced out of the market, and further downwards price corrections are expected by the market in Q3.
- Ince in the UK and Azomures in Romania both closed due to gas prices, and further production cuts are expected in Europe, with BASF's 880,000 t/a Ludwigshaven plant potentially subject to German emergency measures to reduce gas consumption.

UREA

- Prices have fallen sharply in all major markets. Kaltim most recent sales tender saw offers down more than $140/t f.o.b., with the highest offer at $547/t and most below $500/t f.o.b. Middle East prices had fallen to around $545/t by the end of June. NOLA barge prices have halved from their peak to just $410-420/st.
- However, there was a rebound at the end of June as falling prices led to demand beginning to pick up again in several end use markets. Egyptian f.o.b. prices bounced most strongly, up $100/t in a week to $740/t f.o.b.
- Another Indian tender is expected in July, and there is also expectation of more demand from Brazil at the end of July or into August for the summer rainy season. There has also been an uptick in European gas prices which may impact upon ammonia availability.
- With demand in the southern hemisphere due to pick up and no let up in the Ukraine conflict, some are predicting that urea prices may have bottomed out for 2022.

METHANOL

- In Europe, and North America, methanol prices are past their April peak and starting to head down again. Supply is stable and there has been some demand erosion in some derivative markets.
- Rising US gas prices may begin to pull prices upwards again, but inventories seem to be comfortable at the moment.
- European methanol spot prices have been at a 30% discount to contract prices, the latter were around €515/tonne for June.
- European consumers seem to have managed to reorient to pick up supply from North America and the Carbibbean to replace lost tonnage from Russia, which represents around 15% of European imports.
- Chinese methanol prices have been volatile but have essentially fallen back towards pre-Ukraine levels. Lockdowns have impacted upon olefins and hence MTO demand.
- Longer term there is new capacity in the US, while Iran remains a wild card, but the loss of new Russian capacity may now exacerbate looming shortages in the methanol market. ■

Nitrogen Industry News

UNITED KINGDOM

CF Industries to close its Ince plant due to high gas prices

CF Fertilisers has announced a restructuring of its operations in the UK. In a statement the company said that the move was "to position the business for long-term profitability and sustainability and enable it to continue to supply fertiliser, carbon dioxide and other industrial products to its domestic customers." The company will focus its manufacturing operations in the UK exclusively at the Billingham manufacturing facility in Teesside and permanently close the Ince manufacturing facility near Chester, which could result in up to 283 redundancies at the site. The Ince manufacturing facility has not produced ammonia since September 2021 because of high natural gas prices. CF Industries says that it believes the Teesside facility is better positioned for long-term sustainability as it has sufficient capacity to meet all forecast domestic demand for AN fertiliser, is more efficient than the Ince manufacturing facility, has an installed industrial customer base, and has the ability to import ammonia.

CF Industries' Ince fertilizer plant, Cheshire.

Other moves include the adoption of the company's global operating model for corporate functions, which could result in up to 55 further redundancies; this would entail the permanent transfer of select business activities to CF Industries' headquarters in the United States and the closure of Billingham's operations centre as well as the reorganisation of the maintenance and support team, which could result in another 33 redundancies at the facility.

"The people and facilities that make up CF Fertilisers UK are part of a proud, 100-year history of providing customers in the UK with products vital to the country's food security and industrial activity," said Brett Nightingale, managing director, CF Fertilisers UK. "However, as a high-cost producer in an intensely competitive global industry, we see considerable challenges to long-term sustainability from our current operational approach. Following a strategic review of our business, we believe that the best way to continue our legacy of serving customers in the UK is to operate only the Billingham manufacturing facility moving forward while addressing cost pressures throughout our business."

Global nitrogen industry conditions are expected to remain challenging for nitrogen producers in the UK and Europe. The cost of producing nitrogen fertilisers is highly dependent on the cost of natural gas, which is the principal raw material and primary fuel source used in the ammonia production process for manufacturing facilities in the region. For many producers globally, more than 70% of the total cost to produce ammonia is from the cost of natural gas. Natural gas forward curves suggest that nitrogen facilities in the UK and Europe will be the world's high-cost marginal producers for the foreseeable future, presenting a constant challenge to the sustainability of current operations.

Operations at both the Billingham and Ince manufacturing facilities were halted in September 2021 due to high natural gas prices that made production at the sites unprofitable. The Billingham manufacturing facility was subsequently restarted that month following an interim agreement reached with the UK government to cover the costs associated with restarting the ammonia plant to produce CO_2 for the UK market.

The company's AN fertilizer sales volumes to domestic customers have fallen by nearly 30% since the 2017-18 season due to intense competition from lower-cost imports. As a result, when both plants are producing AN even at minimum levels, CF has not been able to profitably sell the entire volume domestically over the last four years.

The Ince site includes a 1960s vintage 380,000 t/a ammonia plant, with 575,000 t/a of downstream ammonium nitrate production, and three NPK plants with a combined capacity of 415,000 t/a. The company's remaining UK site, at Billingham in Teesside, has a 595,000 t/a ammonia plant, together with 625,000 t/a of ammonium nitrate capacity and 410,000 t/a of nitric acid. ■

FRANCE

Agrofert to buy Borealis nitrogen business

Borealis, says that it has received a binding offer of €810 million from Czech firm Agrofert for the acquisition of Borealis' nitrogen business including all fertilizer, melamine and technical nitrogen products. Agrofert is a group active in a number of industries in central Europe, from chemicals and agriculture to food production, with a turnover of €7.5 billion in 2021. It is also one of the leading European nitrogen fertilizer producers, with manufacturing facilities in Germany, the Czech Republic, and Slovakia. Borealis' assets in Austria, Germany and France, as well as its sales and distribution network along the Danube River complements Agrofet's existing capabilities in serving its customers across Europe. Borealis says that it will initiate mandatory consultation procedures with employee representatives shortly. The transaction is also subject to certain conditions and regulatory approvals, with closure expected for the second half of 2022.

In February, Swiss-headquartered Russian fertilizer producer EuroChem made an offer to acquire the business for €455 million, but Borealis declined the offer on 11th March after the Russian invasion of Ukraine.

UNITED STATES

Nuclear power for ammonia production

Terrestrial Energy, the developer of the Integral Molten Salt Reactor (IMSR), has signed an agreement with ammonia technology supplier KBR to investigate the application of zero-emission thermal energy for the production of hydrogen and ammonia. Through the collaboration, KBR's energy advisory services team and Terrestrial Energy will analyse the integration of Terrestrial Energy's IMSR nuclear cogeneration technology for use in ammonia and hydrogen production. KBR's programme management and integrator solutions teams will further support the development of commercial frameworks for future deployment and routes to market for ammonia production technology with IMSR cogeneration.

"This agreement connects Terrestrial Energy and its sector-leading IMSR plant cogeneration technology to the world leaders in ammonia technology," said Terrestrial Energy CEO Simon Irish. "It represents a gateway industrial relationship to the production of affordable and zero-emissions ammonia. Its success will deliver a major global decarbonisation objective to a hard-to-abate industrial sector and drive affordable food supply. We're delighted to be collaborating with KBR to deliver on our shared technological, commercial and market vision."

"This agreement with Terrestrial Energy will leverage KBR's growing capabilities and aligns with our mission to develop new technologies and deliver solutions that help customers accomplish their most critical business objectives with sustainability at the core," said Andrew Barrie, president of KBR's Government Solutions EMEA business.

Nutrien studying blue ammonia conversion at Geismar

Nutrien says that it is evaluating converting its Geismar, Louisiana site to low-carbon ammonia production using carbon capture and storage to achieve at least a 90% reduction in CO_2 emissions. The project will proceed to the front-end engineering design (FEED) phase, with a final investment decision expected to follow in 2023. If approved, construction of the approximately $2 billion facility would begin in 2024, with full production expected by 2027.

Around 1.2 million t/a of ammonia would be produced using low cost natural gas, using autothermal reforming to achieve the lowest carbon footprint at scale, with high-quality carbon capture and sequestration infrastructure to capture at least 90% of emissions, permanently sequestering more than 1.8 million t/a of CO_2 in dedicated geological storage. Nutrien has signed a term sheet with Denbury Inc., a trusted partner for nearly a decade, that would allow for expansion of the existing volume of carbon sequestration capability in the immediate vicinity of its Geismar facility, if selected as the final site of construction. Nutrien has also signed a letter of intent to collaborate with Mitsubishi for the offtake of up to 40% of expected production from the plant to deliver to the Asian fuel market, including Japan, once construction is complete.

"Our commitment to the development and use of both low-carbon and clean ammonia is prominent in our strategy to provide solutions that will help meet the world's decarbonization goals, while sustainably addressing global food insecurity. Leadership in clean ammonia production will play a key role in achieving our 2030 Scope 1 and 2 emissions reduction goals, as part of our Feeding the Future Plan," said Ken Seitz, Nutrien's Interim President and CEO.

"Nutrien is optimally positioned to supply global emerging clean ammonia markets and grow a pathway for a decarbonised supply chain," said Raef Sully, Nutrien's Executive Vice President and CEO of Nitrogen and Phosphate. "We are pleased to partner with Denbury on this initiative given our established track record of cooperation. It is another example of how we are building on our expertise in low-carbon ammonia to decarbonise the agriculture industry while helping to sustainably feed and fuel the future."

AUSTRALIA

Yara signs gas supply agreement with Santos

Australian gas producer Santos has entered into a new gas supply agreement with Yara to supply natural gas to Yara's ammonia plant on the Burrup Peninsula in Western Australia. Santos will supply 120 petajoules of natural gas over five years, starting at the completion of its current agreement with Yara in 2023. In addition to the gas supply agreement, the companies say that they will also work together to explore decarbonisation opportunities in Western Australia, including carbon capture and storage (CCS). Santos CEO Kevin Gallagher said the company continues to support the Western Australian industry through the delivery of competitively priced domestic natural gas.

"Working with our customers to explore decarbonisation opportunities is fundamental to Santos' climate transition action plan. Santos supplies around 40% of the State's total domestic demand, and we are committed to ongoing investment in developing new gas supplies in WA. As Australia's biggest domestic gas supplier and a leading Asia Pacific LNG supplier, we are committed to supplying critical fuels such as natural gas in a more sustainable way through decarbonising projects."

OMAN

Joint development agreement for world-scale green ammonia facility

Air Products, OQ, Oman's leading integrated energy group, and ACWA Power have signed a joint development agreement for a multi-billion dollar investment in a world-scale green ammonia plant powered by renewable energy in Oman. The signing follows a memorandum of understanding signed in December 2021.

Envisioned for Oman's Salalah Free Zone, the joint venture project would include the integration of renewable power from solar, wind and storage; production of hydrogen by electrolysis; production of nitrogen by air separation; and production of green ammonia. It is anticipated that the green hydrogen-based ammonia production facility would be equally owned by the project partners.

Air Products Chairman, President and Chief Executive Officer Seifi Ghasemi, said, "We are delighted and honoured to work with the government of Oman to develop this multi-billion dollar project, which would be similar to the world-scale green hydrogen project we are implementing with our partners in NEOM in Saudi Arabia. We look forward to applying our know-how, technology and more than 60 years of experience in hydrogen to help move this project forward and take another significant step in decarbonising the world."

INDIA

ACME Cleantech signs MoU for green ammonia plant

Indian renewable energy company ACME Cleantech has signed a Memorandum of Understanding with the state government of Karnataka to invest $670 million to set up a solar-powered plant generating hydrogen for 120,000 t/a of ammonia production at the west coast port of Mangalore. The company has already established a solar ammonia demonstrator plant in Bikaner, Rajasthan with 5MW of solar energy, scalable to 10

MW, which produces around 2,700 t/a of ammonia. The firm also operates over 1.5 GW of solar energy capacity with another 10 GW under construction. The Mangalore investment is intended to be phase one of the project, with a second plant ten times the size envisaged in phase 2. India has set a target to manufacture 5 million t/a of green hydrogen by the end of the decade.

Sindri plant to begin production in August

Hindustan Urvarak and Rasayan Ltd (HURL), operators of the new 1,27 million t/a urea plant at Sindri, says that the plant is due to begin commercial production in August. The plant is reportedly in the process of commissioning and testing, with production beginning at the end of July and ramping up during August. A formal inauguration of the unit by prime minister Narendra Modi is said to be scheduled for the first week of September, exactly 20 years after the plant was closed due to lack of financial viability.

RCFL ordered to shut down by government pollution body

Ramagundam Fertilisers and Chemicals Ltd (RCFL) urea plant has been reportedly served with a 'stop production' order by the local Telangana State Pollution Control Board (TSPCB). The order cites alleged non-compliance with operating permit conditions and a failure to take adequate measures to control ammonia emissions. RCFL restarted operations last year using natural gas feedstock after the previous coal-based Fertiliser Corporation of India (FCI) unit at the site was closed in 1999 due to high production costs. Local media say that ammonia emissions were observed from urea prilling tower, ammonia storage tanks and ammonia production plant, and that monitoring of the urea prilling tower found that suspended particulate matter exceeded stipulated standards. However, the company maintains that the plant is equipped with sophisticated ammonia sensors with alarm systems at 51 locations and online continuous emission monitoring systems which have reported no breach.

JAPAN

Ube to stop producing ammonia by 2030

Japanese petrochemical company Ube says it will stop production of ammonia by 2030 as part of efforts to streamline its business and achieve its decarbonisation goals. Ube is targeting to reduce its greenhouse gas emissions from 4.2 million t/a this year to 2.4 million t/a in 2030. The company's existing ammonia plant, Ube-Fujimagari in the southwestern prefecture of Yamaguchi, is an ageing coal-based plant with a capacity of around 385,000 t/a, though the plant has also operated on petcoke feedstock since 1996. Ube has partnered with domestic petrochemical producers Sumitomo, Mitsui and Mitsubishi Gas Chemical to seek stable supplies of 'clean' ammonia. The company also participated in a joint study on using green ammonia as a marine fuel in June 2021.

GERMANY

Clariant wins Sustainability award

Clariant has been awarded the American Chemistry Council's (ACC) Sustainability Leadership Award 2022 in the category "Environmental Protection". The award is a recognition of Clariant's global climate initiative, in which the company offered free installations of its nitrous oxide (N_2O) removal catalyst EnviCat N_2O-S to ten nitric acid producers who did not yet have such abatement technology in place. The ten producers, three in China, two in the US, two in India, and a producer each in Turkey, Egypt and Trinidad, have a combined annual nitric acid production of more than 2 million t/a, and the catalyst will be able to reduce their N_2O emissions by 95%; a total of more than 4 million t/a of CO_2 equivalent. This approximates to more than 860,000 gasoline passenger vehicles driven for one year.

Conrad Keijzer, Chief Executive Officer at Clariant, commented, "We are grateful to the ACC for acknowledging our efforts with the Sustainability Leadership Award for the second year in a row. In 2021, we were recognized for our low-carbon footprint Glucamide surfactants, and this year for our global N_2O reduction campaign. This proves our purpose-led strategy driving towards sustainability transformation, both in our own company and for our customers."

Stefan Heuser, Senior Vice President and General Manager at Clariant Catalysts, added, "Globally, around half of all 500 nitric acid plants operate without N_2O removal technology. Through our campaign, we wanted to show the industry that the problem is serious, yet the solution is simple. We are pleased to have converted our winning nitric acid producers into N_2O reducers, and the strong interest in our initiative gives us hope that many others will follow."

Chris Jahn, President and CEO of the American Chemistry Council, stated, "Judged by an external panel of experts, the Sustainability Leadership Award recognizes outstanding initiatives led by chemical industry visionaries advancing sustainability. Clariant is dedicated to developing innovative products that can considerably reduce its customers' environmental footprint. We applaud Clariant on their achievement, and the impact their products make on helping create a better, more sustainable world."

Formaldehyde-free urea granules and prills

In conjunction with two urea producers, thyssenkrupp Fertilizer Technology (tkFT) says that it has successfully executed the first industrial applications of the company's formaldehyde free additive *UFT®Add*. It has been used in both processes granulation and prilling for the production of automotive and technical grade urea (TGU). In both applications, urea granules and prills were subsequently analysed by the customer, and all of the basic required product specifications such as crushing strength, moisture content and particle size distribution were satisfied. In addition, the urea products complied with technical grade urea standards as well as with DEF standards ISO 22241/AUS32.

For prills, long term analyses were also carried out as to their anti-caking and impact resistance. After months of storage and shipment, the prills produced with the *UFT®Add* showed comparable flowing and impact resistance properties to prills treated with conventional anti-caking agents.

UFT®Add has the potential to improve the process and product quality in granulation and prilling plants. In contrast to urea formaldehyde condensate (UFC) *UFT®Add* consists of different components which allows tailor made mixtures for the adjustment of product properties to the specific requirements of producers or customers. Additionally, the substitution of UFC by *UFT®Add* practically eliminates VOC emissions and thus significantly reduces the environmental impact.

Concerning implementation and plant modification, the change to *UFT®Add* requires only a small dosing system. As

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the dosing rates are much lower than for UFC, there are two options. In case of complete substitution of the suspected carcinogenic urea formaldehyde, the existing dosing system and storage can be used. In case of campaign-wise production with the additive, only a negligible investment is required. It can also open the way into new, profitable and growing market segments for urea producers, as it is suitable for the production of technical and/or DeNOx/DEF/automotive grade urea granules and prills. thyssenkrupp Fertilizer Technology, licensor for the *UFT®* fluid bed granulation technology, also provides *UFT®Add* life cycle support to its customers from initial application to full scale production.

DENMARK

Topsoe claims 12 million t/a of CO_2 reduction

Topsoe says that its technology reduced customers' greenhouse gas emissions by 12 million t/a in 2022, equivalent to about 8% of the EU's aviation industry's emissions. The reductions will primarily come from Topsoe's renewable fuels business. The company sees growing demand for renewable and low-carbon solutions from the heavy-duty transport sector as well as from the aviation and shipping sectors. The key driver of Topsoe's renewables fuels business is its patented *HydroFlex™* technology, which can produce renewable gasoline, jet fuel and diesel from almost any feedstock, including waste-fractions, tall oil, used cooking oil, animal fats, and vegetable oils. Topsoe also has a leading position in "blue" technologies, where CO_2 from the production of hydrogen and ammonia is captured and stored underground, and in developing Power to X-solutions enabling decarbonisation of the hard to abate-sectors such as steel, cement, and mining from electrolysis.

Roeland Baan, CEO pf Topsoe, commented: "Effectively reducing carbon emissions requires a coordinated effort from individual countries, companies and citizens. At Topsoe… we have made it our mission to reduce our customers' emissions by 12 million tonnes this year, and we will continue this work beyond 2022. Renewable fuels like renewable jet fuel and diesel are vital components in solving the net zero equation, to transform the global economy into one that is not dependent on fossil fuels."

NETHERLANDS

OCI to expand Rotterdam ammonia terminal

OCI says it has made a final investment decision on phase one of its ammonia import terminal expansion project at the Port of Rotterdam. The expansion will increase the facility's throughput capacity from 400,000 t/a to 1.2 million metric tons per year. The first phase of the project is estimated to cost below $20 million and completion is slated for 2023. For the second phase, OCI has already completed a basic engineering package for the construction of a new world-scale ammonia tank at the terminal. This will help increase throughput to above 3 million t/a.

"As a global leader in ammonia production, trading and distribution, this project is a very logical step to leverage our incumbency status in Rotterdam to enhance our ammonia value chain: never has this been as vital as it is now," said Ahmed El-Hoshy, Chief Executive Officer of OCI NV. "We are pleased to announce this milestone, enhancing a key ammonia import and future bunkering hub and aggregation point for low-carbon ammonia at a world-scale port, which will serve as an important avenue for clean ammonia imports from our global facilities and addresses current and future European hydrogen deficit needs.

"This vital piece of the global value chain will provide essential ammonia to keep downstream fertilizer plants running today in this volatile global natural gas environment, and in the future will also offer low carbon ammonia to feed the Dutch and wider European hydrogen needs in power generation, marine fuels, and broader industrial value chains, thereby reducing dependence on fossil fuels."

Allard Castelein, CEO of the Port of Rotterdam Authority, added: "OCI's decision to invest in tripling its ammonia import capacity in Rotterdam perfectly fits our plans. Our ambition is to be a carbon neutral port in 2050. This regards not only the industry in the port area, but also shipping. Ammonia is not only a hydrogen carrier and a feedstock for the chemical industry, it's also an important renewable fuel for the shipping sector. To be able to bunker ammonia, steps such as OCI's need to be implemented to increase the base. As sailing on ammonia is something new, we're working hard together with the business community and public authorities to have the regulations and safe handling procedures for ammonia bunkering operations in place in time."

NORWAY

Technip to design green ammonia plant

Iverson eFuels has selected Technip for the engineering design of a green ammonia plant in Norway. Iverson eFuels is a joint venture between Germany's Hy2gen, Denmark's CIP, and Dutch energy trader Trafigura. The ammonia plant will be constructed in Sauda, on the southwestern coast of Norway. The first phase of the project includes a green ammonia plant including utilities; offsites and electrical substation connected to the existing power grid; and pipeline, ammonia storage and offloading system. The ammonia production will be used as fuel for the maritime sector. The plant will have an initial electrolysis capacity of 300 MW to produce 600 t/d of green ammonia (nominal 200,000 t/a). Construction is due to begin in 1Q 2024, with completion in 1Q 2027.

UNITED ARAB EMIRATES

Korean companies plan green ammonia plant

Korea Electric Power, Samsung and Korea Western Power have signed an agreement with Emiraiti partner Petrolyn Chemie to build a $1 billion green hydrogen and ammonia plant in the Kizad industrial zone near the city of Abu Dhabi. Target capacity will be 35,000 t/a of green ammonia in phase one, expanding to 200,000 t/a in phase two, using hydrogen generated from solar power.

UKRAINE

Severodonetsk chemical complex becomes battle zone

Russian troops fighting in the east of Ukraine have attacked the city of Severodonetsk, with artillery and missile strikes hitting the Severodonetsk Azot (Nitrogen) plant, part of the Ostchem Group. Plants at the site include 1.0 million t/a of ammonia capacity in two trains, 390,000 t/a of urea capacity, and 550,000 t/a of ammonium nitrate, as well as smaller methanol and acetic acid units. A nitric acid tank was ruptured on June 1st, sending a plume of orange-brown nitrogen dioxide smoke into the air, and one of the ammonia units was reportedly hit on June 8th. A release of ammonia from the Togliatti-Odessa ammonia pipeline was also reported nearby on June 7th. The city had a population of 106,000 before the start of the conflict, but has now become the front line in the ongoing struggle for control of the eastern Donbas region.

BRAZIL

Yara to complete green ammonia feed next year

Yara says that it expects to deliver the first batch of green ammonia from its plant in Cubatão, São Paulo state, by the end of 2023. The feed will come from 20,000 m^3/d of biomethane being generated at a Shell plant being built in nearby Paracicaba. Yara agreed a deal to purchase biogas from the plant last year. It will only represent 3% of the volume of gas consumed by the Cubatão plant, but Yara says that it aims to have the entire plant running on biomethane by 2030, reducing greenhouse gas emissions from operation by 80%. Yara is reportedly also studying the possibility of having biomethane-powered trucks transport the fertilizers to sugarcane fields, forming a low-carbon circular economy.

INDONESIA

Feasibility study on green ammonia

Toyo Engineering says that Japan's government had awarded it a contract to conduct a feasibility study on green ammonia production in Indonesia. Toyo will collaborate with state-owned Pupuk Iskandar Muda (PIM) for the study. Toyo built the PIM ammonia-urea plant in the 2000s.

LIBYA

Lifeco restarts urea plant

The Libyan Fertilizer Company (Lifeco) says that it has restarted production at the company's second urea plant at Marsa el-Brega. Production was reported at 1,490 t/d, around 85% of the plant's 1,700 t/d capacity. It is the first production from the unit since Yara sold its stake in the two plants to the Libyan government in early 2021.

SWITZERLAND

SABIC reaffirms commitment to carbon neutrality at WEF

SABIC reaffirmed its commitment to reaching carbon neutrality by 2050 at the World Economic Forum meeting in Davos, Switzerland. In line with this year's theme of 'Working Together, Restoring Trust', SABIC used its reception to expand on how it will meet the 2050 carbon neutrality target, highlighting its Circular Carbon Economy (CCE) strategy.

SABIC Vice Chairman and CEO, Yousef Al-Benyan, said: "At SABIC, we recognize the strategic role our industry must play in reaching carbon neutrality by 2050. We know we are working against the clock, and as we outlined during our event, SABIC is committed to taking action to accelerate our journey towards carbon neutrality."

SABIC's CCE strategy is a vital component of its Carbon Neutrality Roadmap, which sets out the company's strategy to decarbonize all owned operations by mid-century in line with the goals of the Paris Agreement. Launched in October of last year at the inaugural Saudi Green Initiative Forum, the roadmap identifies five pathways towards total decarbonisation: energy efficiency; renewable energy; electrification; carbon capture, utilization and storage; and green/blue hydrogen.

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DENMARK

Topsoe to build world's largest electrolyser production facility

Topsoe says it will build what is describes as "the world's largest and most advanced industrial scale electrolyser production plant". The company aims is to accelerate the adoption of green solutions, in particular within the Power-to-X segment. The new electrolyser production plant will be constructed in Herning, Denmark, and operational by 2024, with an annual capacity of 500 MW of electrolysers, and scalability up to 5 GW. Construction is scheduled to begin in the second half of this year, subject to Board and other regulatory approvals.

Roeland Baan, CEO at Topsoe, said: "Topsoe is already seeing considerable interest in our Power-to-X solutions and is in advanced discussion with a number of potential partners over future offtake agreements and commitments to reserve capacity from the electrolyser plant. Developing a strong Power-to-X industry in Europe will also reinforce the EU's ambitions of being independent of energy imports from other regions."

The milestone in ensuring large-scale availability of electrolysers comes at the same time as Ursula von der Leyen, President of the European Commission, and state leaders from Denmark, Germany, the Netherlands, and Belgium signed an agreement to invest in a ten-fold increase in offshore wind capacity by 2050. The agreement ensures availability of the renewable power needed to supply future Power-to-X facilities in the EU.

Baan added: "The agreement between the EU Commission and the four North Sea countries is an important step in the transition to renewable energy. At Topsoe, we are also ready to invest. By introducing solutions to decarbonise transportation and other hard to abate-sectors, we secure significant CO_2 emissions not only in 2022 but for years to come, while also moving closer to energy independence."

BELGIUM

New hydrogen network for Antwerp

INEOS Olefins Belgium has signed an agreement with gas transmission company Fluxys to undertake a feasibility study on the development of an open access hydrogen network in the port of Antwerp. The cooperation follows a market consultation initiated by Fluxys last year to match supply and demand for hydrogen in Belgian industrial clusters. One of the projected major customers will be INEOS's Project ONE, a proposed ethane cracker to be built at the port of Antwerp, which could require up to 100,000 t/a of hydrogen. INEOS is also involved in a collaboration with Fluxys and the other consortium partners in the Power to Methanol project to build a demonstrator plant for the production of green methanol from renewable-derived hydrogen and captured CO_2.

Raphaël De Winter, Director of Business Development & Innovation at Fluxys said: "We are fully committed to helping develop a well-functioning market for hydrogen quickly. This requires an open access grid to which everyone can connect on an equal footing so that supply and demand can find each other smoothly. We are working on infrastructure proposals in the various industrial clusters in Belgium, providing connections between the clusters and to neighbouring countries, and working on import possibilities. In Antwerp, the interest shown by INEOS Olefins Belgium is an important step in the development of the infrastructure needed by industry. The train is leaving now: with the interest of all the companies combined, we will complete the studies for the grid in Antwerp early 2023 and conclude contracts in the first half of 2023 to be able to build."

In November 2020, the INEOS group launched a new business to develop and build green hydrogen capacity across Europe to support the drive towards a carbon-free future. This was followed a year later by the announcement to invest €2 billion in the production of carbon-free, green hydrogen across Europe.

FINLAND

New biomethanol plant

Metsä Group and Veolia have signed a long-term partnership agreement convert crude methanol generated in pulp production at the Äänekoski bioproduct mill into commercial biomethanol. As part of the agreement, Veolia will build a 12,000 t/a methanol 'refinery' at Metsä Fibre's Äänekoski bioproduct mill, at a cost of €50 million. The refinery, owned and operated by Veolia, will be closely integrated into the bioproduct mill processes. It is due to begin production in 2024.

INDIA

Tecnimont wins EPC contract for green hydrogen plant

Maire Tecnimont has been awarded an EPC contract by the Gas Authority of India Limited (GAIL) to build a 4.3 t/d green hydrogen plant via a 10-megawatt PEM electrolysis unit at Vijaipur, Madhya Pradesh state, in central India, for an undisclosed sum. The project's scope of work includes full engineering, procurement and construction up to commissioning, start-up of the plant and performance guarantee test run, while its completion is expected in 18 months from the letter of acceptance.

Alessandro Bernini, CEO of Maire Tecnimont Group, commented: "In line with its National Hydrogen Mission, this project represents an important milestone of India's journey towards a hydrogen-based and carbon-neutral industry and economy, as well as a tangible confirmation of the steady growth of Maire Tecnimont's Green Business. Blending green hydrogen into the gas network or using it as green feedstock to decarbonise the fertiliser and other hard-to-abate industrial processes are essential uses which are enabling the green hydrogen economy to accelerate and scale-up. With our historical presence in India, we are proud to concretely contribute to the country's 2030 decarbonisation targets".

Policy on methanol fuel expected soon

The Methanol Institute says that it expects the Indian government to issue a policy on the use of methanol as an alternative fuel "soon". The Institute has been working since 2016 with government think tank NITI-Aayog on India's "Methanol Economy" programme, which aims to reduce the country's oil import bill, greenhouse gas (GHG) emissions, and convert coal reserves and municipal solid waste into methanol. They are also investigating the

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

production of bio-methanol from renewable sources such as agricultural waste and municipal solid waste, as well as 'e-methanol', made from captured carbon dioxide and green hydrogen. Because of its abundant reserves, methanol derived from coal is the most economically viable option for India, according to the NITI-Aayog. It is less expensive than natural gas and crude oil, both of which are imported. A number of pilot programmes are already under way in India, including one on M15 (a 15% blend of methanol into gasoline) in Assam, run by the Indian Oil Corp. There has also been a successful pilot project on methanol stoves in Assam run by NITI Aayog and Assam Petrochemicals.

NITI-Aayog is projecting that five new methanol plants based on high ash coal, with downstream dimethyl ether (DME) plants, and a natural gas-based methanol plant, with a total combined capacity of 20 million t/a will be built in a joint venture with Israel. In addition, NLC India Ltd (NLCIL) has recently announced that it is planning to build a new $560 million methanol plant at Neyveli in Tamil Nadu using lignite coal as feedstock. The 1,200 t/d (400,000 t/a) plant is aimed to be completed in 2027. Engineers India Ltd (EIL) has been engaged as project management consultant and NITI Aayog is recommending fast track approval. The Indian government says that it hopes to construct 100 million t/a of coal gasification plants by 2030.

UNITED STATES

Construction of methanol plant nears completion

US Methanol says that its Liberty One methanol plant will begin operation in the next couple of months near Charleston, West Virginia. The company says that the facility, a relocated plant from Brazil, is undergoing major upgrades, repairs, and modifications in its construction phase that will result in a reliable methanol plant with increased efficiency and an expected useful life similar to a new plant. Capacity at start-up will be 200,000 t/a, with expansion potential up to 350,000 t/a. The plant will be based on local natural gas feedstock and will market methanol to the northeastern United States.

Fulcrum starts up waste to fuels plant

Fulcrum BioEnergy says it has completed commissioning and begun initial operations at its Sierra BioFuels Plant outside Reno, Nevada. The Sierra plant can gasify up to 175,000 t/a of prepared waste feedstock to syngas. The next phase of the project will be to convert the syngas into aviation fuel using Fischer-Tropsch technology.

"This achievement at our Sierra plant is a real breakthrough step in making waste to fuels a reality. This is a tremendous moment for our company and a major milestone for our construction management, operations and engineering teams who have worked tirelessly to integrate more than 30 different plant systems in Fulcrum's unique and patented process," said Eric Pryor, Fulcrum's President and Chief Executive Officer. "Fulcrum is launching an entirely new source of low-cost, domestically produced, net-zero carbon transportation fuel, which will contribute to the aviation industry's carbon reduction goals, US energy security and address climate stability."

BOTSWANA

Feasibility study on CTL plant completed

The feasibility study on the $2.5 billion Ikaegeng XTL coal-to-liquids plant has been successfully completed, and state-owned developer Botswana Oil says that it is now looking for a private partner for the implementation of the project. The plant is expected to produce 80% of the country's yearly gasoline demand of 1.2 billion litres (21,000 bbl/d) and consequently reduce Botswana's dependence on South Africa, which has recently experienced a rapid loss of refining capacity, with many of its major refineries closed or nearing the end of their life. South African refining capacity reportedly fell from 703,000 bbl/d in March 2020 to 303,000 bbl/d in March 2022.

GERMANY

Demonstration of biomass gasification technology

A pilot plant has conducted successful tests on CLARA, a new biomass gasification technology which is being conducted by the Technical University of Darmstadt with 12 partners from academic and industry under the EU's Horizon 2020 research and innovation programme. It aims to produce sustainable second-generation biofuels for the transportation sector in order to move it towards CO_2 neutrality.

The process converts waste biomass such as wheat straw into syngas via a 'chemical looping gasification' (CLG). The syngas is then treated and purified to enable efficient fuel production. The CLG technology provides oxygen for the reaction through the cyclic reduction and oxidation of an abundant, non-toxic metal oxide, avoiding a costly air separation unit. It also allows for efficient capture of the CO_2 formed during the autothermal gasification step, thus allowing for net negative CO_2 emissions of the biomass to liquid process chain.

SPAIN

Johnson Matthey and BP technologies selected for synfuel plant

Johnson Matthey and BP have announced that their co-developed Fischer Tropsch *CANS*™ technology, together with Matthey's reverse water gas shift technology *HyCOgen*™, have been selected for use by Aramco and Repsol at a new synthetic fuels plant in Bilbao, Spain. The plant will be one of the world's first to use renewable 'green' hydrogen and CO_2 as its only raw materials. It is due to be commissioned in 2024, with a starting capacity of more than 2,100 t/a. It will produce a sustainable synthetic drop-in fuel that can be blended for existing road vehicle engines, planes and ships.

It is the second licence signed for the FT CANS technology, which converts syngas from sources such as industrial emissions, direct air capture, municipal solid waste or other renewable biomass, into long-chain hydrocarbons suitable for the production of diesel and jet fuels. It is also the first licence signed for Matthey's recently launched *HyCOgen* technology, which uses a catalysed process to convert CO_2 and green hydrogen into carbon monoxide (CO), which is then combined with additional hydrogen to form syngas. Coupling *HyCOgen* and FT CANS technologies provides an end-to-end, scalable process optimised for high conversion efficiency.

Aramco Chief Technology Officer, Ahmad Al-Khowaiter, said: "This agreement supports our ongoing work to develop lower-emission transport solutions and we are thrilled by the opportunity it represents. Converting CO_2 into synthetic, lower-carbon fuels can meaningfully contribute to the reduction of transport emissions and, through this strategic partnership, we aim to harness innovative technologies that can unlock the full potential of both sustainable fuels and chemicals and demonstrate their competitiveness." ■

People

Dan Demers.

Fertilizer Canada has announced the appointment of **Dan Demers** as Vice President, Government Relations. Dan brings with him over 30 years of government relations and public affairs experience. Dan will lead Fertilizer Canada's advocacy efforts federally, provincially, and municipally. He was formally the Vice President, Government Relations and Regulatory Affairs at the Canadian Health Food Association, where he oversaw their government relations activities. Throughout his career Dan has worked in politics and a variety of industries including, health and wellness, pharmaceutical, non-profit, and government.

"We are excited to welcome Dan to the team," said Karen Proud, President and CEO, Fertilizer Canada. "We look forward to the expertise and experience he will bring to the role and to our organisation."

Johnson Matthey (JM) has announced a new Group Leadership Team (GLT) to drive the execution of the company's new business strategy. JM's customers will now be served through four core businesses, centred on the company's expertise in platinum group metal chemistry and catalysis, combined with process technology skills.

The new GLT will include: **Anish Taneja** as Chief Executive, Clean Air from 1 July. Anish brings significant commercial acumen and experience, and was most recently President & CEO Michelin Europe North. Anish's role will be to ensure Clean Air maintains its leading position in the auto-catalyst market.

Mark Wilson joins JM as Chief Executive, Hydrogen Technologies from 11 July. Mark is an experienced leader in the chemical and energy industries, having spent much of his early career at BP in various commercial and general management leadership roles, including setting up successful joint ventures and partnerships in China. His role will be to make Hydrogen Technologies the market leader in performance components for fuel cells and green hydrogen electrolysers.

Jane Toogood will be Chief Executive, Catalyst Technologies (CT). Jane was previously Chief Executive, Efficient Natural Resources (ENR) and has extensive chemicals industry leadership experience. She is very familiar with catalyst markets and the company says she is well positioned to strengthen JM's position as market leader in syngas-based chemicals and fuels technology.

Alastair Judge will be Chief Executive, Platinum Group Metal Services (PGMS). Alastair was previously Finance Director then interim CEO of Clean Air. JM says that Alastair has demonstrated strong leadership capability throughout his career, and his role will be to ensure PGMS retains its position as the global leading recycler of platinum group metals as well as looking to maximise the synergy opportunities with the other three core businesses, all of whom already rely on PGMS as an enabler for their businesses.

In addition, **Christian Gunther** has been appointed as Chief Strategy and Transformation Officer to accelerate transformation within JM, and **Anne Chassagnette** joined earlier in May as Chief Sustainability Officer.

The GLT also includes: Stephen Oxley, Chief Financial Officer; Mark Su, President, China; Maurits van Tol, Chief Technology Officer; Ron Gerrard, Chief EHS and Operations Officer; Annette Kelleher, Chief Human Resources Officer; and Nick Cooper, General Counsel and Company Secretary Liam Condon, CEO of Johnson Matthey, said: "JM has a powerful vision for a cleaner, healthier world and the net zero transition is creating new and bigger markets for us. With these appointments I believe we now have the right world-class leadership team to unlock our true potential, drive performance and successfully execute on our strategy moving at pace." ■

Calendar 2022/3

! The following events may be subject to postponement or cancellation due to the global coronavirus pandemic. Please check the status of individual events with organisers.

SEPTEMBER

11-15
66th AIChE Safety in Ammonia Plants and Related Facilities Symposium, CHICAGO, USA
Contact: Ilia Kileen, AIChE
Tel: +1 800 242 4363
Web: www.aiche.org/ammonia

12-14
Argus World Methanol Forum, HOUSTON, Texas, USA
Contact: Michelle Ladiana, Argus Media Group
Tel: +44 (0)20 7780 4340
Email: conferencesupport@argusmedia.com
Web: www.argusmedia.com/en/conferences-events-listing/methanol-forum

OCTOBER

2-7
Ammonium Nitrate/Nitric Acid conference, HOUSTON, Texas, USA
Contact: Hans Reuvers, BASF, Karl Hohenwarter, Borealis.
Email: johannes.reuvers@basf.com, karl.hohenwarter@borealisgroup.com, annaconferencehelp@gmail.com
Web: annawebsite.squarespace.com

26-28
Global Syngas Technologies Conference, TUCSON, Arizona, USA
Contact: Global Syngas Technologies Council, PO Box 18456, Sugar Land, TX 77496 USA
Tel: +1 713 703 8196
Email: info@globalsyngas.org

NOVEMBER

29-30
Argus Clean Ammonia Europe Conference, HAMBURG, Germany
Contact: Argus Media Group
Tel: +44 (0)20 7780 4340
Email: conferences@argusmedia.com
Web: www.argusmedia.com/en/conferences-events-listing/clean-ammonia-europe

JANUARY 2023

30 – 1st FEBRUARY
Fertilizer Latino Americano, RIO DE JANEIRO, Brazil
Contact: Argus Media, Ltd.
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Email: conferences@argusmedia.com

Contents ISSUE 378 NITROGEN+SYNGAS JULY-AUGUST 2022 BCInsight

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

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Ratings Partner: FitchRatings

Supporting Publications: World Fertilizer Magazine, nitrogen+syngas Published by BCInsight

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Plant Manager+

Handling leaks in urea plants: part 2

Leaks in the high-pressure synthesis section of a urea plant may lead to catastrophic consequences. UreaKnowHow.com started to collect incidents in an incident database and in 2017 AmmoniaKnowHow.com and UreaKnowHow.com introduced FIORDA, the Fertilizer Industry Operational Risk Database, a global open source risk register for ammonia and urea plants.

Part 1 of this short series of articles on how to handle leaks in urea plants explained why leaks in the high-pressure synthesis section of a urea plant are so critical and discussed corrosion and sealing challenges and what happens when there is a leak. Part 2 looks at the causes and consequences of leaks and discusses different types of critical leaks.

Causes and consequences of leaks

Leaks can be caused by several factors:

- wrong materials of construction;
- inferior design;
- inferior quality assurance during fabrication/installation
- wrong and inferior torquing practices;
- various corrosion phenomena from the process side and from utilities/the atmosphere;
- end of lifetime conditions.

When there is a leak in a urea plant the best practice is to shut down the plant and solve the leak. If this action is not taken it is important to always perform a proper risk assessment to ensure all possible failure modes have been considered and reference has been made to similar previous cases in the industry.

The following possible consequences should also be taken into account:

- Retightening to stop a leak (hot bolting) during operations is risky and very difficult, if not impossible; it easily introduces the risk of overtightening the bolts since the mechanical properties at elevated temperature differ.
- A leak leads to the formation of solids, which can easily cause clogging.
- It is important to assure that erosion and corrosion properties of the leaking ammonium carbamate do not threaten the mechanical integrity of the carbon and stainless steel parts. Proper flushing and close monitoring are very important. In case of flushing, it is important to avoid water with ammonium carbamate from dripping onto the carbon steel pressure-bearing walls of high-pressure equipment as this can cause stress corrosion cracks in the carbon steel wall.
- Clamping of ammonium carbamate and ammonia pipelines, valves or accessories is extremely dangerous and should never be done.

What are critical leaks?

Leak detection systems for loose liners

Loose liners in high-pressure equipment require leak detection holes in the carbon steel pressure-bearing wall. Relatively long leak detection tubing typically connects these leak detection holes to an ammonia detector (Fig. 1); this tubing is sensitive to clogging due to the formation of solids.

Without this tubing, operators would need to inspect each and every hole during their daily plant tours. As these plant tours take place with limited frequency, the time taken to discover the leak may be too long. During this period the leak detection circuit gets clogged, and nobody is aware of a leak being present. A sudden rupture of the leaking high-pressure equipment is not unthinkable; multiple serious incidents have been reported in the industry[1].

Fig. 1: A typical passive leak detection system.

Connecting leak detection holes with an ammonia detector and waiting until the leaks shows up at the monitor (so-called passive systems as shown in Fig. 1) have not proven to be reliable as several serious incidents with these systems have been reported in the industry[2].

UreaKnowHow recommends an active state-of-the-art leak detection system with a very accurate and reliable ammonia detector as the best solution to detect leaks in loose liners. Such a system is able to confirm the leak, locate the leak area, calculate the leak size and prepare for a repair. In addition, the time required to stop the plant, locate, repair the leak and restart operations will be minimised.

Leak detection systems for tubes and tube-tubesheet connections

High-pressure heat exchangers in urea plants typically consist of carbon steel tubesheets at the process side cladded with a corrosion resistant layer. The carbon steel is sensitive to carbamate corrosion and critical for the integrity of these heat exchangers. In the steam or condensate side, a conductivity analyser is typically present to detect any leak in a tube or tube to tubesheet connection. In case a leak is confirmed, the plant must be shut down as the carbon steel tubesheet will suffer from high corrosion rates as shown in Fig. 2.

Leaks along threaded connections

Leaks along threaded connections causing corrosion of the threads are very dangerous. The mechanical integrity of the

Fig. 2: Severe corrosion of the carbon steel tubesheet due to a leak in a tube.

Fig. 3: Leaks along a threaded bonnet connection of a high-pressure drain valve.

Fig. 4: Cracks in a high-pressure carbamate gas line.

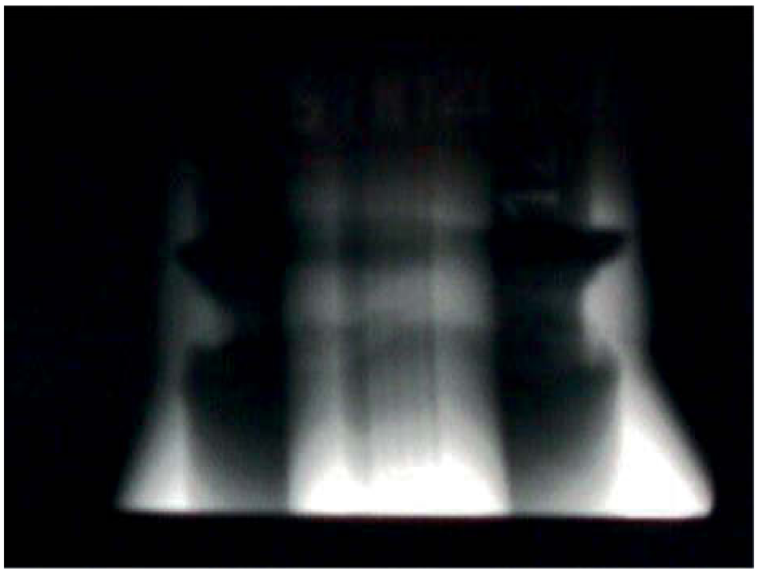

Fig. 5: Severe corrosion in the heat affected zones of a weld-o-let.

threaded connection will weaken and a rupture and serious incident can occur. In case of a leak along a threaded connection, the plant must be shut down.

Threaded connections can be found, for example, in high-pressure valves (Fig. 3) and high-pressure reciprocating pumps.

Cracks

Cracks (Fig. 4) are initiating leaks and a rupture will follow. Cracks can be caused by, amongst others, vibration issues, strain induced intergranular corrosion of high-pressure synthesis gas lines caused by a combination of stresses, large grain sizes of austenitic stainless steels and condensation of ammonium carbamate gases. Leaks due to cracks are critical as the leak size can grow suddenly leading to loss of integrity. It is recommended to shut down the plant if a leak caused by a crack is found.

Accessories in high-pressure piping systems

Accessories in high-pressure piping systems like weld-o-lets are critical parts, even more so when they consist of several parts welded together. Especially in case 316L Urea Grade is applied as material of construction, higher corrosion rates can occur in the heat affected zones (Fig. 5). Also, in case of weld-o-let designs where there is a dead zone, higher corrosion rates can result from lack of sufficient refreshment of oxygen in the liquid phase or condensation of carbamate gases.

End of lifetime conditions

Passive corrosion is a normal and accepted phenomenon in any urea plant, which means that the wall thickness of tubes, liners, overlay welding and piping systems will decrease continuously during the lifetime of the plant. Leaks can occur when one reaches end of lifetime conditions, which is typically between 15 and 25 years for the standard materials of construction like 316L Urea Grade and 25-22-2 in strippers. ■

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Computer rendering of Yara's new ammonia bunkering terminal.

PHOTO: YARA INTERNATIONAL

Barriers to ammonia's adoption as a fuel

Green ammonia is increasingly being looked to as a low carbon fuel for maritime vessels, but this will require it to overcome concerns over availability, toxicity, safety and handling.

As moves to tackle climate change achieve progressively greater momentum worldwide, so various transport sectors are looking towards achieving carbon neutral propulsion systems which do not reply upon fossil fuels. In the realm of private cars and other road vehicles, electric and electric hybrid vehicles seem to be gaining increasing sway. Proposed so-called sustainable aviation fuels (SAFs) currently tend to rely on generating conventional hydrocarbons from renewable or other waste sources, such as gasification of waste biomass, municipal waste or waste cooking oil. But for the maritime sector, methanol and ammonia seem to be the leading candidates, with ammonia, either blue – from existing plants but using carbon capture and storage – or green, using hydrogen generated from water electrolysis using renewable energy – currently looking like the favourite.

The need for a zero carbon shipping fuel is a pressing one. Global shipping accounts for around 3% of global carbon emissions, with 100,000 ships consuming around 300 million t/a of fuel, and the number of global tonne-miles is expected to continue to grow by 1.3% per year to 2050. The International Maritime Organisation (IMO) has set a goal of reducing total greenhouse gas (GHG) emissions from international shipping by at least 50% by 2050, compared to 2008 levels. In addition, a target has been set to reduce the carbon intensity of shipping by 40% by 2030, requiring a low carbon option that can be rapidly scaled. The EU's Emissions Trading System under the so-called 'Fit for 55' package of measures aims at cutting maritime emissions in and around Europe by 90% by 2050. A recent survey of the shipping sector by Lloyds List identified ammonia as one of the top three fuels with potential for use by 2050, with respondents expecting adoption of ammonia as a marine fuel to be 7% by 2030 and 20% by 2050.

Ammonia's credentials

Although ammonia's energy density (higher heat value) is about 22.5 MJ/kg; only around half that of a typical hydrocarbon like gasoline or diesel, it is nevertheless about the same as methanol and significantly more than hydrogen, and certainly close enough to existing fuels that it could be used to run a vehicle. It also – in theory – burns without involving carbon and hence generating carbon dioxide, producing only nitrogen and water, although nitrous oxides can also be produced depending upon the combustion process. Prior to the recent crisis in Ukraine it was also relatively cheap compared to existing bunker fuels on a per tonne basis, and roughly the same on an energy equivalent basis. There is already a large ammonia production and shipping industry, which is used to safely handling and distributing it.

Ammonia's issues

However, there are a number of issues that ammonia must address before it becomes widely taken up as a marine fuel. Table 1 shows a matrix of potential candidates as low or zero carbon marine fuels, as evaluated by the Maersk-McKinney-Moller Centre for Zero Carbon Shipping. Blue and green ammonia can be seen to have a number of outstanding issues.

Engine development

While ammonia can be burned in conventional internal combustion engines, it has a slow flame propagation compared to e.g. diesel. This means it burns more slowly. It also has a much higher autoignition temperature (around 630°C, compared to 210°C for diesel). This means that sustaining combustion is also more difficult with ammonia than for other fuels. One solution has been to mix ammonia at around a 95% ratio to a pilot fuel such as conventional marine gasoil, though for a truly green combustion this might need to be biofuel or similar.

Ammonia's particular combustion properties have necessitated a redesign of marine engines; a costly business for a relatively conservative sector. However, much progress has already been made. Finnish marine engine manufacturer Wärtsilä has been developing new engines with EU funding in the European research initiative the Waterborne Technology Platform. The company says that it has managed to achieved sustainable combustion at blends of up to 70% ammonia, and has a concept that will be running on pure ammonia by 2023. It aims to have a lab-based demonstrator for a four-stroke pure ammonia engine, and a lab-based test engine followed by a vessel retrofit for a two-stroke version by 2025. Meanwhile, MAN Energy has been leading the AEngine joint development project with Eltronic FuelTech, the Technical University of Denmark and DNV. With combustion testing scheduled for this spring, MAN's two-stroke model is expected to go to market in 2024.

Because ammonia combustion can also produce harmful nitrogen oxides, mitigating emissions is another significant challenge. NOx emissions are regarded as less of a problem since abatement using ammonia for selective catalytic reduction is already a well established technology widely used in diesel road vehicles using a urea solution to provide ammonia. A pure ammonia fuelled vessel of course would be able to use the fuel itself. Some form of exhaust gas recirculation system might also be required. However, nitrous oxide (N_2O) emissions are a greater challenge, because of its much greater global warming potential, and require the combustion process itself to be tweaked to help mitigate its generation. Secondary and tertiary (end of pipe) N_2O reduction processes are also available to deal with any slip from combustion and widely used in the nitric acid industry.

Toxicity

Safety of ammonia use is another major concern. Concentrations in air as low as 0.25% can cause fatalities. Fortunately, the odour threshold for ammonia is very low, ranging from 0.037 to 1.0 ppm, meaning it can be detected by most people at low concentrations that do not constitute a health risk. Nevertheless, in low concentrations, it can be irritating to the eyes, lungs, and skin and at high concentrations or through direct contact it is immediately life threatening. Skin contact with high concentrations of anhydrous ammonia may cause severe chemical burns, and exposure to the eyes can cause pain and excessive tearing, in addition to injury to the corneas. Acute exposure to anhydrous ammonia in its liquid form can cause redness, swelling, ulcers on the skin, and frostbite. If it comes in contact with the eyes it can cause pain, redness, swelling of the conjunctiva, damage to the iris and cornea, glaucoma, and cataracts.

While the modern ammonia industry is well used to dealing with ammonia and its attendant hazards, the shipping industry has no experience of ammonia as a fuel. Modern vessels are built based around the use of conventional fuels, with engines and fuel systems in confined spaces on lower decks. The different requirements of ammonia could alter ship layouts or could even lead to complete redesigns. Handling ammonia onboard ships will require a complete new set of skills and safety procedures. There is a need to understand the potential negative impacts on human lives, water and soil in case of leakage or accidents, and how to mitigate these types of risks.

In order to do so, Lloyd's Register Maritime Decarbonisation Hub has been working with the Maersk McKinney Møller Centre for Zero Carbon Shipping (MMMC-ZCS) in a project to develop guidance around the safe use of ammonia as a fuel. Other industry partners involved in the project include MAN Energy Solutions, Mitsubishi Heavy Industries, NYK Line and Total. It aims to develop a mature and detailed

Table 1: **Challenges for alternative marine fuels**

mature and proven | solutions identified | major challenges remain

Energy carrier	Feedstock availability	Fuel production	Fuel storage, logistics, bunkering	Onboard fuel conversion[1]	Onboard safety and fuel management[2]	Regulation[3]
Fossil fuels	mature and proven	mature and proven	mature and proven	mature and proven	mature and proven	mature and proven
e-hydrogen	mature and proven	solutions identified	major challenges remain	major challenges remain	major challenges remain	major challenges remain
Blue hydrogen	mature and proven	mature and proven	major challenges remain	major challenges remain	major challenges remain	major challenges remain
e-ammonia	mature and proven	solutions identified	major challenges remain	major challenges remain	major challenges remain	major challenges remain
Blue ammonia	mature and proven	mature and proven	major challenges remain	major challenges remain	major challenges remain	major challenges remain
e-methanol	solutions identified	solutions identified	mature and proven	mature and proven	solutions identified	solutions identified
Bio-methanol	solutions identified	solutions identified	mature and proven	mature and proven	solutions identified	solutions identified
e-methane	solutions identified	solutions identified	mature and proven	mature and proven	solutions identified	major challenges remain
Bio-methane	solutions identified	mature and proven	mature and proven	mature and proven	solutions identified	major challenges remain
Bio-oils	solutions identified	major challenges remain	mature and proven	solutions identified	mature and proven	solutions identified

Note: Emissions reduction impact from direct electrification of ships and nuclear-powered vessels is not modelled in NavigaTE 1.0
1. Considers onboard fuel supply and storage, fuel conversion and emissions control systems.
2. Considers fuel toxicity, flammability and explosiveness.
3. Includes regulatory framework supporting onboard regulatory aspects, and market mechanisms supporting adoption.

Source: MMM Center for Zero Carbon Shipping understanding of risk and safety concerns, via a Quantitative Risk Assessment methodology in phase one of the project. This will ultimately lead to the development of best practices for safeguards in design and arrangements when using ammonia as a shipping fuel. The project will also determine the risk of fatality from unintended releases of ammonia, as well as determine the risk contribution of key equipment and spaces dedicated to ammonia storage. To illustrate the potential for risk mitigation measures, the project partners will assess alternate vessel designs, optimised to be fuelled by ammonia.

Rules and recommendations for ammonia's use the shipping industry are beginning to be developed however. DNV class rules for ammonia as ship fuel were published in July 2021, including provisions for storing, handling and bunkering ammonia on board, via the use of toxicity zones and venting masts in specific locations. Engines are recommended to be fitted with double wall piping, so that the pipe containing ammonia is surrounded by a ventilated space, making it easy to detect leaks. Additional solutions such as double block and bleed valves ensure that systems can be separated for maintenance.

Land-side bunkering and handling is also a concern. DNV has completed studies on ammonia bunkering operations in the Ports of Amsterdam and Oslo, examining the potential ramifications of a large ammonia leak in ports. It defined external safety zones and risk-reduction measures, looking at the radius which would be affected by an ammonia leak. For the Port of Oslo, it found that in principle using a bunkering vessel with refrigerated ammonia would come with an acceptable risk level, because the residential area in Oslo would not be affected by a leak. But in its report it also admitted that there is still work to be done to ensure safe handling on board.

The Global Centre for Maritime Decarbonisation (GCMD) in Singapore has also recently initiated a study that aims to define a robust set of safety guidelines and operational envelopes for ammonia bunkering trials at two local sites.

Corrosion

Ammonia can also be highly corrosive when dissolved in water to metals such as copper, brass, zinc and various alloys. It is also an alkaline reducing agent and reacts

Wärtsilä's offshore supply ship Viking Lady; in use as an ammonia fuel test bed.

PHOTO: WARTSILA

with acids, halogens and oxidising agents. Materials will need to be carefully selected when ammonia is used on board a vessel. Iron, steel and specific non-ferrous alloys resistant to ammonia will need to be specified for tanks, pipelines and

structural components. Stress corrosion cracking can be induced and proceed rapidly at high temperatures in steel when oxygen levels are more than a few ppm in liquid ammonia.

But these issues with handling ammonia are well known to the chemical industry. There is no need for the shipping industry to reinvent the wheel if it is able to take sufficient steer from the expertise that is already available.

Availability

While the potential demand for ammonia from the shipping industry is great; the International Energy Agency (IEA) has suggested that its use for shipping could reach 130 million t/a tonnes by 2070 – on the same scale as its use for fertilizer; while the American Bureau of Shipping suggests that one third of all shipping fuel consumption could be represented by ammonia by 2050, well over 100 million t/a at current fuel consumption rates. The question is whether sufficient low carbon ammonia can be produced to meet anticipated demand.

At the recent European Mineral Fertilizer Summit, Marina Simonova of IHS Markit (now S&P Global) presented a potential outlook for blue and green ammonia production[6]. She forecast that although only a few percent of ammonia capacity will be carbon free by 2030, by 2045 it is likely to be a majority of capacity, even accounting for a doubling of ammonia production over that period to feed other applications such as use in maritime shipping. Initial investments are likely to focus on hybrid production – green feeds to existing gas based plants – and carbon capture options, but longer term as electrolysis costs come down, green incentives such as carbon pricing proliferate, and increased demand comes from ammonia's use as a marine fuel and even energy carrier (these two uses could account for 200 million t/a of capacity by 2050, she said), will see green ammonia coming to predominate. Meanwhile, consumption of carbon-free ammonia in conventional applications may reach 75 million t/a by 2050.

There are also concerns that there may not be enough shipyard capacity to allow for rapid adoption of alternative fuel technologies. At present around 20% of the global shipping fleet is replaced every five years and vessel lifespans can be around 25 years, limiting the potential uptake of new ships, and there may not be enough shipyard capacity to cover conversions. However, sufficient financial incentive could overcome this.

Cost

One of the major concerns for the industry is the cost of using ammonia. CF Industries puts the cost of producing fully green ammonia at $500/t for a new 20,000 t/a side stream at its Donaldsonville plant. However, while this is more than the average f.o.b. cost of ammonia over the past decade, it is significantly below the current elevated market levels. Likewise, electrolyser costs have already come down tenfold over the past decade, and as renewable power continues to be introduced at scale, so unit costs are likely to come down still further. BP suggests that by 2050, the cost of renewable energy will have fallen by 30-70% compared to its current value – already cheaper than conventional fuels in many markets. Emissions trading schemes which put a price on carbon emissions will also help the transition. MMMCZCS has developed a techno-economic model which it calls NavigaTE which predicts that green ammonia will actually be the cheapest zero carbon fuel option for shipping by 2050.

Even so, there is a whole supply chain which needs to be converted, from production and supply of fuel, through transport, distribution and storage at ports. A worldwide ammonia distribution system is already in place, but fuel needs to be available in the right locations at the right volumes. The existing ammonia transport network connects production and storage locations that serve the industrial market; it does not reach ports in a way that would allow ships to bunker. A 2020 study by University Maritime Advisory Services (UMAS) and the Energy Transitions Commission found that $1.0-1.4 trillion is needed to achieve the IMO's carbon reduction ambition by 2050, with around 87% of the total investment needed in land-based infrastructure and production facilities for low carbon fuels.

Developments

While there are concerns around the use of ammonia as a fuel, work is proceeding at a rapid pace to overcome them, and in the meantime, developments in the industry are continuing. During the Singapore Maritime Week in April 2022, a memorandum of understanding was signed to develop an ammonia bunkering ecosystem at the port of Singapore, the largest bunkering port in the world, with around 110 bunker calls per day, with the goal to commence ammonia bunkering by 2030. In Europe, Yara International has pre-ordered 15 floating bunkering terminals from Azane Fuel Solutions, to allow the delivery of green ammonia fuel to the shipping industry in Scandinavia. Azane Fuel Solutions is a joint venture created last year by technology company ECONNECT Energy and zero-emission ship project specialist Amon Maritime to develop ammonia ship bunkering infrastructure technology, products and services. Yara says it will make green ammonia available as fuel for ships in Scandinavia as soon as 2024. The company plans to supply green ammonia from its Porsgrunn ammonia plant in Norway, and suggested in a recent report[7] that up to 69% of emissions from Norway's domestic shipping fleet could be reduced by 2030.

There is a growing momentum in the shipping industry that is steering it slowly but increasingly inevitable towards the widespread use of ammonia as a low carbon fuel over the next 2-3 decades. The implications for the ammonia industry are profound. ■

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A shock to urea markets

PHOTO: OQ

Loading urea at Omifco's jetty, Oman.

The Russian invasion of Ukraine has presented urea markets with a major shock, but there are signs that this may now be easing.

The global market for urea had been facing overcapacity prior to the run-up in natural gas costs and ammonia prices at the end of 2021, and then the disruption caused by the Russian invasion of Ukraine in February 2022, both of which set prices heading towards record levels. After that shock, prices seem to have peaked and have been falling back substantially, with further falls anticipated. However, the market has been badly shaken up by the dislocations caused by the blockade of Ukrainian ports and the sanctions which prevent dollar payments for Russian goods. Russia represented 23% of ammonia and 14% of urea trade in 2021, two thirds of which had left via the Black Sea. Although Russia had imposed a ban on exports of some fertilizers to protect domestic supplies and the Baltic ports have remained open, the OPZ ammonia pipeline across Ukraine is now closed and Ukraine is unable to export – many of its plants have been attacked and damaged or even overrun; the Severodonetsk complex was at the forefront of recent fighting.

All of this has had the effect of taking significant volumes of urea out of the market. European production has also been affected by high gas prices. Last winter had seen a gas price spike in Europe to record levels, with prices rising 600% across 2021, but the events of February 2022 also delivered geopolitical concerns about a potential shut-off in Russian gas deliveries. Though this has not yet come to pass, Russian gas exports to Europe are down, no doubt to put pressure on western European countries over Ukraine. Russia has insisted that some customers must pay in roubles, and halted supplies to Poland and Bulgaria in April. Europe has also set itself a target of reaching 80% storage levels before next winter, in the expectation of a complete halt to Russian supplies, and this is drawing in LNG supplies, though storage had only reached 55% by the end of June in spite of Germany switching back towards some coal-fired power production. While European gas prices are down from their peak, they are still averaging $35-40/MMBtu, equivalent to a base urea cost of $1,000/t. The result of high gas prices has been idling of ammonia and urea capacity across Europe (as well as AN), drawing in imports and supporting higher prices.

Crop prices

Nitrogen fertilizer prices as high as have been experienced in the first half of this year would normally lead to demand destruction, but high crop prices have helped support high nitrogen prices. Grain exports from Ukraine have been halted in spite of attempts by the United Nations to open an export corridor to get badly needed grain to countries in Africa. Corn, soybean, wheat and cotton prices are expected to remain high in 2022 thanks to strong demand, moderate supplies and weather-related production fears. Nevertheless, nitrogen prices have been so high that affordability is at its lowest level since 2008, and demand is certain to be down over the year unless prices are able to find a lower level.

Longer term factors

It remains unclear how long the disruption caused by the Ukraine conflict is likely to continue, but the prospects of a settlement look remote in the short term, with little appetite for compromise from either side. Longer term, however, the actions of a number of major players will affect the prospects for the urea market. In 2021, China, India, the United States and Brazil between them consumed 55% of the world's urea. China, India and the US are also the three largest producers, with 53% of total production between them in 2021, although outside of those countries, Russia and Ukraine collectively represented another 7% of production and the Middle East another 12% (15% if Egypt is included).

China

China remains the largest producer and consumer of urea in the world. In 2021 it consumed 33% of all of the 150 million tonnes of urea produced globally. The gov-


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ernment had historically tried to ensure self-sufficiency in urea production to make sure that food production targets were reached – important in a country with 20% of the world's population but only 7% of its arable land. However, this has created its own issues in terms of overapplication of fertilizer, degradation of soil and pollution form mainly coal-based urea production. The Chinese government is now taking major steps to tackle environmental issues, which have included much stricter regulation of the fertilizer industry, enforcing the closure of less efficient and more polluting capacity. According to IFA figures, Chinese urea production peaked in 2015 at 71 million t/a, and by 2021 this had fallen to 55 million t/a. New capacity is mainly larger, more efficient plants based on cheaper bituminous coal, replacing older, less efficient capacity.

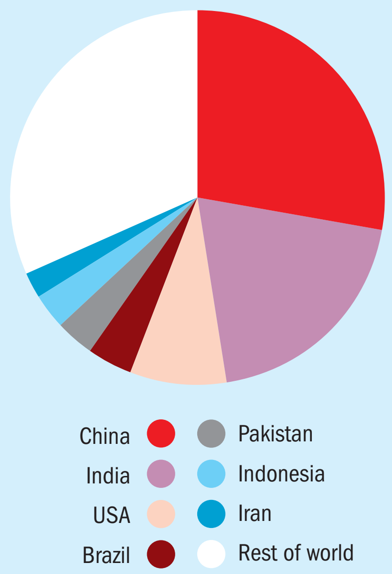
Feedstock pricing and availability is also an issue for Chinese producers. Around 20-25% of Chinese urea capacity uses natural gas as a feedstock, which is virtually unavailable during winter because it is required for power generation. Coal prices have also been rising, eroding margins, and has occasionally not been available at any price. And central targets for Chinese states to reduce CO_2 emissions means that some state governments such as Inner Mongolia and Shanxi are also forcing local urea plants to run at lower rates or not at all.

Consumption likewise peaked in 2013 at 60 million t/a, and by 2021 had fallen to 50 million t/a, as the government tries to encourage farmers to be more sophisticated in their application of fertilizer to balance nutrient requirements and nutrient use efficiency increases. At the same time, industrial consumption of urea for diesel exhaust treatment, urea-formaldehyde and urea-melamine resins, is rising, roughly balancing falling agricultural demand.

China's surplus of urea means that it became the largest exporter in the world, with exports reaching 13.7 million t/a in 2015. However, although consumption has declined, production has declined faster, leading to exports dropping rapidly, to just 2.4 million t/a in 2018, before settling back at around 5 million t/a since then. However, Chinese urea producers have also faced increasing difficulties on export, with additional customs requirements. China also occasionally imposes tariff quotas on exports to try and keep domestic production at home at times of high international prices, when it can be more profitable for Chinese producers to export than serve the domestic market.

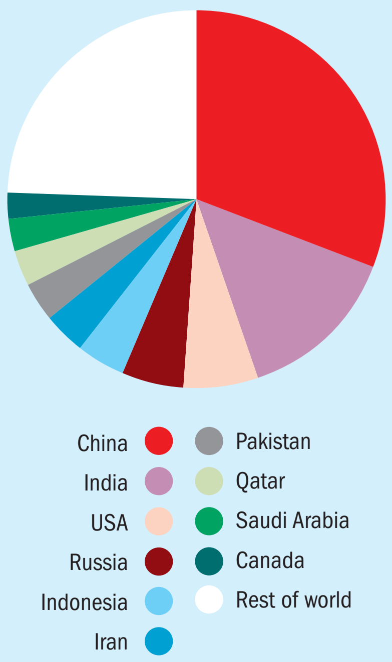
Overall, Chinese urea exports were around 5.3 million tonnes in 2021, but this figure is likely to continue to fall as domestic capacity is throttled back at the same time that consumption remains relatively constant. Urea export restrictions mean that Chinese exports may only reach 3 million t/a this year.

Fig. 1: **Urea consumption by country, 2020**



Source: IFA

Fig. 2: **Urea production by country, 2020**



Source: IFA

India

India is the second largest urea player in the world, with demand totaling 32.0 million t/a in 2021. India, like China, had a policy of self-sufficiency in urea production dating back to the 'Green Revolution' of the 1970s and 80s, but unlike China, this lapsed in the mid-1990s as naphtha and natural gas prices rose and along with them government subsidies. The expense of running plants off naphtha led to almost all of India's urea plants being converted to run off natural gas during the 1990s, but shortages of gas supply, especially at times of high power demand, often meant that plants were unable to run at capacity, and forced a moratorium on new urea plant building. So at the same time that China became the world's largest exporter of urea, India became the largest importer, with imports reaching 11 million t/a in 2020.

Tackling this deficit has been a major policy issue for nationalist prime minister Narendra Modi, who began a programme in 2017 of building new domestic urea capacity based on imported liquefied natural gas (LNG) feedstock. Five new gas-based plants, all of 1.3 million t/a capacity, formed part of the programme, along with a sixth that was to have run on coalbed methane but which was converted to gas after the feedstock earmarked for the plant proved insufficient. Two of these were private projects, the rest under a new state development company called Hindustan Urvarak and Rasayan Ltd (HURL). Four of these plants are now operational, one very recently, with two more nearing completion or commissioning. In addition to these, there is a coal-based urea project at Talcher, construction of which has faced delays over coal allocation and covid-related disruptions. Completion is now planned for next year.

In theory, these seven units should increase Indian urea capacity by 9.1 million t/a from 2019-2023, almost eliminating import requirements. However, things are rarely that simple in India. Domestic urea consumption also continues to increase – mainly because it is the only fertilizer whose price is still completely government controlled, and hence it tends to be cheaper compared to other alternatives. With ammonia prices so high at the moment, India is likely produce and consume less diammonium phosphate this year, as it imports ammonia to do so, and this may leave an additional nitrogen requirement that may be filled by urea. Overall, however, Indian imports are expected to roughly halve from 2020 to 2025 due to increased domestic capacity.

United States

US urea production has almost doubled over the past decade from 6.1 million t/a in 2010 to 11.2 million t/a in 2020. The reason for this has been the exploitation of cheap shale gas, allowing domestic production of ammonia to return, and the construction of new urea and urea ammonium nitrate (UAN) solutions plants at places such as CF Industries' sites at Donaldson, Louisiana and Port Neal, Iowa, as well as Iowa Fertilizers at Wever, and Koch Industries at Enid, Oklahoma. The US remains a net urea importer, to the tune of around 3.7 million t/a in 2020, though this is down from 6.3 million t/a in 2010. However, most of the capacity building programme is now complete, and aside from an incremental expansion at Enid, there is not much extra urea expected in the foreseeable future. Consumption is relatively stable, slightly down from its peak year in 2018.

Brazil

Brazil is the world's second largest importer of urea, and this figure has been growing due to shutdowns of domestic capacity. The country is a major agricultural exporter and one of the world's leading producers of soybeans, corn, cotton and coffee, and fertilizer demand rises year on year. However, its domestic fertilizer industry, never large, has progressively shrunk, in no small part due to the fallout from the Petrobras bribery and corruption scandal. In 2020 the country's nitrogen fertilizer requirement was 5.2 million tonnes N, of which it produced only 4% domestically. The last domestic urea plant, at Araucaria, closed down in January 2020, and an attempted sale to Russia's Acron fell through. As a result imports of urea continue to rise, reaching 7.0 million t/a in 2020. Longer term there are plans to tackle this, but it awaits a restructuring of the domestic gas industry and new bilateral agreements with neighbouring Bolivia and Argentina to supply gas from 2025. This may finally also allow the completion and start-up of the part finished 1.2 million t/a urea plant at Tres Lagoas near the Bolivian border. For the moment, however, Brazil remains one of the importing mainstays of the urea industry, with imports expected to continue to increase. As new Indian domestic capacity starts to make itself felt, Brazil may well move into the position of the world's largest urea importer.

Middle East

The Middle East remains the largest exporting region for urea. However, much of this capacity was built in the 1980s and 90s when gas was plentiful and often 'stranded' with no alternative uses. Since the development of the global LNG industry and the rapid expansion of cities in the region and hence requirements for electrical power, natural gas is often in shorter supply and more expensive. New plant construction in the region is mainly in Iran, although development of Iran's huge gas reserves has been complicated by the international sanctions regime over its nuclear programme. The other major capacity builder has been Egypt, which has also sought to monetise abundant natural gas reserves. Egypt has now risen to become the world's sixth largest producer of urea, with nine plants producing a total of 6.7 million t/a in 2021.

Elsewhere

There has been new capacity constructed in Nigeria and Brunei, but one of the largest sites for new urea capacity planned over the next few years was to be Russia, with Metafrax building a new 570,000 t/a urea plant at the company' Gubakha site, TogliattiAzot a third, new 726,000 t/a urea plant at Perm, and KuibyshevAzot a new 540,000 t/a urea plant at Togliatti. EuroChem has announced plans for a 1.32 million t/a urea plant at Kingisepp near St Petersburg, and Shchekinoazot is building a new 660,000 t/a plant in the Tula region. All of this combined could have added an additional 3.8 million t/a of urea capacity, but with engineering and licensing companies pulling out of Russia, and payment on contracts becoming difficult or impossible, how many of these plants will be compelted in the medium term remains very hard to gauge.

Over the next few years, new capacity had been expected to roughly balance or slightly exceed additional demand, especially in India and China, but it is beginning to look as though the market may be short for several years to come, boosting international prices. ■

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New value chains for sustainable chemistry

At the Clariant Catalysts Media Event 2022 held in London on June 1, 2022, Clariant informed Nitrogen+Syngas magazine about some of the actions Clariant Catalysts is taking and focussing on in research and development to enable its customers to reach their sustainability targets.

Clariant Catalysts – a leading and innovative player in core businesses including petrochemicals, syngas and speciality chemicals – is focussed on creating sustainable value for its customers and partners. The chemical industry is currently in a transition phase, incremental improvements are being made to existing processes to reduce their carbon footprint and GHG emissions. Small improvements in catalyst performance can have a large impact and drop-in solutions that do not require further investment are already making a difference.

Reducing GHG emissions today

Over 60 million tonnes of nitric acid are produced annually around the world, mainly for the manufacture of fertilizers. Despite its importance for our food chain, the chemical has a major drawback: its production emits the greenhouse gas (GHG) nitrous oxide (N_2O), which is extremely harmful to the climate, remaining for approximately 114 years in the atmosphere and thus impacting global warming around 300 times more than CO_2. Annually, N_2O emissions from the production of nitric acid and its derivative adipic acid are equivalent to about 100 million t of CO_2.

Of the approximately 500 nitric acid plants operating globally, more than half run without N_2O abatement, mostly in regions without applicable emission control regulations.

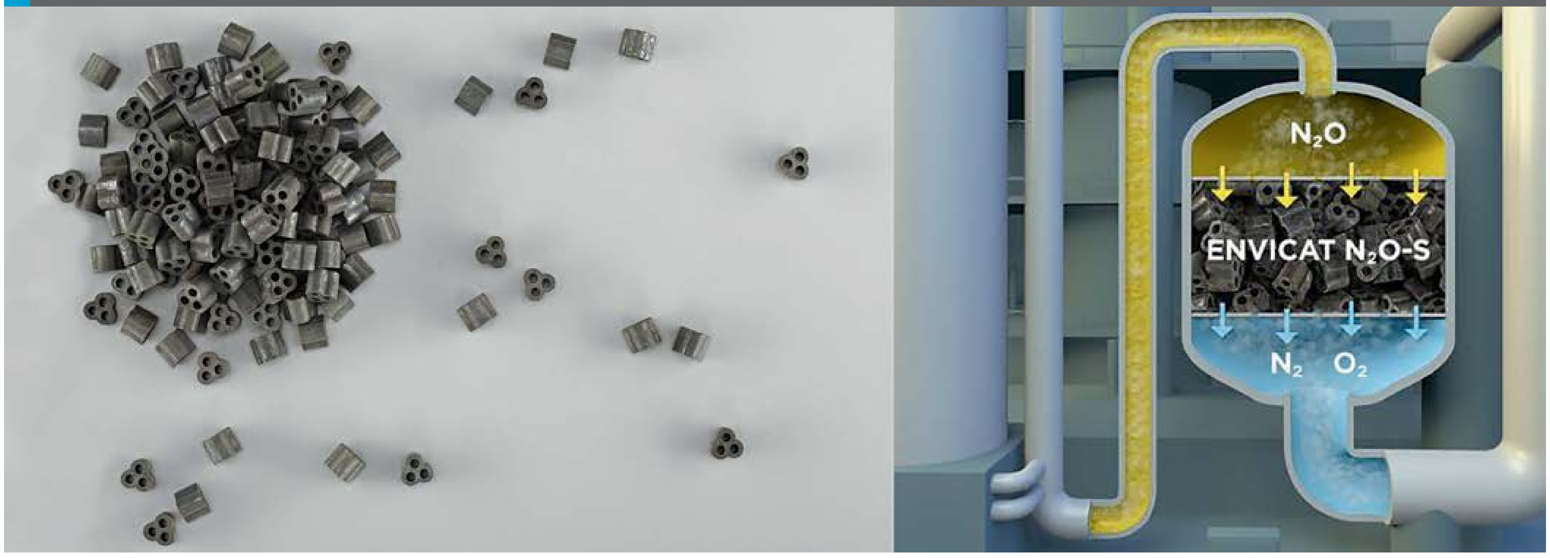
To tip the balance towards more sustainable production processes, in November 2021, Clariant launched a major climate campaign, offering a free first load of its highly effective nitrous oxide abatement catalyst, EnviCat N_2O-S, to ten nitric acid producers that do not already have N_2O off-gas treatment in place.

Clariant's EnviCat N_2O-S catalyst converts up to 95% of the N_2O formed during nitric acid production into harmless oxygen and nitrogen. Besides climate benefits, the catalyst can also slightly increase nitric acid yield by improving the efficiency of the ammonia oxidation process. Designed as a convenient "drop-in" solution, the catalyst is easy to install with almost no engineering modifications (Fig. 1). The catalyst has an average lifetime of three to four years.

The application period to receive the free fill of catalyst, without obligations, ended in March 2022. Applications were received from 19 nitric acid producers from ten countries. Of these, ten nitric acid producers have been selected from the Caribbean, China, Egypt, India, Turkey and the USA, representing more than 2 million t/a nitric acid production. Based on the N_2O global warming potential of 265, once N_2O abatement has been installed, the estimated annual CO_2 equivalent savings from these plants will be more than 4 million t CO_{2e} adding to the > 20 million t/a CO_{2e} already being saved by EnviCat N_2O-S catalyst installed in more than 45 nitric acid plants globally.

In recognition of this global climate initiative, Clariant has been awarded the American Chemistry Council's Sustainability Leadership Award 2022 in the category Environmental Protection.

Fig. 1: **EnviCat N_2O-S catalyst removes N_2O from nitric acid plant tail gas and converts it into harmless nitrogen and oxygen**



PICTURES: CLARIANT

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Future energy transition

Clariant's broad catalyst portfolio and partnerships enable new value chains for sustainable chemistry driving the energy transition.

Supporting the scale-up of SAF

Aviation currently accounts for approximately 3% of global GHG emissions which cannot be abated by electromobility.

In Europe, the ReFuelEU Aviation Proposal establishes SAF blend mandates: 5% by 2030, 20% by 2035 and 53% by 2050, with penalties for failure to meet blending mandates.

In the US, legislation is under discussion to establish a low carbon fuel standard for aviation fuels, with tax credits to substitute higher costs.

The airline industry is also driving towards net-zero emissions:

- United committed to reduce GHG emissions 100% by 2050 and to purchase over 7 million t of SAF;
- Delta Airlines and British Airways committed to carbon neutrality and to replace 10% of jet fuel by SAF by 2030;
- Lufthansa committed to spend $250 million on SAF through 2024 and to achieve 50% CO_2 emission reduction by 2030.

With its broad catalyst portfolio Clariant is well positioned to pave the way for all future sustainable aviation fuel (SAF) production routes (see Fig. 2).

Since 2017, Clariant's tailor-made catalysts have supported tech startup Ineratec with its power-to-liquid technology for producing sustainable fuels from lab-scale to industrial pilot-scale. The collaboration focuses on the first reaction step within the power-to-liquid process, the reverse water-gas shift (RWGS) reaction to produce syngas from CO_2 and renewable hydrogen. Due to the cutting-edge reactor technology Ineratec has developed for this step, the catalyst must provide specific characteristics to be applicable within the microstructured system. The tailored catalyst from Clariant allows the optimal desired syngas composition to be reached for the subsequent synthesis reactions.

The next stage is a larger globally pioneering pilot plant in Frankfurt Höchst, Germany. Due to start up in 2023, the new plant will have up to ten times higher production capacity, making it Ineratec's largest power-to-liquids plant, producing 3,500 t/a of e-fuels, and temporarily capturing 10,000 t/a of CO_2 per year.

The new plant will use Clariant's ShiftMax® 100 RE to produce renewable syngas via the reverse water-gas shift reaction – an essential step in the conversion of CO_2. The promoted nickel catalyst shows an unprecedented high resistance against coking and low methane by-product formation. Other key features of the catalyst include high CO_2 conversion over a long lifetime, high poison resistance, and superior strength.

Clariant's ShiftMax 100 RE reverse water-gas shift catalysts have already been used and proven to meet the expected syngas yield and composition in two industrial pilot plants, located in Germany.

Marvin Estenfelder, Head of R&D at Clariant Catalysts, commented, "The successful scale-up is a major step towards accelerating pioneering work in sustainable fuel production to gradually drive the decarbonisation of the transport sector."

Low-carbon hydrogen

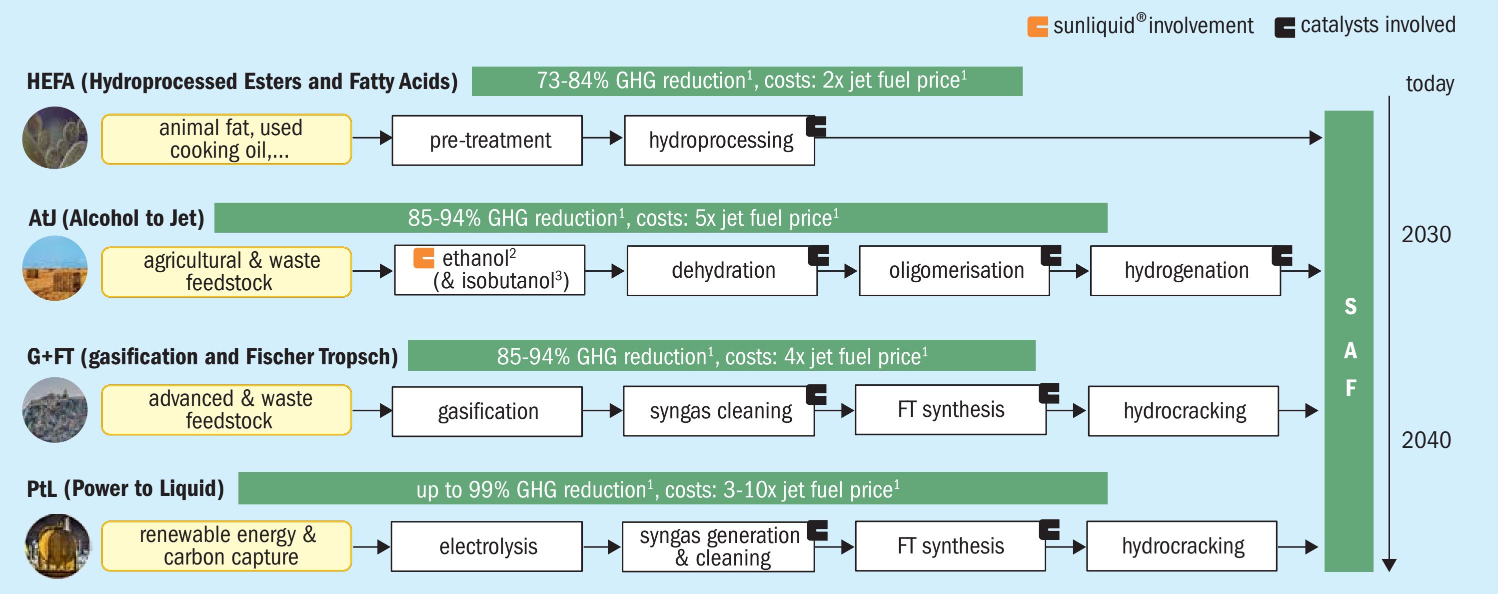
The transition towards sustainable energy will drastically increase the demand for low-carbon hydrogen due to its high versatility and driven by stricter policies and country regulations. Low-carbon hydrogen is becoming more competitive and in future it will be used as an energy carrier (e.g., for mobility, power generation, building, and industry heat) and as a platform chemical to produce chemicals from CO_2.

Low-carbon Hydrogen will be produced in favourable locations and will need to be transported to end-users. Current methods for transporting hydrogen include compression for shorter distances (<4,000 km) and liquefaction followed by regasification for longer distances. Emerging technologies for long distance hydrogen transportation via chemical conversion are also being developed.

Clariant offers two catalytic solutions for efficient long-distance hydrogen transport via chemical conversion (Fig. 3):

- conversion to ammonia for transportation followed by ammonia cracking at the destination;

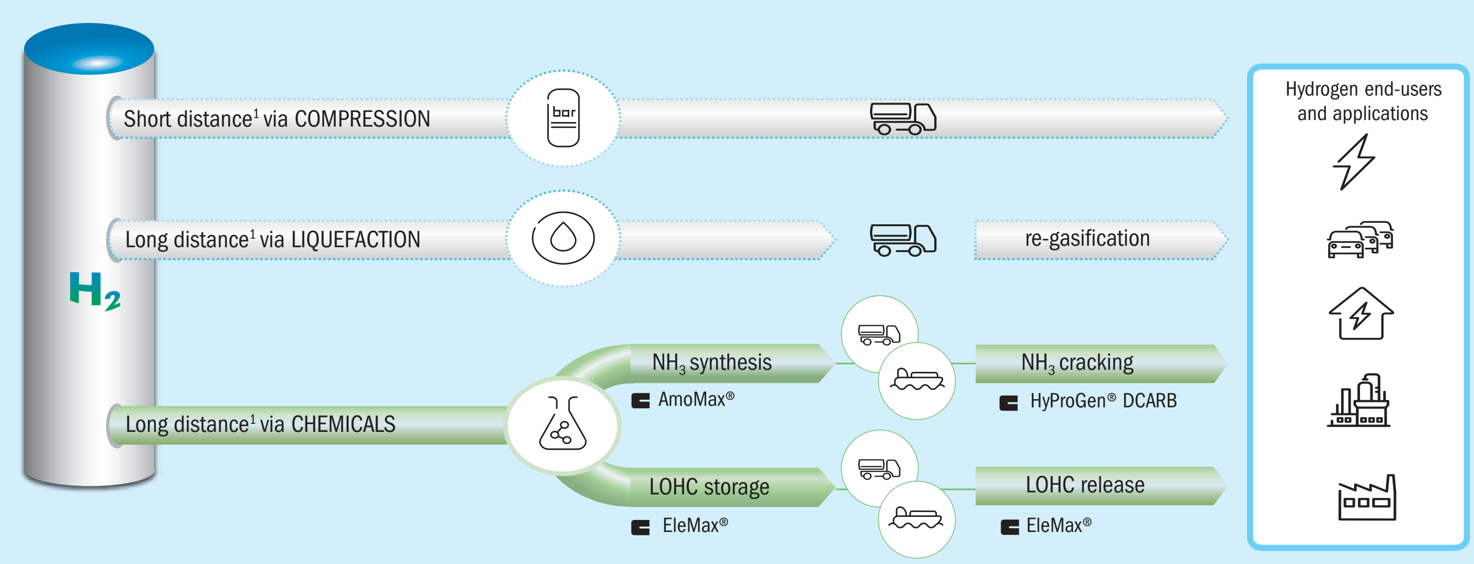
Fig. 2: **Clariant is well positioned to pave the way for all future SAF production routes**



[1]vs. fossil jets – McKinsey Clean Skies of Tomorrow, 2020, costs in 2020 [2]in US: 1st & 2nd gen EtOH and isobutanol; in Europe only 2nd gen EtOH and isobutanol eligible [3]production route dependent on Gevo technology

Source: Clariant

Fig. 3: **Clariant offers two catalytic solutions for efficient long-distance hydrogen transport via chemical conversion**



Source: Clariant

¹short distance < 4000km < long distance / NH_3: ammonia, LOHC: liquid organic hydrogen carrier.

- storage of hydrogen in a liquid organic hydrogen carrier (LOHC) followed by release at the destination.

For long-distance hydrogen transportation the most cost-competitive solution is to convert hydrogen to ammonia for storage and transportation, followed by ammonia cracking at the point of use to convert the ammonia back to hydrogen.

An alternative solution is to use Hydrogenious' LOHC plant systems, a highly promising and viable hydrogen storage and transport technology with references in Europe and the US. Clariant provides its EleMax® H and D catalysts to technology partner Hydrogenious for LOHC storage and/or release plants. A new 1,800 t/a LOHC storage system will be commissioned at Chempark Dormagen, Germany, in 2024. Several other advanced projects are in the pipeline.

Low carbon ammonia

Low-carbon ammonia will play a crucial role in the future hydrogen economy. Green ammonia as a hydrogen carrier can facilitate future transport for supplying hydrogen to high-energy demand regions with limited renewable energy sources. It has a higher energy density compared to liquid hydrogen, LOHC and methanol and infrastructure for the transportation of ammonia already exists.

The main challenges for green ammonia producers are:

- process and catalyst reliability, especially at fluctuating feed conditions due to changing availability of renewable energy;
- reduction of energy consumption to minimise costs for decarbonised ammonia;
- lowest capex for new plants;
- cost efficient purification of green H_2 from electrolysis or bio route.

Clariant's benchmark AmoMax series ammonia synthesis catalysts are perfectly suited for green ammonia production. They offer:

- lower operating pressure (down to 90 bar) and/or recycle ratio;
- lower energy consumption (up to 0.2 GJ/t NH_3) due to higher catalyst activity;
- improved water and oxygen resistance robust in dynamic conditions.

Many new low-carbon ammonia projects have been announced including the two prestigious green ammonia projects highlighted below.

Green ammonia project in Australia

Clariant's innovative ammonia synthesis catalyst "AmoMax-Casale" was selected for a major, groundbreaking green ammonia project, being jointly developed by The Hydrogen Utility (H2U), a leading Australian developer of green hydrogen infrastructure, and Casale. AmoMax-Casale is tailor-made and thus an optimal choice for green ammonia synthesis based on the Casale ammonia synthesis loop technology. The catalyst offers outstanding activity, stability, and energy efficiency.

The project will commence with two pilot plants at H2U's Eyre Peninsula Gateway™ in South Australia, with the aim of expanding the technology to various plants, industry sectors, and regions. In the first phase of the project, 44,000 t/a of green ammonia will be produced. The plant will avoid up to 100,000 t CO_2 per year in comparison to standard ammonia production*. In phase 2 of the project green ammonia production will be increased to 0.8 million t/a.

Stefan Heuser, Senior Vice President and General Manager of Clariant Catalysts, commented, "Clean energy is the only way in the future, and Clariant is fully committed to decarbonising the chemical industry through sustainable innovations like AmoMax-Casale. Our award-winning catalyst is one of the most important breakthroughs in the ammonia industry and one that we believe will pave the way for further green ammonia projects that contribute to solving the future energy challenge. We are excited to participate in the highly ambitious H2U project with our technology partner Casale and look forward to driving change together."

Green ammonia project in Oman

ACME Group selected KBR to provide ammonia synthesis technology for its new green hydrogen and ammonia production facility to be built in Duqm, Oman. KBR will provide technology license, engineering, proprietary equipment, catalyst (Clariant's AmoMax 10 Plus), and commissioning services for a plant to produce 300 t/d of ammonia. The plant will be an integrated facility using solar and wind energy to produce green ammonia. The plant is due to start up in 2023 and will avoid up to 270,000 t CO_2 per year in comparison to standard ammonia production*.

* based on CO_2 footprint of 2.5 t of CO_2 per t of NH_3

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New technologies for nitrogen fertilizer production

Casale, thyssenkrupp Industrial Solutions, Toyo Engineering Corporation and Stamicarbon report on some of their latest technology developments.

CASALE

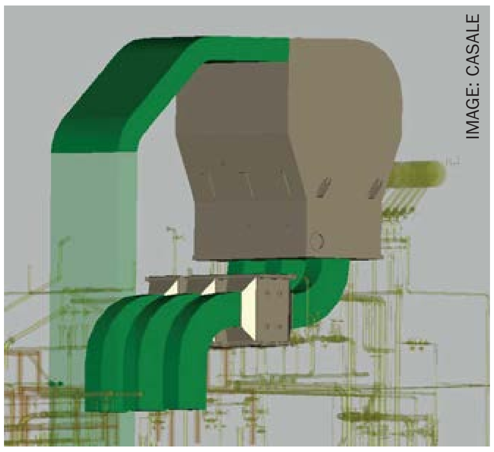
New technology for solid fertilizers

K. Monstrey and M. Fumagalli

Casale offers technologies for the entire chain of nitrogen-based fertilizers from syngas production to NPK including ammonia, urea, nitric acid and ammonium nitrate. The range of services covers the revamping business as well as the design and construction of greenfield fertilizer complexes. To complete its portfolio of technologies and strengthen its position in the market of technologies for nitrogen fertilizers, Casale recently acquired Green Granulation Ltd. Traditionally more active in the Chinese market, Green Granulation is a licensor of plants and technologies for the production of granules of urea and ammonium nitrate (AN). With Green Granulation technology (GGT) being part of the group, Casale is the only licensor able to provide an entire nitrogen-based fertilizer complex from gas treatment to solid finishing. The recent award of a contract for the front-end engineering of a new 1,800 t/d granulated urea complex in Yangiyer, Uzbekistan, provides the first opportunity to combine the technologies of both Casale and Green Granulation.

Green Granulation technology

Since its establishment, Green Granulation has developed revolutionary new elements to the fluidised bed granulation technology used to produce urea fertilizer granules, resulting in a technological edge over its competitors.



Casale GGT granulator.

Developments such as the Optimised Fluid Bed Dynamics and Double Temperature Scrubbing are embedded in the Cold Recycle Urea Granulation (CRG) technology.

The Green Granulation fluid bed urea granulation plant receives concentrated solution from the evaporation section of the upstream synthesis plant. This solution is sprayed in the granulator where it is transformed from liquid into solid granules of the desired size and quality. After cooling, the end product is sent to a bulk storage and/or bagging section.

The Green Granulation fluid bed granulation process is characterised by producing granules by spraying the provided solution onto seed particles, which are kept in a fluidised state. The seeds grow by continuous evaporation, crystallisation and solidification. The spraying system produces a large number of very fine droplets, which guarantees a highly homogeneous granule structure.

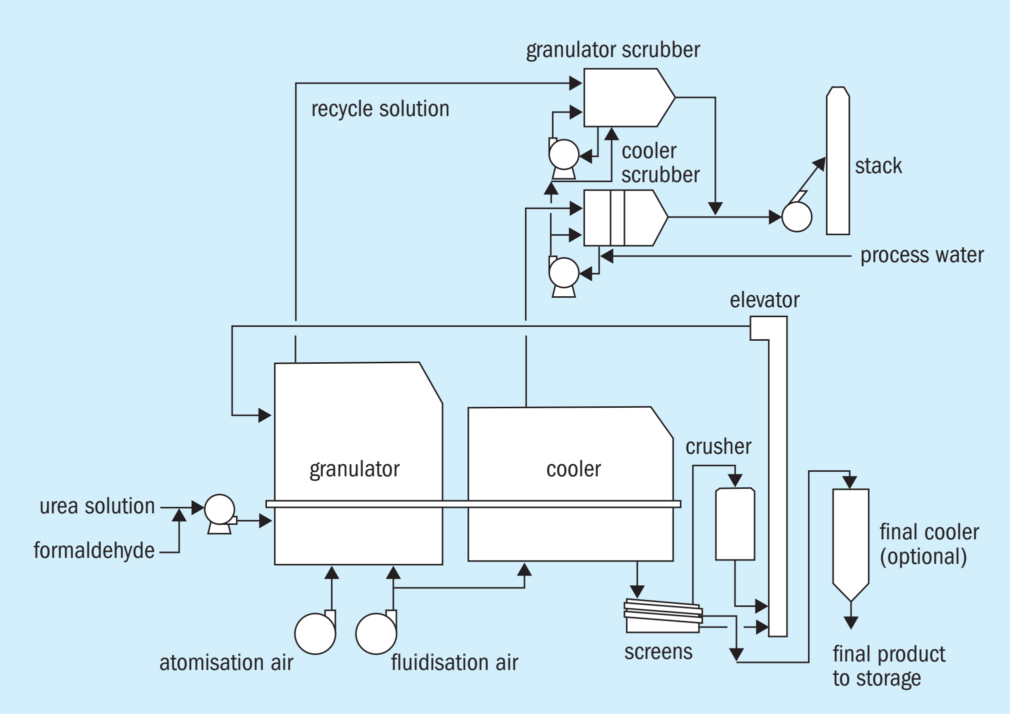
The urea process uses a feed of melt urea solution with a concentration of 96-97% (urea + biuret). The AN process introduces the AN melt to the granulation section at a concentration of 97.5-98%.

Optimised Fluid Bed Dynamics

Crucial in producing a superior quality granule, whether it is urea, urea +, ammonium nitrate, CAN or any other fertilizer or non-fertilizer grade granule, is realising proper movement inside the fluidised bed layer in order to create a continuous stream of fresh particles towards the different spray zones to obtain a homogenous build-up and proper evaporation of the remaining water from the melt feed.

The big technical advantage from the featured Optimised Fluid Bed Dynamics (OFBD) technology is the combination of a low operating fluidised bed level and a rolling movement inside the bed ensuring a constant and predictable feed of seed particles to the different spray zones. The low bed level allows fluidised bed operation with low pressure drop over the system, which leads to lower power consumption. The rolling movement in between the consecutive sprayer banks ensures a more predictable

Fig. 1: **Casale Green Granulation Process**

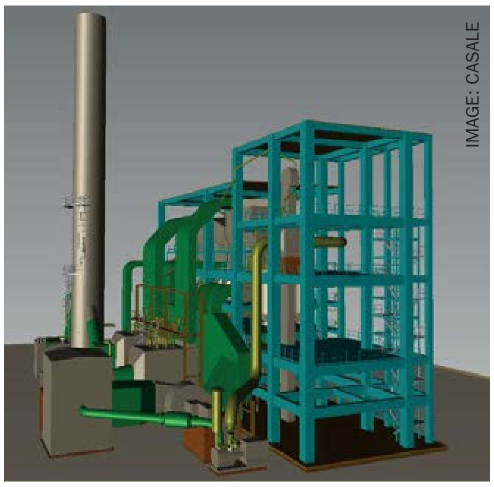


Source: Casale

movement than a traditional bubbling bed. Such a traditional fluidised bed, which is referred to as a bubbling bed, requires a high bed level and by consequence a high pressure drop over the system, resulting in high power consumption. The Green Granulation process has the advantage of Optimised Fluid Bed Dynamics to ensure the movement in the bed and does not need a high level, high pressure drop bubbling bed.

A crucial aspect of the OFBD technology is the in-house developed liquid sprayers that produce a homogenous spray of fine, uniform droplets in the spray zones. These hydraulic sprayers are assisted by a stream of atomisation air that ensures deep penetration into the fluidised bed layer without producing too much dust inside the spray zones.

In any fluidised bed production process, for every granule that leaves the system, a seed was needed to start the build-up. Traditionally, these seeds are provided by crushing over-size or even on-size product and feeding it to the granulator. This feeding of seeds needs to be constant in order to have a reliable process and stable size distribution. The hydraulic sprayers in the Green Granulation spray system can be set to generate seeds, which, in turn, makes the OFBD process much more stable and less dependent on the feed from the crusher(s). The recycle ratio can be kept very low thanks to the proper build-up, while still providing a very stable production process without size distribution fluctuations.



Casale GGT plant.

Cold Recycle Granulation process

Thanks to the low temperature of the solid recycle in the Cold Recycle Granulation process, the crushers and vibrating screens are kept clean and in optimum condition to guarantee a stable process. Warm granules are softer than cooled granules, which leads to fouling of the screen decks and roll crusher. Screen decks that are plugged will have a huge influence on the size distribution of the end product. Fouled crusher rolls will create an overload of dust and will upset the build-up inside the granulator. Therefore, the Green Granulation process is designed to handle the solid recycle at the lowest temperature that is still economically justifiable. The deep cooling action also contributes to the intense polishing of the granular product.

The overall reliability of the production process is ensured by optimising the airflow through the system. This airflow creates movement, evacuates heat from the fluidised bed layer, removes dust particles from the spray zones and ensures clean walls and roof sides inside the granulator and cooler(s) to maximise the interval between wash stops.

Double Temperature Scrubbing

The tail gases from the Green Granulation unit are treated in the Double Temperature Scrubbing system. Depending on the requirements and on the composition of the end product, the system is composed of two, three or four consecutive wet scrubbing stages that can meet the strictest emission restrictions. The horizontal wet scrubbers with vertically installed, irrigated demister stages feature highly efficient scrubbing action at very low pressure drop. The mist formed in the double temperature stage(s) of the granulator scrubber makes it possible to even catch sub-micron dust particles. The recovered solution can be recycled to the synthesis unit of the plant at high concentration (50-55 wt-%) so that the steam consumption in the evaporation section can be kept low.

Fields of application

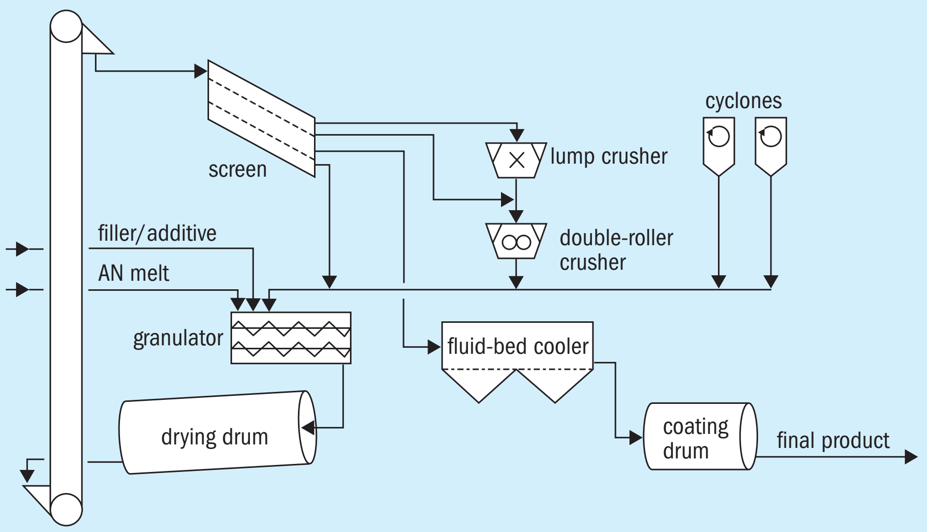
The Green Granulation technology can be applied for the production of granular urea, urea+ (such as U+AS, U+(E)S, U+micronutrients, etc.), ammonium nitrate, calcium ammonium nitrate or compound fertilizers, but also for the production of urea for DEF applications, for cattle feed applications and technical grade urea. Since the nitrogen-based fertilizer market is continuously looking for enhanced fertilizers, higher nitrogen efficiency and more effective fertilizers or tailor-made products for specific crops, making requirements from fertilizer producers ever more challenging. Casale is positioned to offer the technological solutions that meet the market demands of today and tomorrow. The state-of-the art finishing technologies in the Green Granulation portfolio open up opportunities in various application fields to offer front-to-end solutions and complete key-turn projects as well as revamping outdated units to meet the current standards or future challenges.

THYSSENKRUPP & NITROGÉNMŰVEK

Real-time product quality prediction of solid fertilizers

Dr K. D. Rodermund, Dr J. Franz, and S. Brasseler (tk Uhde), Dr G. Sieber and Dr S. Wei (thyssenkrupp Transrapid), and Z. Mürkli and J. Szilágyi (Nitrogénművek)

Fig. 1: **The uhde® AN/CAN granulation process**



Source: tkIS

The production of solid nitrate fertilizers such as calcium ammonium nitrate (CAN) and ammonium nitrate (AN) with uniform product quality is a complex task. The last step in nitrate fertilizer production, granulation (Fig. 1), with its large recycle loop is a particularly complicated system, depending on multiple variables with a high degree of variance. The following parameters all influence product quality:

- nitrogen content;
- moisture content of the product;
- particle size distribution;
- grain hardness;
- coating quality;
- friability;
- caking tendency of the product.

The product quality of nitrate fertilizers depends on a wide range of process and feedstock parameters including but not limited to the following:

- chemical composition and particle size distribution of the filler;
- climatic conditions;
- concentration, temperature and pH value of the AN melt;
- recycle rate of different solid fractions;
- temperature, humidity and amount of air to the dryer;
- the type and amount of additives;
- the frequency of revolutions adjusted for the granulation and drying drum.

This non-exhaustive list illustrates the complexity of quality control in solid fertilizer plants. The challenge is increased by the fact that there is always a time delay between cause and effect, as the intermediate streams are run in a recycle loop and the residence time in this loop is quite high. The lack of reliable online measurement methods for main product quality parameters, e.g., composition, granulometry and moisture content, also causes a time delay, as laboratory analyses have to be performed for accurate measurements. During the time taken to carry out the laboratory analyses, from sampling until knowledge of the results, production continues and off-spec product may have already accumulated by the time the operators are notified of deviations in product quality.

Furthermore, continuous monitoring of product quality is not possible if product quality is only determined by laboratory analysis, which represents product quality at a specific time.

The interdependencies between the process parameters measured by the DCS and the resulting product quality are also highly complex. Even with experienced personnel off-spec product cannot be fully eliminated, thus reducing the profit of the fertilizer producer. Additionally, off-spec product potentially harms good batches of product depending on storage procedures in place. Therefore, identifying off-spec production as early as possible and taking corrective countermeasures is beneficial for production.

Besides the operational challenges, the need for laboratory measurements requires resources for sampling and analysis by skilled personnel and therefore incurs operational expenses.

Machine learning as a solution

To solve these challenges, thyssenkrupp Industrial Solutions – Business Unit Uhde (tk Uhde) has developed a method for quality prediction based on state-of-the-art machine learning algorithms and successfully implemented it together with Nitrogénművek Zrt (NZRT) in a tk Uhde pugmill granulation plant.

Combining its domain expertise in combination with a machine learning approach, tk Uhde has developed a soft sensor based on artificial intelligence (AI). The soft sensor is able to calculate product quality from DCS data in real time and to maximise the yield of high-quality product from CAN/AN-production plants.

Neural network models were trained with historical data in order to predict quality parameters of the solid nitrate fertilizer.

After initial training, the model was rolled out and now predicts almost instantaneously the quality parameters based on live process data coming from the DCS. Comparisons with laboratory test results show the high accuracy of the model. The offered insights regarding the expected product quality enable the operator to take measures to avoid off-spec material immediately without the delay of laboratory tests and thus maximising the yield of the production facilities. This approach can be adapted to other solid fertilizer productions and other processes with complicated interdependencies between product quality and process parameters.

Additional features like forward predictions or quality calculations in the start-up

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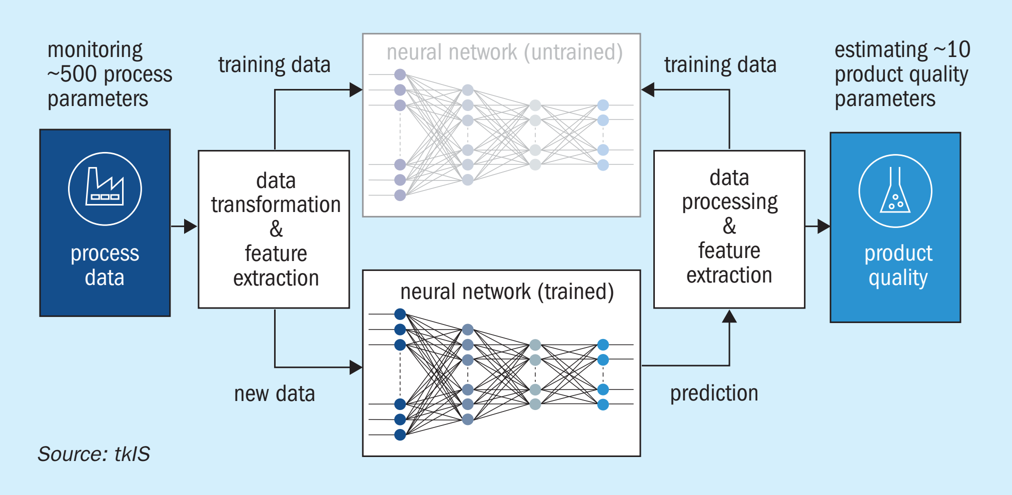
Fig. 2: **AI model for quality prediction[1]**



Source: tkIS

phase are currently under development. The ability to look ahead will help to minimise the inherent time delay between cause and effect of the recycle loop. In addition, it will allow timely countermeasures to be initiated to avoid off-spec production. The start-up phase is one of the most challenging periods of production and the precise knowledge of acceptable product quality is therefore of high value to the plant operator.

AI model

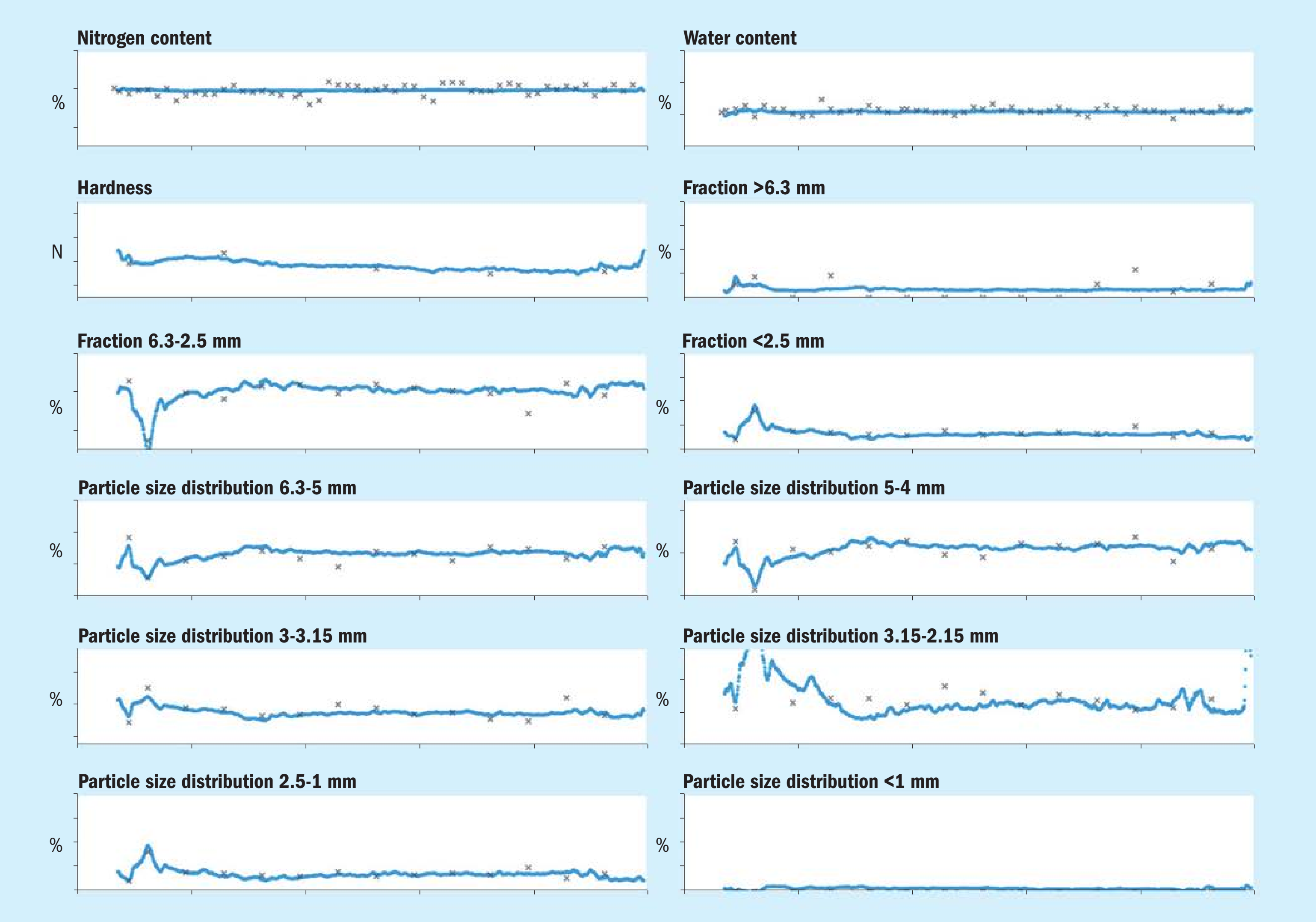
The complex relationship between process parameters and the resulting product quality in solid fertilizer production make this process particularly suitable for AI-based approaches.

As shown in Fig. 2, an artificial neural network (ANN) is a collection of connected computational units (i.e. nodes) ordered in layers, which receive input signals from nodes in front of them. The signals are processed and passed to the nodes behind them. The output of each node is the value of a non-linear function of the sum of its inputs. Each node has a weight attached which is adapted during the training procedure.

All ANN have an input and an output layer and possibly multiple hidden layers in-between. More sophisticated network architectures like recurrent neural networks (RNN) allow connections of nodes to previous layers or themselves. Such network architectures are well suited to learn contextual behaviour or temporal sequences.

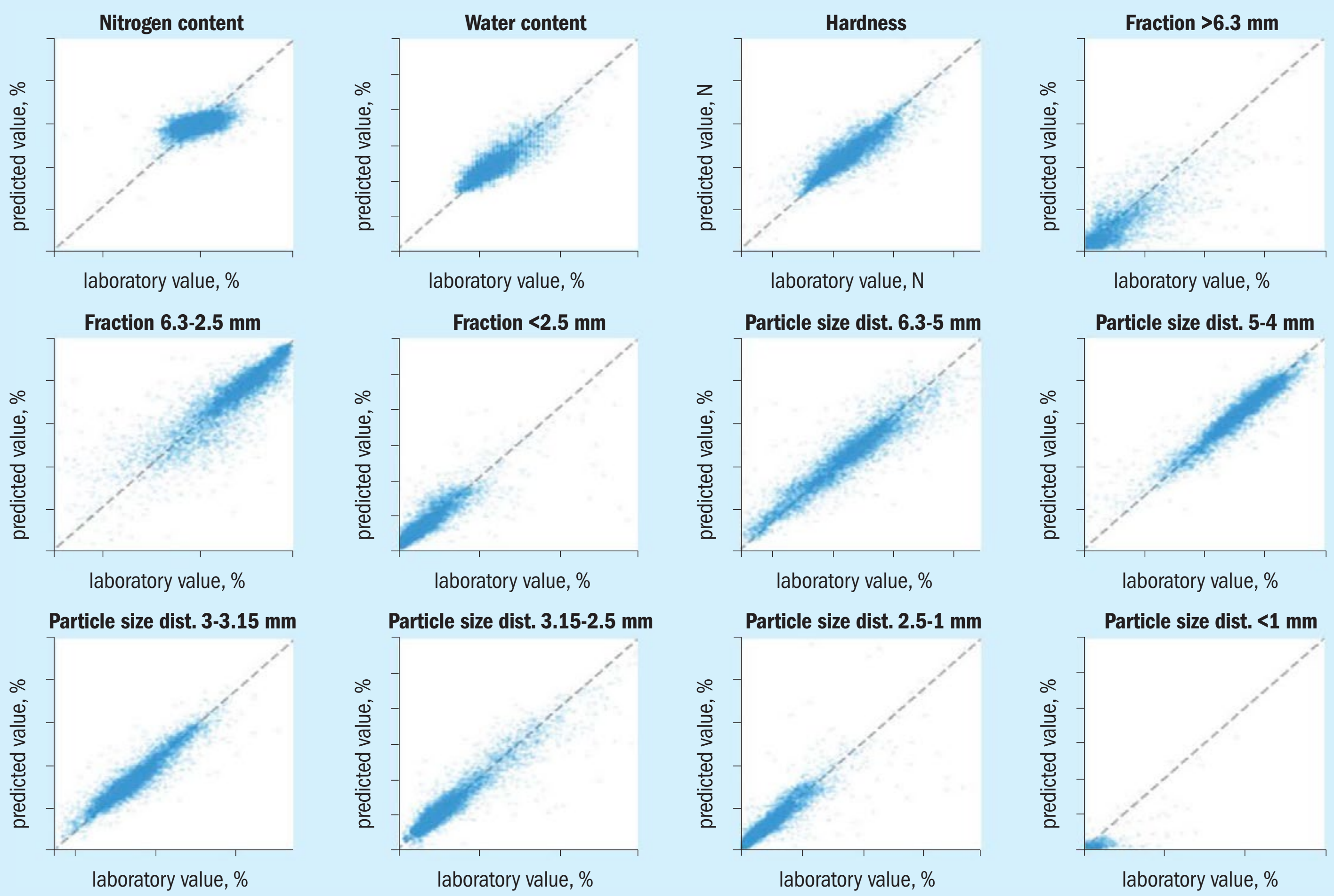
In the present study, a model based on recurrent neural networks has been developed, which links the measured process data from the last 45 minutes to the

Fig. 3: **Comparison of soft sensor data and laboratory results**



Source: tkIS

Fig. 4: **Prediction accuracy of the AI-based soft sensor**



Source: tkIS

currently expected product quality. The model takes approximately 500 process parameters as input and outputs a prediction about approximately 10 product quality parameters. The predicted parameters are the nitrogen content, product humidity, particle size distributions and hardness of the granules.

Over a period of four years, an extensive dataset was collected which consists of data of almost 1,600 process parameters and their related product quality measurements. In order to reduce the model complexity, the initial number of input process parameters could be reduced to 500 by carefully analysing and excluding parameters which are not correlated to the product quality or did not show any impact on the model performance.

The model is trained with the objective to optimally predict the product quality. The weights of the nodes in the RNN are iteratively adjusted in the training process to yield a prediction which deviates minimally from the measured product quality in the historical dataset.

In the reference project historical data was used of the installed sensors, actuators and the laboratory data of the product to set up and train a neural network. The trained neural network gives in-situ feedback to the operator about the expected quality of the product (e.g. hardness, nitrogen content, humidity, particle size distribution) and thereby eliminates or at least minimises the time delay between cause (i.e. production process) and effect (i.e. resulting product quality).

Soft sensor and dashboards

The outcome of the procedure described above is a trained model which is applied to make predictions from live process data during plant operation. In the present application, the model is installed on premises at the plant site. It queries the live process data from the plant and continuously makes predictions on resulting product quality.

The trained neural network is continuously fed with live input data of the plant and predicts the expected quality figures without delay. If the plant data change, the neural network automatically provides an updated estimation of the product quality. While the measurements from the laboratory analyses are only available at distinct points in time and with an additional delay after sample collection, the AI model delivers its predictions continuously at any point in time and with almost no time delay. Thus, the operator knows without a delay that the expected quality deviates from the desired ranges and can act in accordance with the suggestions of the model. Thereby, the amount of off-spec product will be reduced, and the yield of high-quality product will be maximised.

In addition, the AI-based soft sensor offers the unique advantage of being adaptive: As operating conditions of the plant change over time, the model will continuously learn from new data and thus can automatically adapt to any future conditions.

All results as well as the underlying process are visualised in web dashboards, which are fully customisable and can be adapted to customer needs. Furthermore, they allow process data to be queried and analysed and provide predictions at any point of time.

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1 47 2 48 3 49 4 50 5 51 6 52 7 53 8 54 9 55 10 56 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

Table 1: **Relative prediction accuracy of main product quality parameters**

Parameter	Relative prediction accuracy, %
Nitrogen content	99.7
Water content	92.8
Hardness	96.6

Source: tkIS

Fig. 3 shows product quality over a time range of five days in NZRT's pugmill granulation plant designed by tk Uhde. The grey markers indicate the measured results of the laboratory analysis at the timestamps of sample collection. The multitude of blue points show the continuous predictions of the AI-based model.

As can be seen in Fig. 3, the general trend of the product quality parameters is well described by the model. To further discuss the accuracy of the results of the implemented soft sensor in NZRT's pugmill granulation plant, the predicted values are plotted versus the laboratory values in Fig. 4. In the ideal scenario without any measurement uncertainties and at perfect prediction precision, all values would reside exactly on the diagonal line. Measurement uncertainties as well as model prediction errors cause a deviation from the diagonal. As shown, most parameters, especially main product quality parameter like nitrogen content, humidity, hardness, and product particle size fraction, can be predicted very well. Currently, only oversize and fines fraction show slightly larger deviations.

As shown in Table 1 the AI-based soft sensor reaches an accuracy of 92% to more than 99% for the main product quality parameters as the relative prediction uncertainty ranges between 0.3 and 7.2%.

The soft sensor does not control any actuators or set any process parameters. It is essentially a tool which is reading data and estimating the product quality, i.e. an assistance system for the operator.

The operator always stays in full control of the process. Further soft sensor functions like forecasting in continuous operation or quality prediction during start-ups as well as extended dashboard functions are still under development.

Digital services offered by tk Uhde

For tk Uhde, digitalisation is a promising tool that can bring specific benefits to customers:

- extended plant uptime;
- increased production;
- enhanced efficiency;
- better maintenance planning;
- improved safety.

Any digital solution proposed by tk Uhde will optimise the plant in its lifecycle and increases the profit. Depending on the type of plant or process, this solution can be, for example, a statistical data evaluation, a digital twin of the plant or a process, or an operator training simulator[1,2]. Added value is created by combining state of the art data analytics methods with tk Uhde' expert know-how as process licensor and EPC contractor[3].

Fig. 5 is a schematic showing the interaction between the fertilizer producer and tk Uhde. Different ways exist to extract recommendations from process data and several approaches exist to combine artificial and human intelligence and hence expert know-how. A selection is made depending on the process and the situation:

- Model-driven approach: Physics-based models and simulations are combined with real-time data analytics (e.g., digital twin).
- Expert-driven approach: Known correlations, specifications and patterns are used as guiding principles for learning algorithms (e.g., statistical data analysis for trip prevention).
- Data-driven approach: Generic analytics and machine learning methods are employed, followed by expert interpretation of the results (e.g., neural network-based machine learning tools)[3].

To select the best method applicable to a task, both technology expertise as well as digital know-how is required and provided. tk Uhde experts guide the plant owner through this process.

Digital products and services provided by tk Uhde combine the vast engineering and process expertise gathered as EPC contractor during decades of engineering and commissioning of process plants worldwide with state-of-the-art data-driven methods and artificial intelligence. With the best digital services, tk Uhde helps to analyse, stabilise, and optimise the plant during its lifetime and supports a safe operation[3].

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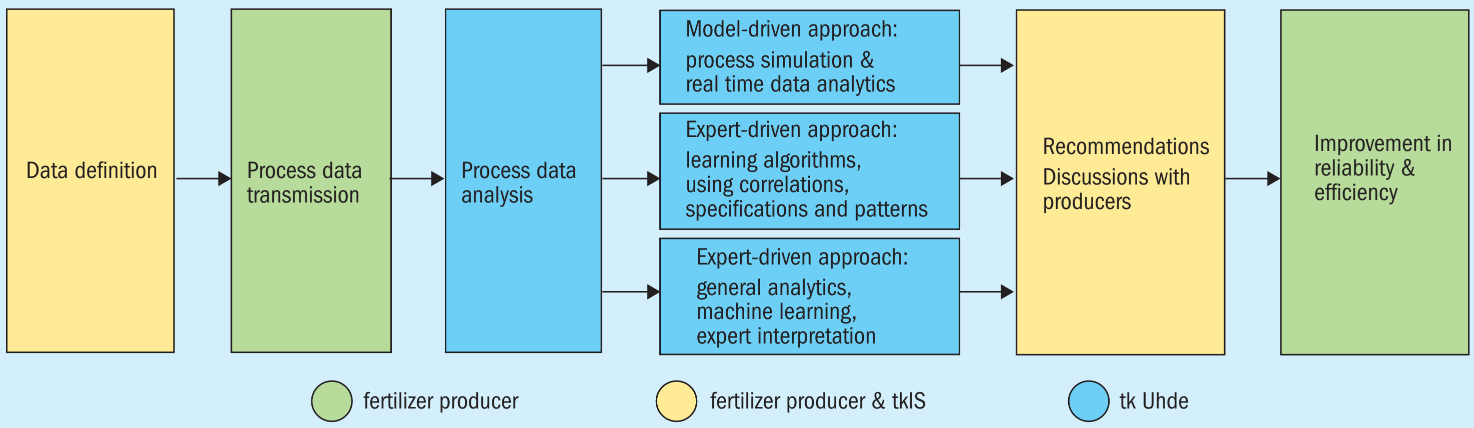
Fig. 5: **Information flow between fertilizer producer and tk Uhde for process modelling[3]**



Source: tkIS

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TOYO ENGINEERING CORPORATION

Innovations in urea synthesis technology and sustainable urea production

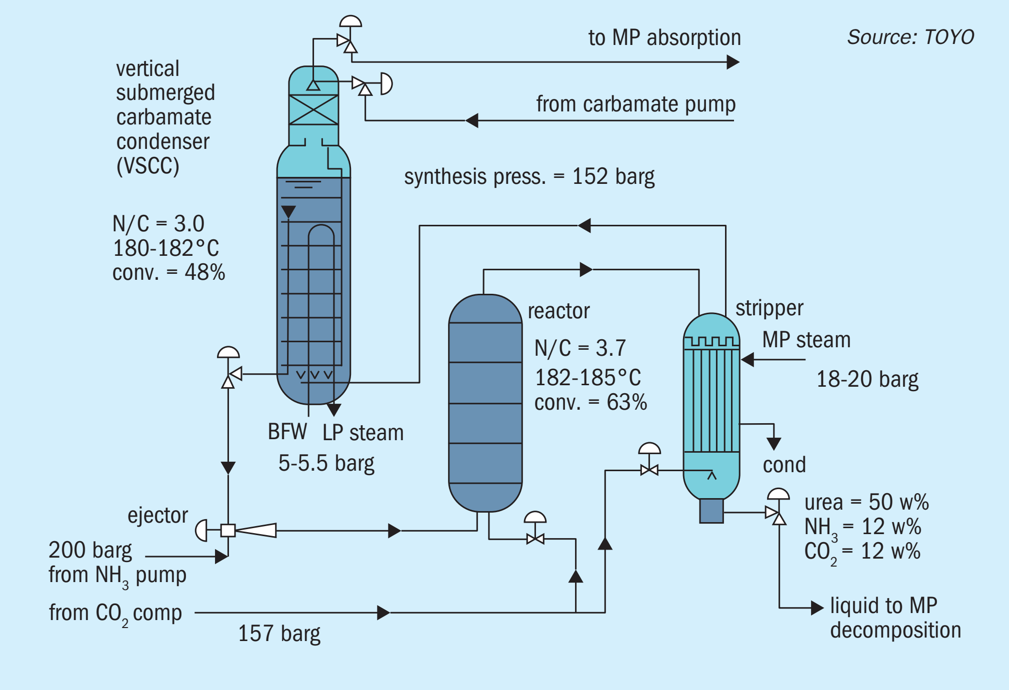
T. Yanagawa

Toyo Engineering Corporation (TOYO), a global leading engineering contractor and urea process licensor, has developed proprietary urea processes since the development of the partial recycle process in 1950s. Using its expertise, advanced technology and novel thinking, TOYO established the ACES21® process in the late 1990s, which achieves further energy savings and plant cost reductions while maintaining high performance and high efficiency of the urea plant. ACES21® was developed together with P.T. Pupuk Sriwidjaja (PUSRI) of Indonesia. TOYO has since been awarded 16 ACES21® projects, including two 4,000 t/d urea projects for Indorama Eleme Fertilizer and Chemicals Limited (IEFCL) which is world's largest single train urea plant.

TOYO has been working on further innovations and improvements to its proprietary urea processes and has developed ACES21-LP™, the next generation ACES21® which achieves the lowest urea synthesis pressure among modern urea processes. ACES21-LP™ realises further energy savings and plant cost reductions while maintaining all salient features of the current ACES21®, reaping the rewards of technologies cultivated over many years.

In addition, TOYO is launching a new concept, "g-Urea®", aimed at carbon neutral urea production utilising renewable energies and feedstocks. One promising solution is urea production from green ammonia. Another is urea production from ammonia and carbon dioxide derived from biomass and/or waste gasification.

Fig. 1: **ACES21® synthesis section with current operation parameters**



TOYO'S ACES21® urea synthesis technology

ACES21® is a low cost, low energy urea process. A major feature of the ACES21® process is the reduced equipment in the urea synthesis loop resulting in a simplified system. Thanks to the introduction of the HP carbamate ejector, the urea reactor layout is compact and has a low elevation. In addition, since the operating condition in the ACES21® process is optimised, operating at lower pressure than the previous process, a remarkable reduction in energy consumption is achieved. ACES21® becomes more advantageous as urea plant capacity increases owing to the fewer and smaller high pressure (HP) equipment laid out at low elevation, which leads to significant improvements in equipment manufacturability, transportability, constructability, operability, and maintainability.

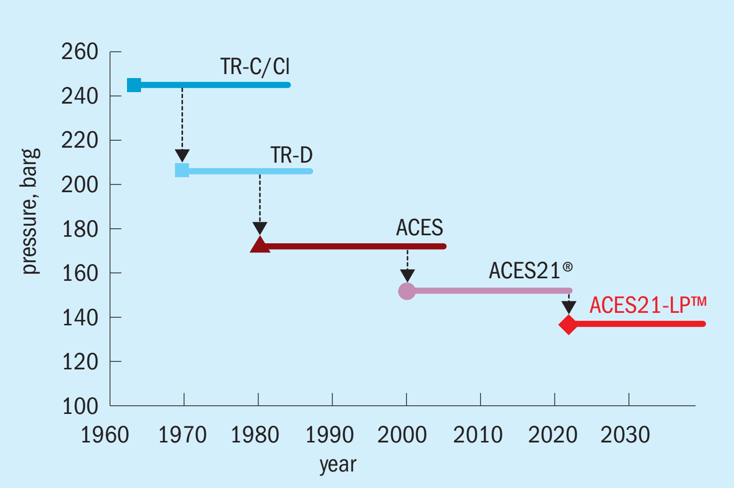
Fig. 1 shows a schematic flow sheet of the ACES21® synthesis section with current operation conditions. Liquid ammonia is fed to the reactor via the HP carbamate ejector which provides the driving force for circulation in the synthesis loop. Most of the carbon dioxide with a small amount of passivation air is fed to the stripper as a stripping medium for urea synthesis, while the rest is fed to the reactor to passivate the reactor. The reactor is operated at a NH_3/CO_2 molar ratio (N/C ratio) of 3.7, temperature of 182-185°C and pressure of 152 barg. Carbon dioxide conversion to urea is as high as 63% at the exit of the reactor. Carbamate solution from the carbamate condenser is fed to the reactor after being pumped by the HP ejector that is driven by high pressure liquid ammonia. Urea synthesis solution leaving the reactor is fed to the stripper where unconverted carbamate is thermally decomposed, and excess ammonia and CO_2 are efficiently separated by CO_2 stripping. Stripped urea solution is sent to the MP decomposition stage to be purified further. Stripped off gas from the stripper is fed to vertical submerged carbamate condenser (VSCC), operated at an N/C ratio of 3.0, temperature of 180-182°C and pressure of 152 barg. Ammonia and CO_2 gas condense to form ammonium carbamate and subsequently urea is formed by dehydration of the carbamate in the shell side. The reaction heat of carbamate formation is recovered to generate 5-5.5 barg steam in the tube side. A packed bed is provided at the top of the VSCC to absorb uncondensed ammonia and CO_2 gas in the recycle carbamate solution from MP absorption stage. Inert gas from the top of the packed bed is sent to the MP absorption stage.

Next generation ACES21®

TOYO has developed the next generation ACES21®, ACES21-LP™, to realise further energy savings and plant cost reductions while maintaining all salient features of current ACES21®.

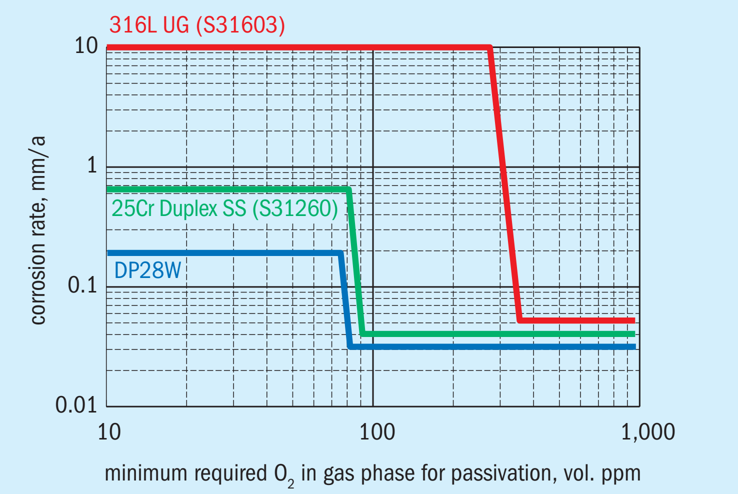
Fig. 2 shows how TOYO has lowered the urea synthesis pressure over the past 60 years. The urea synthesis pressure has been lowered step-by-step from around 240 bar to around 152 bar as the

Fig. 2: **Lowering of urea synthesis pressure over time**



Source: TOYO

Fig. 3: **Minimum required oxygen concentration for passivation**



Source: TOYO

technology has advanced. The ACES21-LP™ concept lowers the urea synthesis pressure even further to 136 bar. Table 1 summarises and compares key features of the synthesis section in ACES21® and ACES21-LP™.

The key to realise ACES21-LP™ is the sophisticated application of DP28W™, conventional duplex SS and 316L SS to the synthesis section in combination with reduced passivation air.

The simple and sophisticated concept of ACES21-LP™ enhances features of current ACES21® as follows:

- lowest synthesis pressure among commercial urea processes owing to uniquely optimised synthesis conditions and reduced passivation air requirement;
- highest CO_2 conversion among advanced modern urea processes;
- 5-10% further energy savings (less opex) due to less power requirements for the CO_2 compressor, ammonia and carbamate pumps;
- less capex due to less intense mechanical design conditions of synthesis equipment (synthesis section HP equipment cost reduction 5-10%)

Table 1: **Key features of urea synthesis section**

Process	ACES21®	ACES21-LP™
Pressure, barg	152	136
Reactor	2-stage reaction	2-stage reaction
N/C ratio, mol/mol	3.7	3.7
CO_2 conversion, %	63	62

Source: TOYO

DP28W™ – TOYO's proprietary super-duplex stainless steel for urea plants

TOYO and Sumitomo Metal Industries (now Nippon Steel Corporation) developed a new super duplex stainless steel DP28W™ specially for application in the urea synthesis section. DP28W™ has been used in commercial urea plants since the early 2000s thanks to its excellent corrosion resistance, passivation properties and mechanical properties. DP28W™ shows excellent corrosion resistance even in weld metal and the heat affected zone because of the optimised alloying design of the base metal and the welding material. DP28W™ can be easily passivated and contributes to a reduction in the required passivation oxygen concentration.

Optimum application of materials for HP equipment and piping

Based on TOYO's intense R&D and electrochemical studies, TOYO has identified the minimum required oxygen concentration for passivation in the gas phase to prevent active corrosion for each material as shown in Fig. 3.

TOYO's urea process simulator confirms the oxygen concentration for passivation in the process fluid for each item of equipment and piping with regard to oxygen concentration in CO_2 which is fed to the synthesis section as raw material. It also confirms that the oxygen concentration in the HP synthesis section is lowest in the stripper and stripper outlet gas.

Based on these studies, the application of DP28W™ or 25Cr duplex stainless steel (S31260), which is passivated at low oxygen concentration for the stripper outlet piping in the synthesis section, can reduce the requirement of oxygen concentration drastically without paying a high cost for material.

Optimum application of DP28W™ and duplex stainless steels to the synthesis section further reduces passivation air requirement.

Suitable for revamp applications

Since the basic process scheme of the current ACES21® has been maintained, existing operating ACES21® plants can be easily upgraded to ACES21-LP™ with very minor modifications, receiving full benefits such as opex saving, and additional capacity margins of the CO_2 compressor, ammonia pump and carbamate pump.

TOYO's approach for sustainable urea production

With the ambition to achieve a carbon-neutral society, TOYO is working to provide a wide range of solutions, including technology and business development support, ranging from the capture of CO_2, to the utilisation and storage of CO_2 (CCUS), through collaboration with leading-edge technology partners and through TOYO's expertise established in the plant engineering

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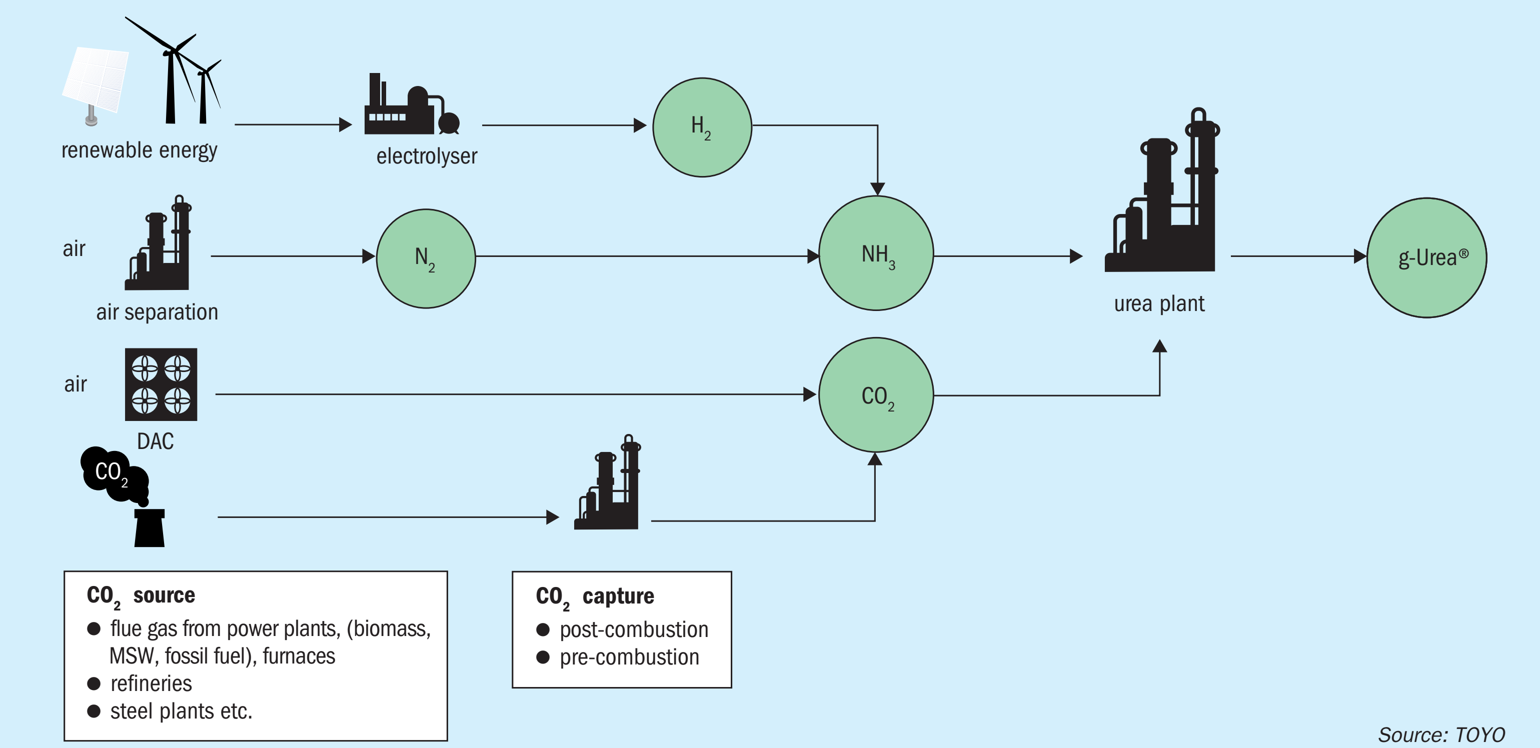
Fig. 4: **g-Urea production from green ammonia**



Source: TOYO

business. TOYO is also working on establishing chemicals and synthetic fuel production systems in combination with renewable feedstock and/or waste gasification technologies. Urea is one of the final products.

TOYO believes the carbon footprint of fertilizer production and usage must be considered using a "scientific, fact-based, comprehensive and quantitative approach", not an "ideological or political approach". TOYO's views on this issue are summarised below:

- CO_2 emissions from nitrogen fertilizer production simply depend on the feedstock used for ammonia (hydrogen in nature) production, not the nitrogen fertilizer itself. When the nitrogen fertilizer is produced from ammonia from fossil fuel (grey ammonia), the CO_2 footprint for nitrogen fertilizer production is totally attributable to the ammonia production. On the contrary, nitrogen fertilizer produced from green ammonia and renewable energy/feedstocks should be regarded as "green".
- When fossil feedstock is used, there is no significant difference in GHG footprint between urea and ammonium nitrate (AN), another typical nitrogen fertilizer. Ammonium nitrate production does not utilise any CO_2 emitted by ammonia production, whereas urea production utilises CO_2 from ammonia production as a feedstock. It is also noted that the CO_2 utilised for urea production is not totally emitted to the atmosphere at the use stage. Emission of all CO_2 (0.733t-CO_2/t-urea) is a conservative expedient assumption to omit more detailed models or measurements that incorporate the possibility of bicarbonate leaching to deep groundwater, and/or lakes and oceans as stated in IPCC guidelines[1].
- Carbon reduction is achieved when urea is synthesised from green ammonia and CO_2 is captured at emission source and/or from direct air capture (DAC) based on renewable energy and even a part of CO_2 leached to deep groundwater, lakes and/or oceans at use stage. Even if all of the CO_2 in urea is emitted at the use stage, it is regarded as carbon neutral and leads to reduced equivalent CO_2 emission compared to the same quantity of urea produced from fossil feedstocks.
- Urea contains the highest nitrogen content of all nitrogen fertilizers, thus GHG emissions attributable to the transportation of urea are lowest from a life cycle assessment (LCA) point of view.
- Urea is easy to handle, store and transport since it is not classified as a hazardous substance and has provided great benefits to fertilizer logistics and farmers. On the other hand, ammonium-based fertilizer requires careful handling and storage, especially ammonium nitrate which has explosive potential.

g-Urea® concept

Assuming there is no established definition for green urea, TOYO defines it as "carbon neutral (or negative) urea production or a process utilising renewable energy and feedstocks" and names it g-Urea®.

g-Urea® can be produced from green ammonia synthesised from hydrogen produced from the electrolysis of water and nitrogen from air separation (Fig. 4). CO_2 will be sourced separately from ammonia production, for example, from thermal power plants, refineries, and other industrial facilities where CO_2 is currently emitted from stacks. Utilisation of this waste CO_2 for urea production from green ammonia reduces the equivalent CO_2 emission compared to urea produced from fossil feedstocks. TOYO is ready to integrate CO_2 capture technologies with green ammonia and urea production in order to source CO_2 from stacks and/or direct air capture (DAC) which are crucial components to bring the fertilizer industry in harmony with a circular carbon society.

g-Urea® can also be produced by gasification-based ammonia-urea production where biomass and/or MSW (municipal solid waste) is the feedstock for gasification (Fig. 5). The overall process scheme is basically very similar to conventional gasification-based ammonia-urea production from coal, heavy oil, etc.

Fig. 5: **g-Urea Production from ammonia/CO_2 derived from biomass/MSW**

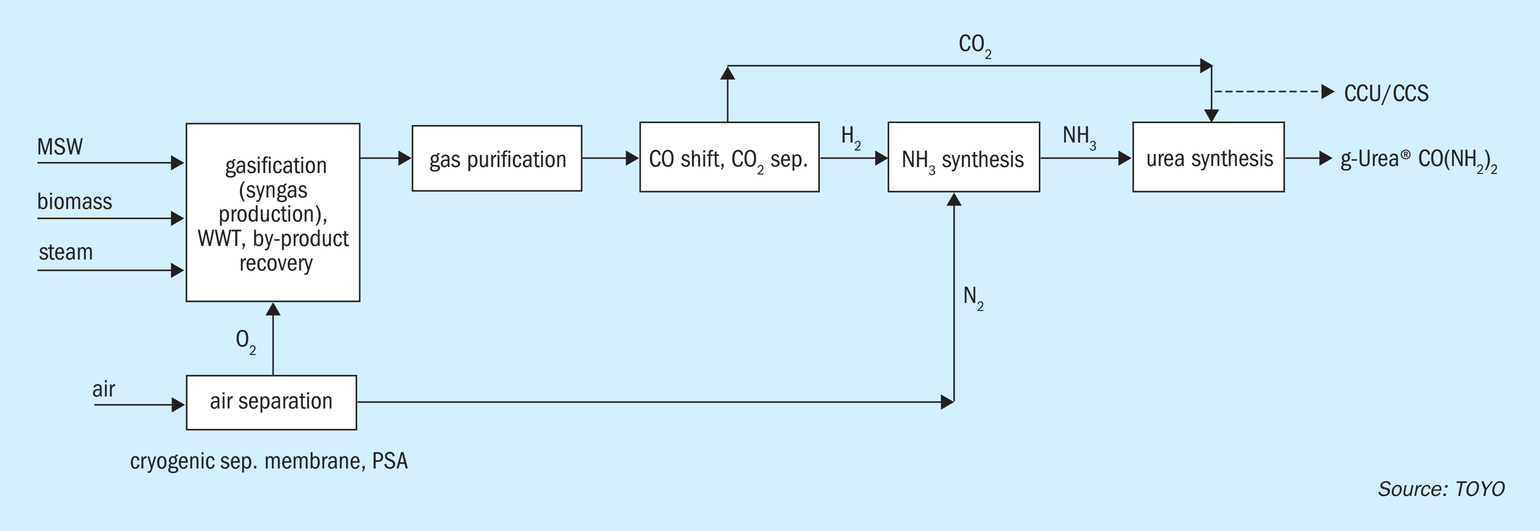


Fig. 6: **Breakdown of global N_2O emission[2]**

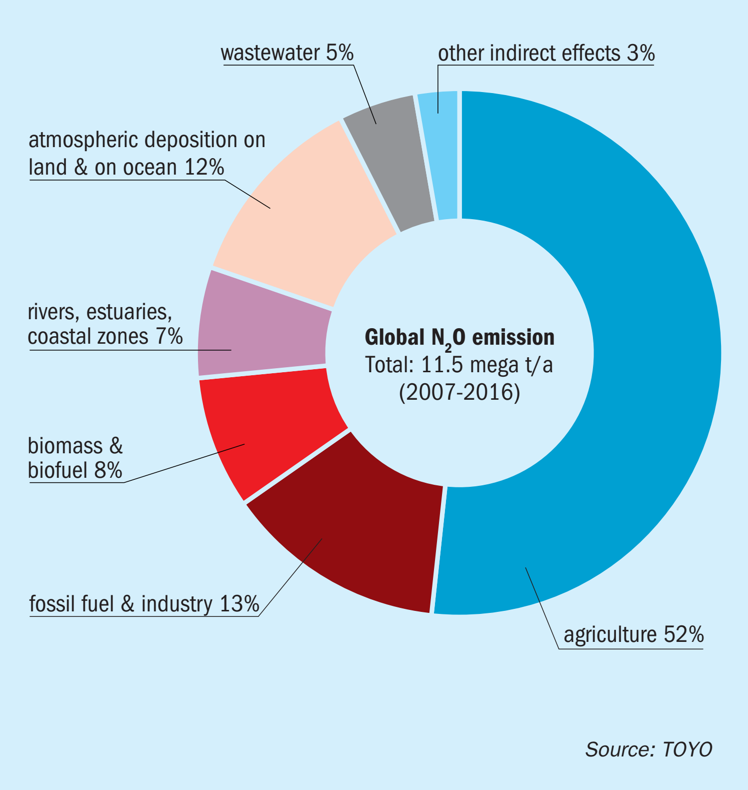
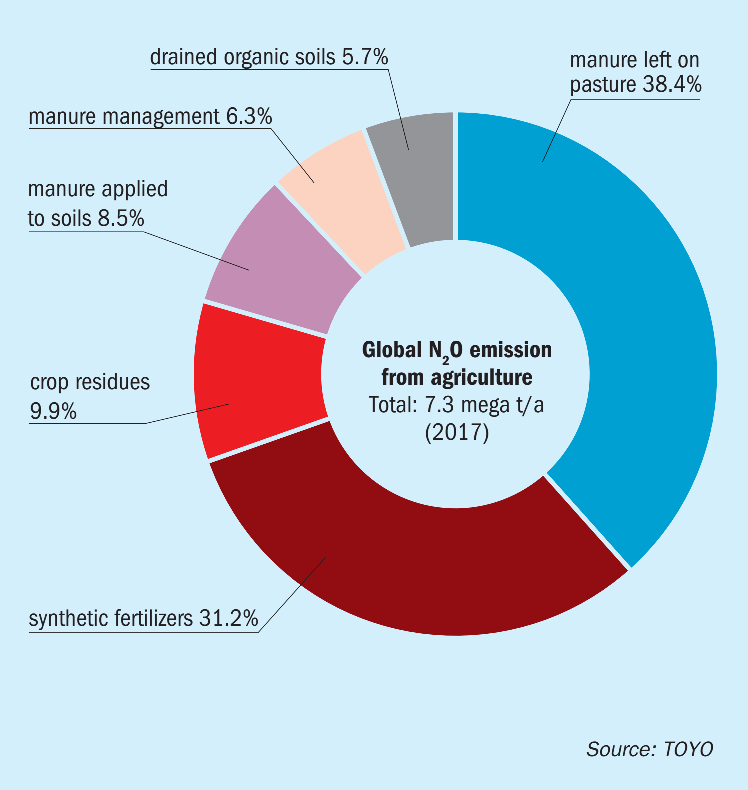


Fig. 7: **Breakdown of N_2O emissions from agriculture[3]**



N_2O emission from nitrogen fertilizer application to fields

Application of substances containing nitrogen such as livestock manure, crop residues, synthetic fertilizers etc, to fields leads to N_2O emissions. N_2O emissions from agricultural sources accounts for around 52% of anthropogenic N_2O emissions as shown in Fig. 6[2]. Fig. 7 shows a breakdown of global N_2O emissions from agricultural sources in 2017 based on data sourced from FAO (Food and Agriculture Organization of the United Nations)[3].

N_2O is emitted from soil as a by-product of two processes in which soil microbes convert ammonia back to nitrogen gas; nitrification which converts ammonium to nitrate; and denitrification which converts nitrate to nitrogen gas. Nitrogen fertilizers such as urea and AN are no exception to these processes. However, N_2O emissions from soil per unit of nitrogen fertilizer is highly dependent on application practice, soil type and conditions, humidity and other weather conditions.

Intensive research and development are ongoing to evaluate and reduce N_2O emissions from fertilizer application. In general, the following measures can be taken to reduce N_2O emissions:

- nutrient use efficiency measures, such as the 4Rs (right source, right rate, right time and right place);
- nitrification inhibitors;
- slow-release fertilizers or controlled release fertilizers;
- application of soil conditioning material with an N_2O reducing denitrifier. ■

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STAMICARBON

Powering ammonia synthesis with renewable energy sources

M. Patel and D. Shetty

The fertilizer industry can't escape from the increasing focus on sustainability. Conventional processes that rely on fossil fuels and other non-renewable energy resources must be redefined to ensure a sustainable, environmentally friendly future.

In the last decade, innovations have focused on the economy of scale and a higher fertilizer production output. However, now that the industry is moving towards greener technologies, the availability of renewable electricity and the limitations in electrolyser production capacity are considered a bottleneck in facilitating large-scale green projects in the short term. Furthermore, downscaling existing large-scale and fully integrated ammonia plants to suit a small capacity is unattractive especially in relation to the required capex.

Challenges

Stamicarbon, Maire Tecnimont Group's innovation and licensing company, is well aware of the need to develop and invest in sustainable, carbon-free fertilizer production. The use of fossil fuels as feedstock for ammonia production in the first step of the process results in carbon dioxide production alongside hydrogen. While hydrogen continues further into the synthesis, carbon dioxide, having no other role, is mainly released into the atmosphere. The output of this process is known as "grey" ammonia. When the carbon dioxide is captured and sequestrated, this is referred to as "blue" ammonia.

With the fossil fuel route, it is not possible to fully decarbonise existing facilities. In the "green" ammonia process, water electrolysis is used to derive hydrogen. Nitrogen is separated from the air and the rest of the production is powered by renewable or carbon-free energy sources. Water is separated into hydrogen and oxygen using electricity derived from renewable sources like solar, wind, water, and geothermal energy.

Stami Green Ammonia technology features

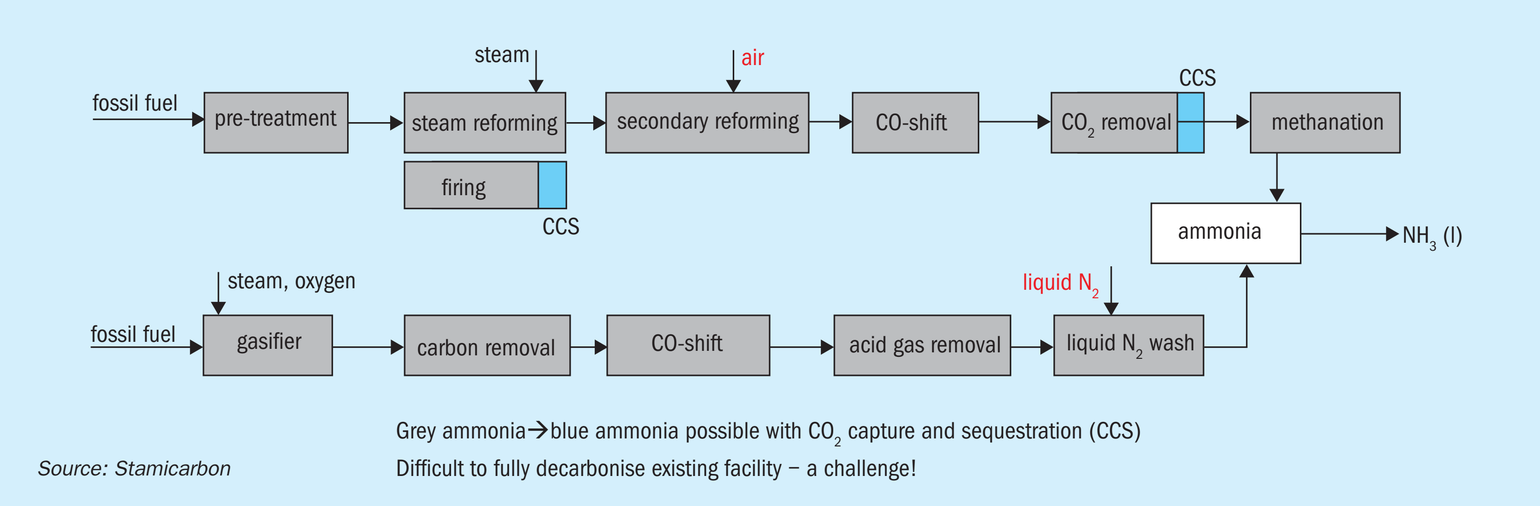
Compared to other conventional ammonia technologies, the Stami Green Ammonia technology (Fig. 1) differs in the synthesis gas pressure (approximately 300 bar). According to the principle of chemical equilibrium, ammonia synthesis is favoured at low temperature and high pressure due to an exothermic reaction and reduction in number of moles. The high-pressure ammonia synloop at the heart of the technology has been customised to make the most efficient plant design at a small scale, especially with green feedstock. As a result, the plant operates with a single proven and reliable electric-driven multiservice reciprocating compressor. The minimal equipment needed for plant operations leads to substantial capex savings of approximately 25-30% – an important consideration for small-scale applications. Furthermore, due to the high pressure, the ammonia synthesis only requires a very small catalyst volume.

The Stami Green Ammonia technology configuration (Fig. 2) characterised by a modular approach and thus perfect for small-scale facilities, is the first of its kind, based on proven technology. The operating reference plants are based on natural gas and have been adapted to produce ammonia from make-up gas via a green route. This technology is especially suitable especially for decentralised production of green ammonia utilising a renewable source of energy. The plant is fully flexible in managing the intermittent nature of renewable energy if that is required. The technology package is available in tailored capacities for small-scale plants in the range of 50 to 300+ t/d of ammonia production, but can be scaled upwards to capacities of 500 t/d. The plant has a lean and compact design. The capacity of a 100 t/d ammonia plant has a footprint of approximately 15 x 30 m, including the compressor building. It utilises about 35-100 MW of power, depending on its capacity.

Stamicarbon's technology package offers a competitive solution for local production on a small scale. It can be applied in combination with its existing (mono-pressure and dual-pressure) nitric acid and urea technologies, moving from grey ammonia to green ammonia-based fertilizers to produce green nitrate fertilizers. In combination with the use of recycled or recovered CO_2, it reduces the carbon intensity of urea fertilizer production.

The technology has operating references based on natural gas. This is the

Fig. 1: **Shades of ammonia: grey/blue process**



Source: Stamicarbon

strongest technology reference in a small-scale range that makes a sound basis for further development of the future small-scale ammonia plant concept.

The technology includes the following key features:

- high capex efficiency;
- strongest reference base with five small-scale plants in operation;
- lean, compact and modularised design;
- high plant reliability thanks to a multi-service reciprocating compressor;
- compliance with the highest environmental standards;
- dedicated operator training simulator available;
- access to digital solutions, such as a process monitoring tool;
- agnostic to upstream water electrolysers and can be integrated with Stamicarbon's nitric acid and urea technologies.

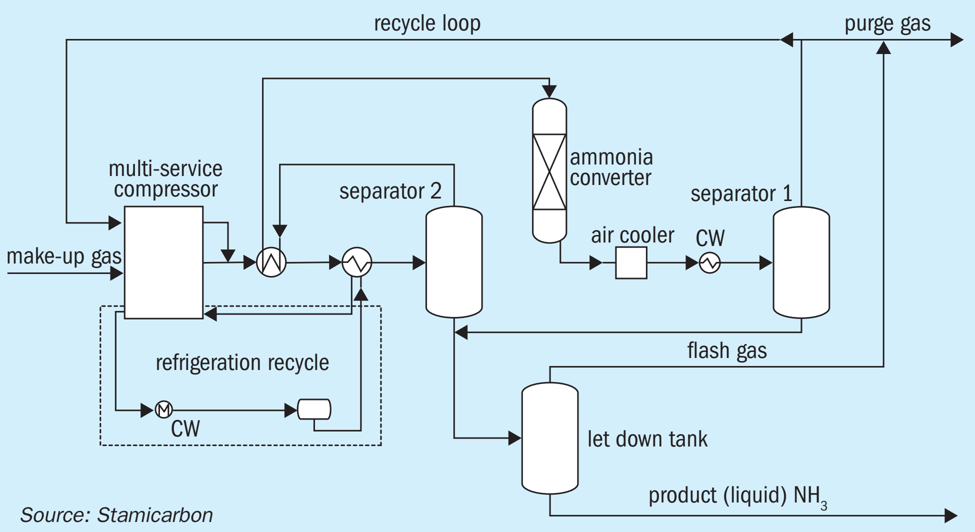
Fig. 3 shows a typical 3D model of a Stami Green Ammonia plant.

Examples of ongoing projects/studies include:

Green Fertilizer Kenya
Location: Osirian Two Lakes, Kenya
Ammonia plant capacity: 180 t/d
Configuration: power-to-fertilizer (ammonia to green nitrate fertilizers)
Energy source: geothermal, solar.

Greenfield Nitrogen
Location: Garner, Iowa, USA
Ammonia plant capacity: 250 t/d
Energy source: 100 % renewable electricity.

Fig. 2: **Typical process flow diagram: Stami Green ammonia**



Source: Stamicarbon

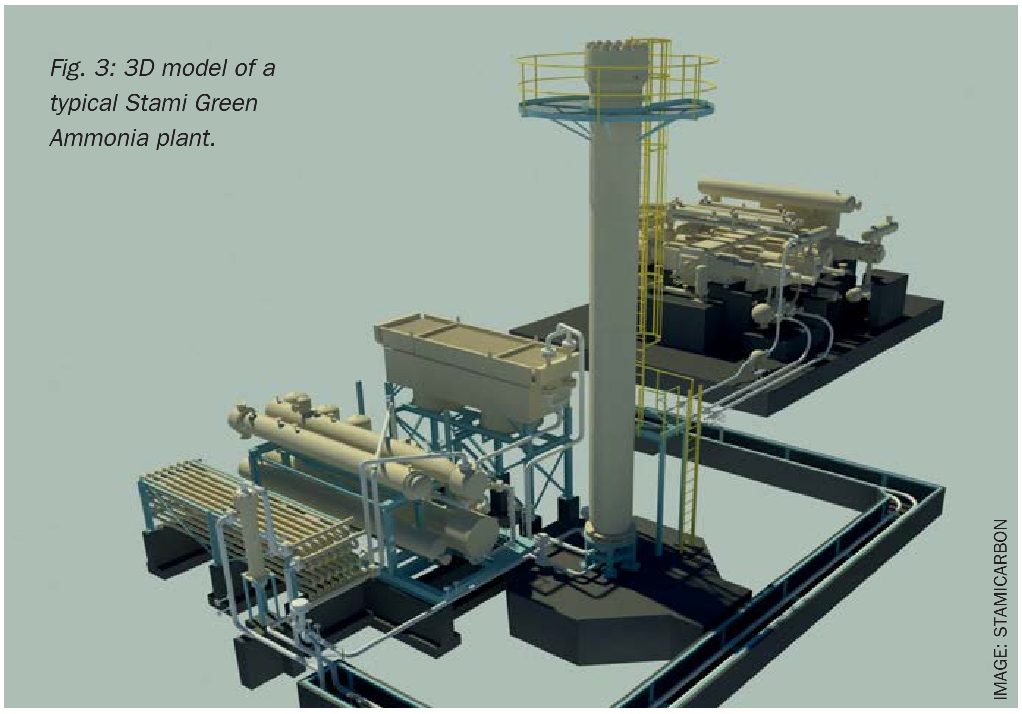


Fig. 3: 3D model of a typical Stami Green Ammonia plant.

IMAGE: STAMICARBON

Participation in European green initiatives

Besides the direct development and licensing of new commercial green ammonia plants, Stamicarbon also participates in European green initiatives to make the industry more sustainable. The first one is an EU-funded project INITIATE (Innovative Industrial Transformation of the Steel and Chemical Industries of Europe) to use the carbon-rich off-gases from steel mills as feedstock for urea production. The core of this process is a modular carbon-capture utilisation-and-storage (CCUS) technology, which allows for the integration and conditioning of steel gases with ammonia synthesis.

Stamicarbon will be responsible for the commercial implementation plan and supply its green ammonia technology to justify the pilot project's viability and prove the capability to produce ammonia to build a reference plant for urea production in the next stage. In addition, it will supply the ammonia technology license and ammonia converter for the 3 t/d pilot plant in Luleå, Sweden.

In a second initiative Stamicarbon will supply its green ammonia technology to Prometeo, a European Horizon 2020 project to develop an innovative prototype for high-temperature electrolysis, using renewable energy to power the continuous production of green hydrogen. The innovative solution will address intermittency in the solar power supply by managing energy conversion and regeneration phases. Green hydrogen produced in this way will contribute to the production of green ammonia and green fertilizers.

Green ammonia for a greener future

By 2050 the world's population will grow to nearly 10 billion people. Also, by 2050 hundreds of countries will have to achieve their targets of net-zero emissions aligned with the Paris Agreement. Ammonia acts as a building block for nitrogen fertilizers and plays an important role in providing optimal plant nutrition, yet it is responsible for 1% of the world's greenhouse gas emissions. Powering ammonia synthesis with renewable energy sources thus becomes a significant step towards more sustainable fertilizer production. The Stami Green Ammonia technology aims to serve as a gateway to carbon-free and futureproof ammonia production and a solution for the production of smart, sustainable, renewable feedstock for nitrogen-based fertilizers.

Upgrading the ammonia plant CO_2 removal section

Casale and Giammarco-Vetrocoke discuss different strategies to revamp the CO_2 removal section in ammonia plants for improved efficiency and capacity increase.

CASALE

Casale CO_2 removal revamp strategies for ammonia plants

Improved efficiency, capacity increase and new requirements coming from industrial decarbonisation and energy transition strategies are driving existing industrial complexes towards improving currently installed CO_2 removal sections.

Parameters to be considered when planning an upgrade of the CO_2 removal section in ammonia plants: energy consumption, CO_2 capture rate, CO_2 quality, and CO_2 operating pressure. The revamp may involve a change to the process arrangement as well as modifications to the specific existing equipment to improve performance.

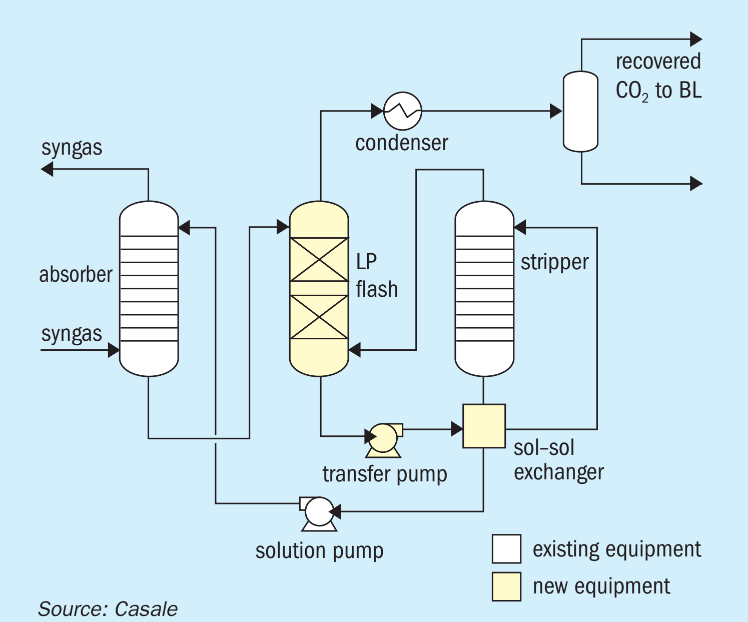
Depending on the design technology of the CO_2 removal section, different strategies can be applied to improve this part of the plant. To date, Casale has modernised more than 20 CO_2 removal sections world-wide.

When revamping amine-based CO_2 removal units, Casale mainly co-operates with BASF. Among the various strategies to improve the efficiency of this section it is normal to install an additional LP flash tower, which adds equilibrium stages to the regeneration section, saving reboiling duty on the process and steam reboilers.

Another modification aimed at reducing the specific energy consumption of the CO_2 removal section entails replacing the existing shell-and-tube rich/lean solution exchanger with a new plate-and-frame exchanger. A welded plate heat exchanger can also be considered when operating pressure limitations exclude the use of plate and frame exchangers.

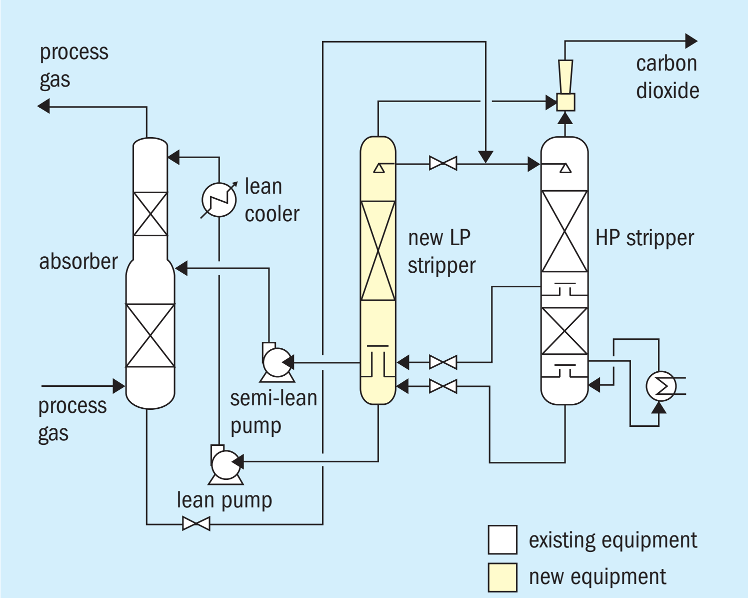
The main advantage of the plate-and-frame exchanger is the better temperature approach between the hot and the cold side. The pressure drop on the hot side is also somewhat lower in the plate heat exchanger, which improves the operation of the solution pump (on account of the higher net positive suction head).

Fig. 1: **Improvement of amine-based CO_2 removal section**



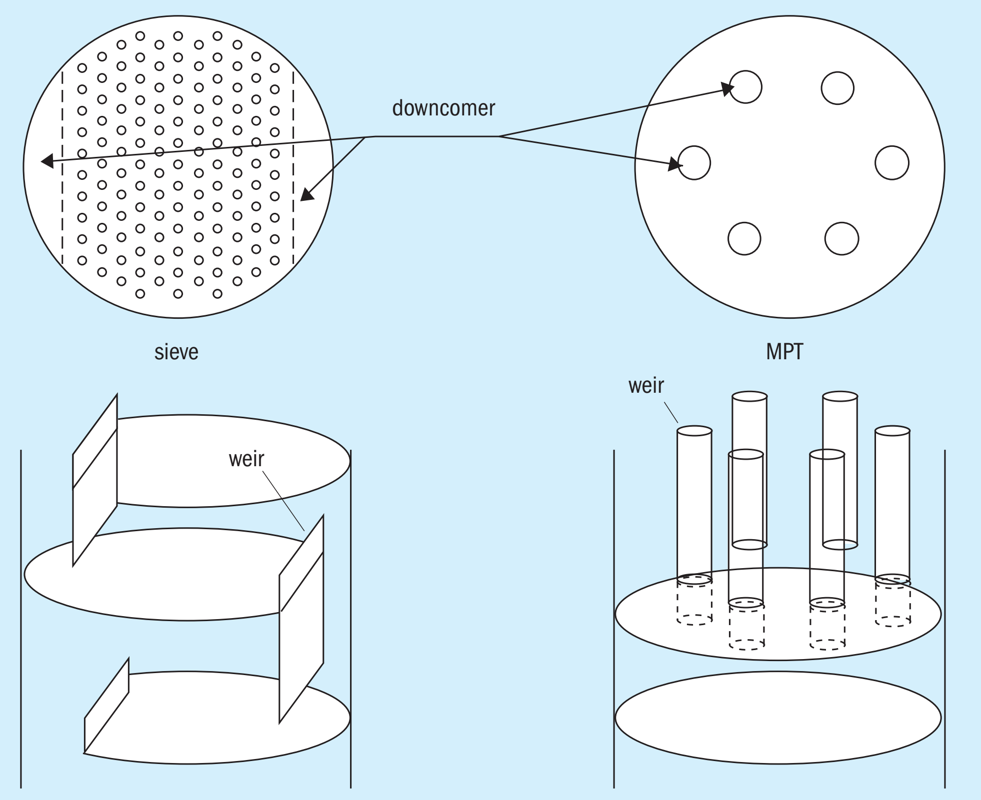
Source: Casale

Fig. 2: **GV low-energy CO_2 removal scheme**



Source: Casale

Fig. 3: **Typical sieve tray and MPT arrangement**



Source: Casale

In summary, rich solution coming from the CO_2 absorber is first depressurised in the LP flash tower, after which partially regenerated "semi-lean" solution is pumped to the existing regenerator, where it is completely regenerated thanks to the energy supplied by the bottom reboilers (see Fig. 1).

The calculated energy saving resulting from the installation of the LP flash tower and the rich/lean solution plate-and-frame exchanger is about 0.2 Gcal/t of ammonia, as proved in modifications accomplished in previous successful projects.

For hot potassium carbonate systems, Casale has an active collaboration with Giammarco-Vetrocoke and can implement the GV low-energy process (see Fig. 2) to improve the CO_2 removal section. In this way the regeneration consumption is decreased to 650-750 kcal/Nm^3 CO_2.

The GV low-energy process is a two-stage scheme with two separate strippers working at different pressures – a high-pressure (HP) stripper and a low-pressure (LP) stripper. Part of the rich solution from the absorber (about 60% of the total circulation) is introduced into the top of the HP stripper, while the remainder, let down in pressure by about 1 kg/cm^2, passes into the LP stripper. The pressure difference between the HP and LP strippers is such that sufficient flashed steam is produced to strip out the CO_2 from the rich solution fed to the top of the LP stripper, achieving the same quality as the semi-lean solution withdrawn from the HP stripper.

As a reference example, this scheme was successfully applied by Casale in the three ammonia lines of a single complex in India, which was revamped in 2013 with a saving of about 0.2 Gcal/MT of ammonia. Other applications are in Spain, Russia, Romania and Ukraine.

As most of the work can be done while the plant is in operation, the modification can be accomplished in a normal turnaround. Even easier is the case in which the plant is already equipped with two solution regenerators.

Different configurations involving different arrangements are possible with the aim of making the existing unit more efficient and flexible.

Casale technologies for CO_2 removal revamping

Besides offering upgraded CO_2 removal sections in cooperation with solution licensors, Casale is also able to provide technologies for the upgrading/revamping of existing equipment.

Multi pipe trays

A typical example of this capability is the adoption of Multi Pipe Trays (MPT); these are sieve trays with special downcomers consisting of several pipes.

The following definitions will help to understand the benefits achievable by using this technology:

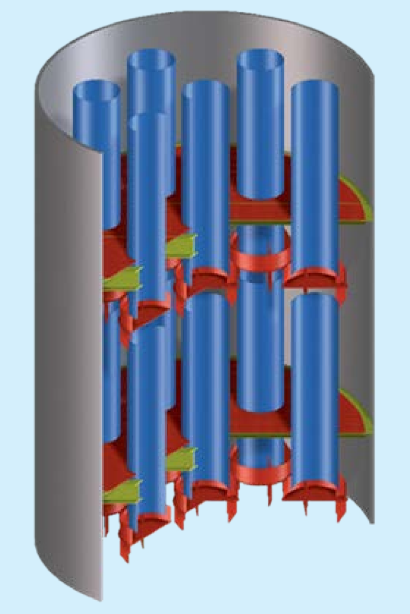
- **Active area** is the potential area available to the vapour flowing in a distillation or absorption column, this is basically the total tower cross-section area less the total of downcomer area, downcomer seal area, and any other non-potentially perforable area.
- **Perforated area** is the area effectively flown by the vapour due to the presence of holes or slots.
- **Downcomer area** is the tower cross-section area taken by the downcomers

In a typical valve or sieve-based tray there is an inlet downcomer area and an outlet downcomer area that reduces the area available for effective contact between the vapour and the liquid.

Fig. 3 shows a typical sieve tray and MPT arrangement.

The MPT arrangement (Fig. 4), on the other hand, overlaps the inlet to the outlet downcomer area, thereby increasing the active area. This makes the MPT technology suitable for revamping the standard sieve or valve trays in existing towers, because more area is potentially available to the flowing vapour and therefore the system gains more margin compared to the jet flood conditions.

Fig. 4: **MPT 3D arrangement**



Source: Casale

Another advantage of the MPT is its much higher weir compared to standard sieve trays. A higher weir significantly improves the vapour-liquid contacts, increasing the efficiency. For instance, the Murphree tray efficiency of a MPT tray is more than double that of a standard sieve tray.

A higher weir impacts the tower pressure drop, but since far fewer trays are required to achieve the targeted performance due to the higher efficiency, the overall pressure drop is not so different compared to a typical CO_2 removal section based on standard technology.

The MPT trays can also be used in towers loaded with random packing. MPTs do not suffer from the wall effect and their separation is more efficient than with random packing. In case of an existing tower based on random packing, rather than complete replacement of the random packing, the two technologies (random packing and MPT trays) can be integrated. In fact, the MPT technology can be used to replace the distributor (or re-distributor) adding additional separation stages to the random packing-based system.

The advantages of Casale multipipe tray technology can be summarised as follows:

- High efficiency – efficiency can be estimated as double that of standard sieve trays.
- No wall effects – preferential paths and distribution problems are avoided (different to random packing absorbers);
- A higher approach to the equilibrium is achieved.
- A higher active area compared to standard sieve trays, allowing a smaller absorption column design.

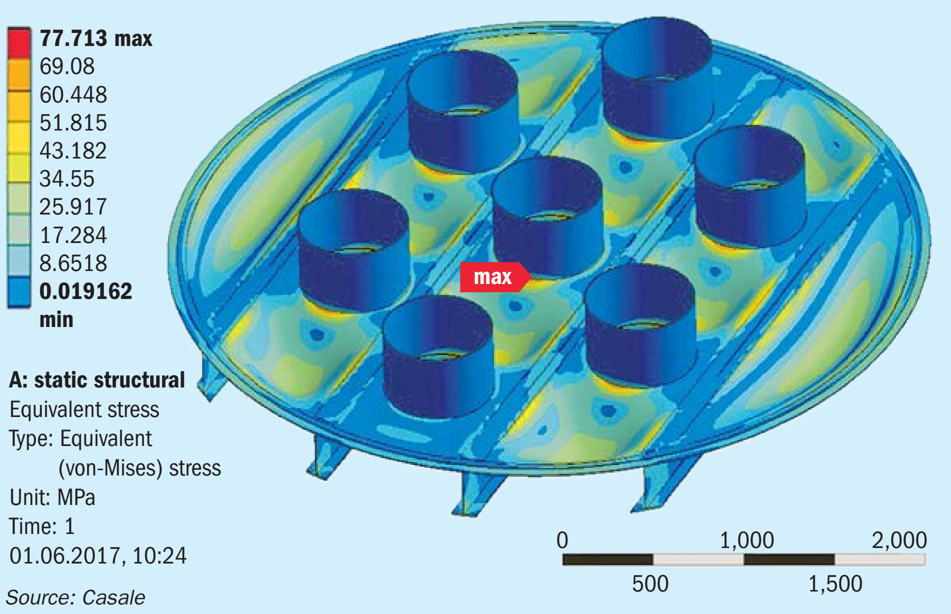
All the design and manufacturing steps, including the simulation check for the stress (Fig. 5) and deformation (Fig. 6) analysis, are developed during the engineering phase.

Casale has successfully applied this technology for the revamping of various GIAP plants where standard sieve trays were installed. In particular, absorber tray revamping has been carried out to make these sections suitable for a capacity of at least 2,000 t/d.

CO_2 clean/dirty separation device

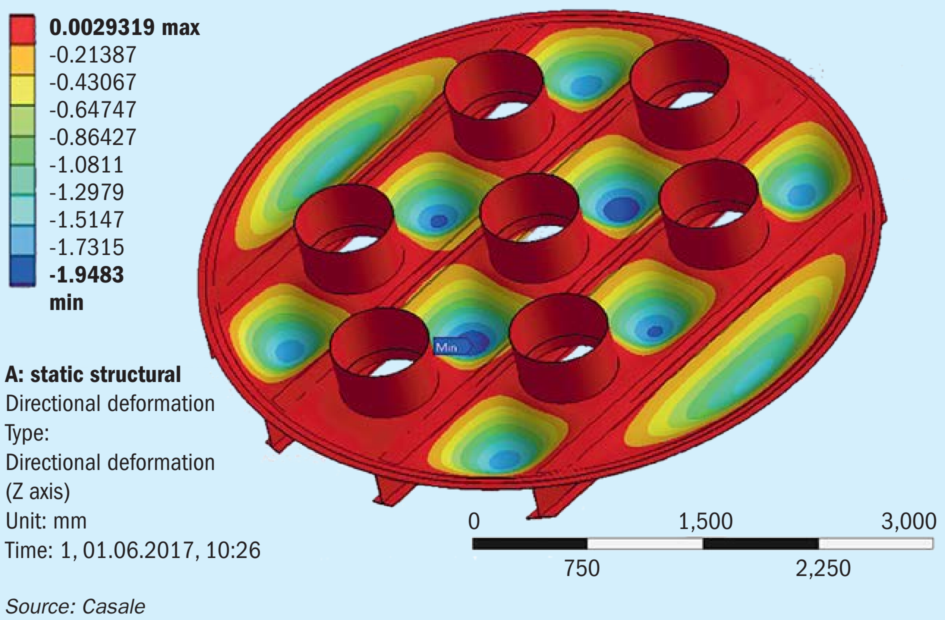
Very often the existing CO_2 removal section produces CO_2 with higher H_2 content than desired, and if this carbon dioxide is used downstream, e.g., in a urea plant, stream cleaning is required. Treatment is typically

Fig. 5: **Stress analysis developed by Casale on multi-pipe trays**



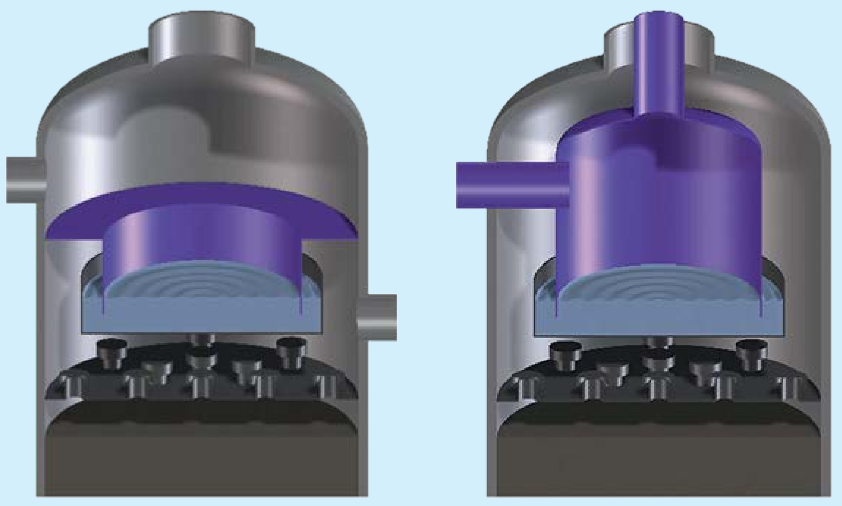
Source: Casale

Fig. 6: **Deformation analysis developed by Casale on multi-pipe trays**



Source: Casale

Fig. 7: **Internal separation device for new and revamped tower**



Source: Casale

accomplished by the catalytic conversion of hydrogen to water by means of air; such air and the relevant inerts negatively impact the conversion of the urea plant synthesis section.

To avoid catalytic treatment of the CO_2 stream it is possible to install a separating device that operates like a low-low flash releasing most of the H_2 still contained in the CDR absorption solution. This dirty stream containing H_2 is separated and typically accounts for 10-15% of the overall CO_2 flow rate, the balance CO_2 (so-called clean CO_2) is generated by regeneration inside the regenerator.

Such improvement can be accomplished by the internal modification of regeneration towers or by the installation of a low-low flash installed in an elevated position.

The engineering solution, involving the modification of the regenerator top, foresees the installation of a separation device where dirty CO_2 is separated from clean CO_2 (see Fig. 7). A hydraulic sealing system avoids any mixing between the two streams.

The solution involving the installation of an external pre-flash foresees the installation of an external vessel where proper residence time and a degassing device are provided to ease the release of CO_2 from the CO_2 removal solution.

This technology can be applied both to amine and hot potassium-based CO_2 removal section.

Recent case history

The Novomoskovsk plant AM2 has been recently completely upgraded. The plant was designed for a nameplate capacity of 1,360 t/d and after various modifications was able to produce 1,600-1,700 t/d. Following a complete modernisation performed by Casale the plant was able to produce 1,850-1,900 t/d.

Among the various modifications, the CO_2 removal section was one of the sections requiring major changes, in particular the following changes were implemented:

- CO_2 absorber tray replacement from standard to MPT trays;
- plate welded solution/solution heat exchanger installation;
- low-low desorber installation;
- additional cooling on the lean solution heat exchanger.

The existing trays of the CO_2 absorber were replaced with MPT trays increasing the available active area and the vapour-liquid equilibrium exchange making this part of the CO_2 removal section suitable for a capacity of more than 2,000 t/s.

A welded plate solution/solution exchanger was chosen considering the high-pressure operation (up to 28-29 barg) of one of the exchanging streams.

The low-low desorber unit was installed to produce a clean CO_2 stream having less than 100 ppm of residual H_2 in the CO_2 provided to batter limits.

Thanks to this modification, and without substantial modification to the amine solution strength, the plant was able to provide a CO_2 slip in the treated process gas of less than 200 ppm. ■

GIAMMARCO-VETROCOKE

GV processes for revamping the CO_2 removal section in ammonia plants

Revamping older ammonia plants to drastically reduce energy consumption and increase capacity is essential to make them competitive with modern units. The CO_2 removal section in the ammonia plant is a major consumer of energy and has been identified as an attractive target area for improvement to attain the goals of energy saving and capacity increase.

Giammarco-Vetrocoke (GV) is a well-known licensor of a leading CO_2 removal process based on activated hot potassium carbonate (HPC) solution, with 70 years of activity, including many years in the field of revamping the CO_2 removal section, based on extensive experience in design and implementation of debottleneck solutions widely applied to the GV process and competitor processes.

The GV revamp strategy has always been the implementation of well-proven and advanced technologies to achieve the planned targets with low capex thanks to maximum utilisation of the existing equipment. The tie-in time required for the revamped CO_2 removal section is normally kept within a typical annual plant turnaround to avoid affecting normal operation and to maintain full capacity production.

GV has developed various innovative low-energy regeneration processes for the energy and capacity revamp of the CO_2 removal section. GV technologies include:

- GV low-energy Dual Pressure Regeneration (DPR)
- GV low-energy Multi Flash Regeneration (MFR)
- GV low-energy Vacuum Pressure Regeneration (VPR)
- GV low-energy Hybrid Scheme (GHS)

Dual Pressure Regeneration (DPR)

The GV low-energy DPR process is extensively proven, in commercial use since 1980 in 70+ new and/or revamped CO_2 removal units.

The DPR process offers an attractive revamp scheme for CO_2 removal systems erected at the time of construction with two parallel strippers.

The simplified process flow diagram of a standard two-stage CO_2 absorption/regeneration system based on the GV low-energy DPR process is shown in Fig. 1.

The DPR process is based on the use of two strippers operating at different pressures, the HP (higher pressure) stripper and the LP (lower pressure) stripper.

The rich solution from the bottom of the CO_2 absorber is shared between the HP stripper (about 60% of the total circulation amount) and the LP stripper (the balance amount).

The heat for solution regeneration is supplied to the HP stripper only by process gas reboiler(s) and/or by direct/indirect LP steam.

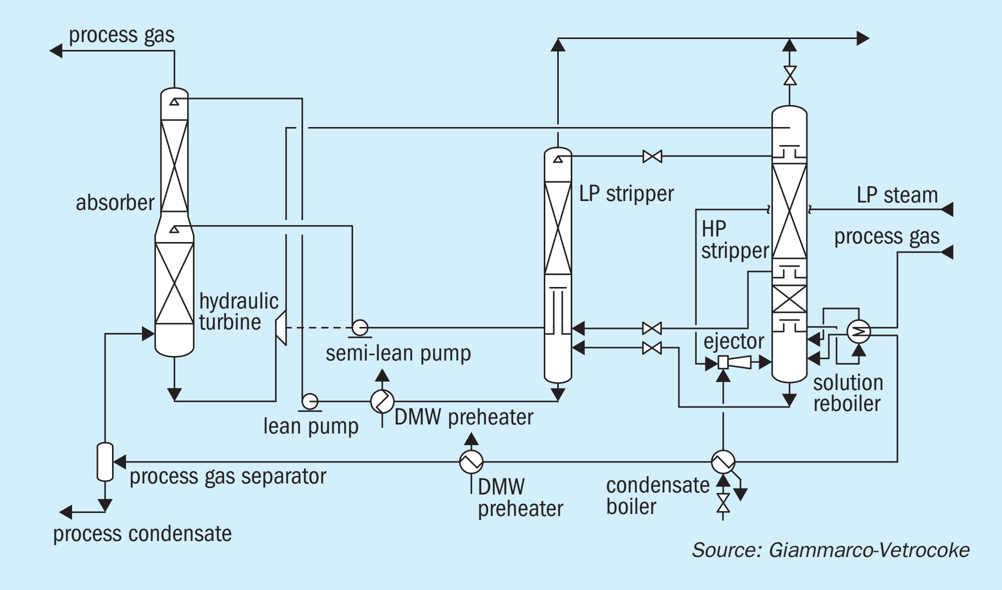
The semi-lean solution withdrawn from the mid zone of the HP stripper feeds the mid zone of the LP stripper, from which, after releasing steam by flashing, is recycled to the lower zone of the CO_2 absorber.

The lean solution withdrawn from the bottom of the HP stripper feeds the bottom of the LP stripper and then, after releasing steam by flashing, is cooled and recycled to the top of the CO_2 absorber.

The LP stripper operates autogenously with the steam flashed from the incoming lean and semi-lean solutions when they are depressurised flowing from HP to LP stripper.

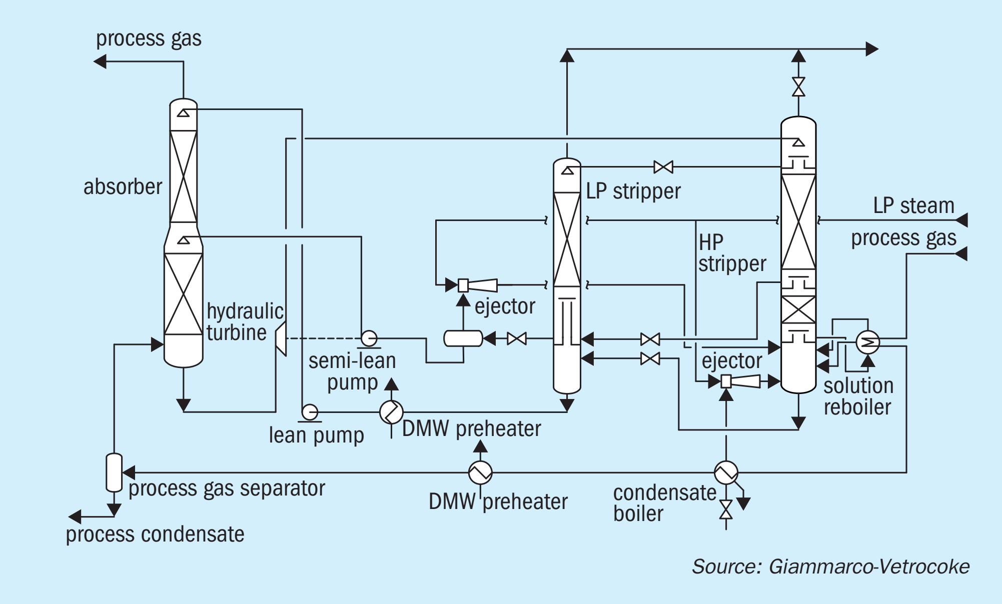
The pressure difference between the HP and LP strippers (typically 0.80-0.90 kg/cm^2) is such that sufficient flashed steam is produced to strip out the CO_2

Fig. 1: **The GV DPR process**



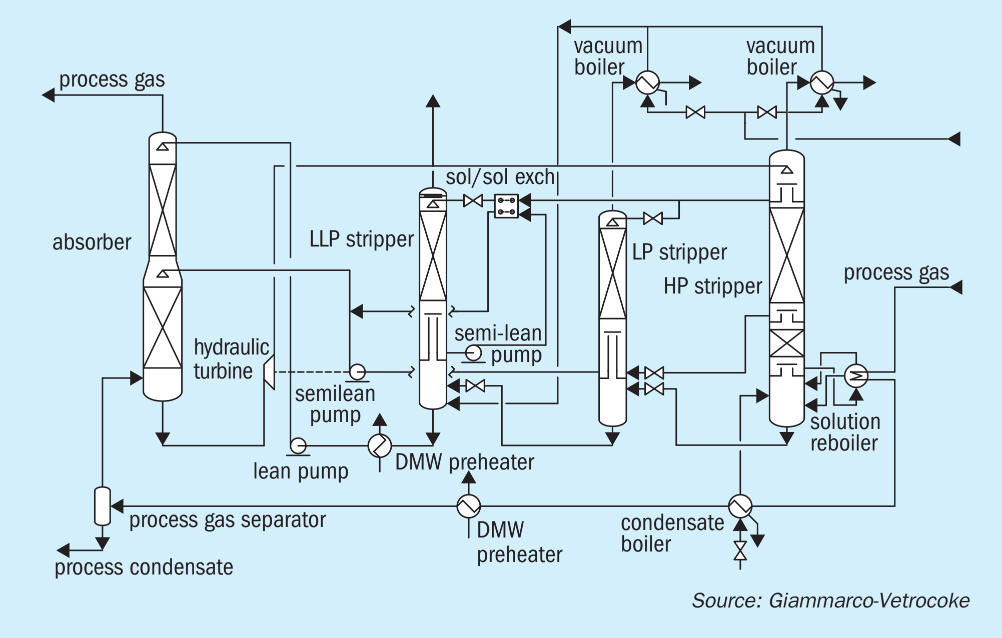
Source: Giammarco-Vetrocoke

Fig. 2: **The GV MFR process**



Source: Giammarco-Vetrocoke

Fig. 3: **The GV VPR process**



Source: Giammarco-Vetrocoke

GV low-energy CO_2 removal unit.

from the rich solution fed to the LP stripper achieving, before the mixing with the semi-lean solution withdrawn from the HP stripper, a similar Fractional Conversion (FC).

Multi Flash Regeneration (MFR)

The GV low-energy MFR process is an improved configuration of the DPR process profitably applied in the revamping of low-energy CO_2 removal processes operating with the multistage flash tank ejector system.

Four CO_2 removal systems based on competing HPC process have been converted to the GV low-energy MFR process.

A simplified process flow diagram of a standard two-stage CO_2 absorption/regeneration system based on the GV low-energy MFR process is shown in Fig. 2.

The MFR process is based on the use of two strippers HP and LP operating at different pressures by retaining the existing flash tank for a final mild flash of the semi-lean solution withdrawn from the LP stripper upstream of the circulation pump.

The final flashed steam is recompressed by a steam ejector and fed to the bottom of the HP stripper.

The MFR process is an attractive revamping option, achieving a 10% energy saving over the DPR process and can be easily achieved at a very low capex by reutilisation of existing equipment only.

Vacuum Pressure Regeneration (VPR)

The GV low-energy VPR process is a substantial evolution of the MFR process where the final flash tank is replaced by a low-low pressure (LLP) stripper operating under light vacuum.

A simplified process flow diagram of a standard two-stage CO_2 absorption/regeneration system based on the GV low-energy VPR is shown in Fig. 3.

The innovative concept of the GV low-energy VPR process is based on the implementation of the final regeneration stripper LLP operated under vacuum which, by reducing the boiling point of the lean solution below 100°C (typically 80-90°C), allows the recovering of heat at low temperature from the top head of the HP and LP stripper to produce LP steam at low thermal level suitable for the regeneration of the lower boiling point of the solution stream fed to the LLP stripper.

By optimising the process parameters, up to 35% of the total amount of the rich solution can be diverted to the final LLP stripper to be regenerated with recovered heat at low thermal level allowing a dramatical saving (up to 40%) of the required regeneration heat supplied through the process gas reboiler(s) connected to the HP stripper.

The GV low-energy VPR process can be operated without any import of LP steam and at a steam to carbon ratio (S/C) in the primary reformer assessed to the lowest figures proposed by the most efficient technologies currently available on the market.

The VPR process is also an attractive and innovative proposal for new grass root ammonia units.

Hybrid Scheme (GHS)

Another revamping scheme proposed by GV, the GV Hybrid Scheme is an innovative CO_2 removal concept based on the integration of physical CO_2 absorption and a chemical CO_2 absorption as shown in Fig. 4.

The CO_2 physical absorption is implemented as a standalone unit upstream of the existing GV low-energy scheme to absorb a portion of CO_2 at higher partial pressure. Typically, 30-35% of the CO_2 is easily absorbed from the process gas and is then stripped by flash only without any need for stripping energy.

The existing GV low-energy system is kept as it is. All the existing equipment is reutilised for the absorption/regeneration of the balance amount (65-70%) of CO_2 contained in the process gas.

Accordingly, the regeneration heat required is drastically reduced to 65-70% of the present specific energy consumption.

The proposed revamp has a good flexibility for further increase of the plant capacity.

The revamp can be implemented in a very short time, typically during a planned plant annual turnaround (ATA), because the added physical absorption/flash regeneration unit can be erected during the operation of the existing CO_2 removal unit and hooked up within the normal ATA time.

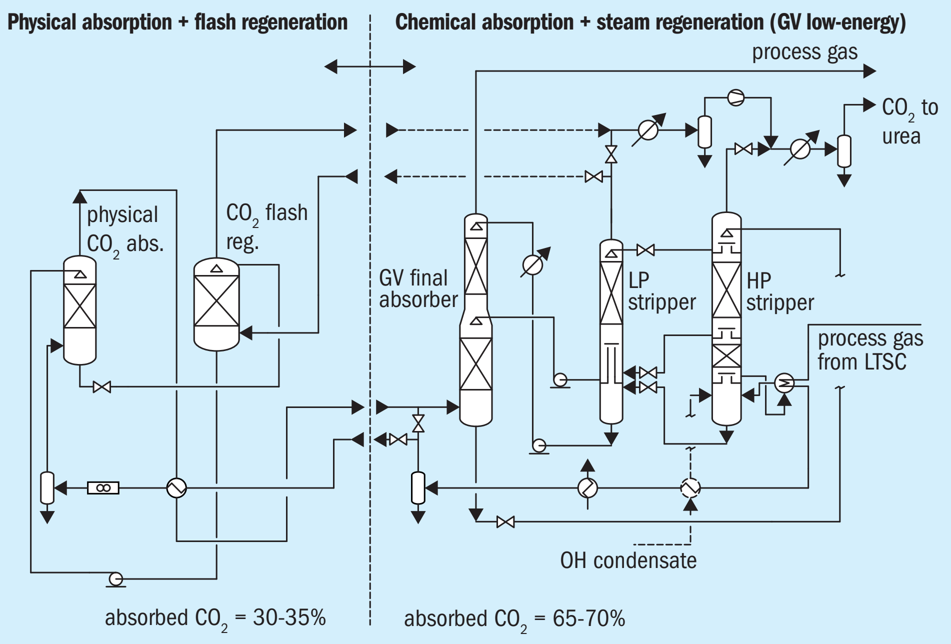
The extent of the flashing regeneration can be controlled according to process requirements by integration with the GV steam regeneration by diverting if required a stream from the top of the LP stripper.

The benefits of the GV Hybrid concept are:

- Installation of a small pre-absorber based on a physical absorption solvent, sized to absorb about 30% of the CO_2 from the process gas.
- The new added physical absorption/regeneration unit can be implemented as a standalone unit upstream the GV CO_2 low-energy scheme.
- The existing equipment of the GV CO_2 low-energy scheme is fully reutilised with little or no modification.
- The tie-ins required for the hook up to the existing GV CO_2 low-energy scheme are very limited.
- The physical solvent is regenerated by flash alone thanks to the high CO_2 partial pressure in/out of the pre-absorber. However, when required, the flash can be easily enhanced by feeding a CO_2 + H_2O stream taken from the GV steam regeneration section.
- The inventory/procurement of the new physical solvent is very limited.

The typical features of the GV low-energy processes are summarised in the Table 1.

Fig. 4: **The GV Hybrid Scheme**



Source: Giammarco-Vetrocoke

Table 1: **Typical features of the GV low-energy processes**

	DPR	MFR	VPR	GHS
Specific regeneration energy, Kcal/Nm³ CO_2	700-800	630-720	450-500	400-500
CO_2 slip, ppm vol	< 500	< 500	< 500	< 500
DMW final pre-heating temperature, °C	115	115	115	115

Source: Giammarco-Vetrocoke

CO_2 footprint reduction in ammonia production

One of the most effective options for carbon footprint reduction in ammonia production is energy intensification of the primary reformer furnace. In this case study, **N. Zečević** of Petrokemija and **O. Brasseur** of BD Heat Recovery show how digital twin modelling and simulation concepts can be combined with proven methods such as pinch analysis and heat exchanger networks to identify and optimise the main bottlenecks in primary reformer furnaces with the main goal of finding the best possible retrofit options for fuel savings and related CO_2 reduction.

In 2020 global ammonia production accounted for around 8.6 exojoules (8.6 x 1,018 J) of final energy consumption (over 95% from fossil fuels) and around 450 million tonnes of CO_2 emissions. This is around 20% of the energy consumption of the wider chemical sector and around 35% of its CO_2 emissions. Measured against the energy sector as a whole, ammonia production accounts for around 2% of final energy consumption and 1.3% of energy sector emissions (including energy-related and industrial process emissions). If the ammonia industry were a country, it would be the 16th largest emitter in the world, between South Africa and Australia.

Ammonia producers face the huge challenge of eliminating CO_2 emissions by 2050, turning near-zero CO_2 emissions production technologies from a theoretical possibility to a practical reality. Emerging near-zero CO_2 emissions production methods include electrolysis, methane pyrolysis and fossil-based routes with carbon capture and storage (CCS). The routes are typically 10-100% more expensive per tonne of ammonia produced than conventional routes, depending on energy prices and other regional factors. Near-zero-emission technologies are not yet available at commercial scale in the marketplace because of constraints related to the level of technical readiness. CO_2 separation is an inherent part of ammonia production today, but permanent storage of the CO_2 is not yet widely adopted. Electrolysis-based ammonia production has already been conducted at scale using high load factor electricity, but challenges remain regarding the use of hydrogen produced from variable renewable energy sources.

The average net energy efficiency for the 35 ammonia plants operated by 15 companies located in the European Union (EU) was 34.8 GJ/t NH_3 (LHV) with an average generation of 1.93 tonnes of CO_2 for each tonne of NH_3 produced. From total CO_2 generation, 1.34 t CO_2/t NH_3 (69.5%) was process-generated CO_2, while the remaining 0.59 t CO_2/t NH_3 (30.5%) was from fuel burning. The main part of the fuel burning is related to the biggest equipment in an ammonia production facility, namely the primary reformer furnace.

The primary reformer furnace, consisting of critical high temperature process equipment, is one the most energy intensive sections of an ammonia plant. It is the biggest energy user since essentially all of the hydrocarbon feed and fuel are consumed in the reforming section. Due to the combustion processes taking place in the primary reformer furnace, it is one of the major factors defining plant energy efficiency and a major source of CO_2 emissions. Possible limitations on energy efficiency can have their origin either in convection coils or in an air preheater.

To overcome this problem and to further improve the overall primary reformer furnace efficiency by recovering excess stack waste heat, ammonia producers can also consider the replacement of old designed combustion air preheaters with a new improved design in order to save energy and reduce CO_2 emissions. This measure in combination with a new medium pressure (MP) steam heat exchange coil was performed in Petrokemija's ammonia plant. This article reflects the operational experience of these two heat exchangers commissioned in early 2021 to provide a transitive technical solution until additional near-zero technologies will be deployed.

The new air preheater is based on modern counter-flow heat-exchange technology rather than the traditional cross counter equipment used in the old KBR plant. This kind of heat transfer allows a much narrower pinch point within a very small space. The performance of this new air preheater has been precisely monitored and the fuel saving with subsequent CO_2 reduction has been carefully measured.

Description and modelling of process modifications

Primary reformer furnace

The primary reformer furnace is the major energy consumer during synthesis gas production, using over 70% of the overall fuel supplied to the ammonia plant. During the design and operational stage of this unit, three aspects are important; the heat consuming reaction of the hydrocarbons with the steam inside of the reformer tubes filled with the nickel catalyst, the heat supply by radiation from the outside to the reformer tubes, and the heat supply by the convection section to the heat exchanger network. The aim is to match all of them properly regarding the desired conversion of the hydrocarbon at an economic steam-to-carbon molar ratio with a reasonable tube wall temperature and with the possibility to maximise the usage of heat from the waste gas. Regarding the arrangement of burners, the primary reformer furnace classifications are as follows: top fired, bottom fired, side fired, and terraced wall fired. In top-fired reformers, as in this case study, the hot waste gas exits at the bottom of the radiation section through tunnels made of brickwork at a temperature of around 1,050°C. Various processes use this heat recovered in the convection section. The major purpose of the primary reformer furnace is to maximise the conversion of hydrocarbons in the reformer tubes with minimum energy demand. At the same time, it is necessary to optimally utilise the remaining thermal energy of the waste gas to preheat process streams and generate steam at different pressure levels before the waste gases exit through the stack. With natural gas firing, a relatively clean fuel free of sulphur compounds, the waste gas outlet temperature can be reduced to a level of 120°C without having to worry about acid dew point (here 92.6°C) issues or a sulphuric acid corrosion attack, respectively. However, it can be a problem for oil-fired furnaces.

Petrokemija operates a Kellogg ammonia plant in Kutina, Croatia. The ammonia plant was originally designed by Kellogg International Corporation with a nameplate capacity of 1,360 t/d and was commissioned in 1983/1984. The primary reformer furnace in original design operates with 198 down firing burners between 10 rows of 520 catalyst tubes, 11 tunnel burners to increase the temperature of the flue gas leaving the radiant section, and 21 superheater burners to maintain the temperature of the high-pressure steam. In parallel with the primary reformer furnace there is an auxiliary boiler fired with five burners to allow for steam production which is necessary to keep the ammonia plant in self-sustaining mode of operation. The primary reformer furnace is designed to attain maximum thermal efficiency by recovering heat in the convection section from the flue gases. The heat is used to preheat the air supplied to the secondary reformer, to preheat the natural gas feed and fuel, to superheat steam, to preheat boiler feed water, to generate high pressure steam and, finally, to preheat the combustion air. The configuration of the primary reformer furnace with cold and hot process streams is shown in Fig. 1.

Analysis, synthesis, and process modelling

The specific motivation for the primary reformer furnace optimisation was an improved utilisation of waste heat from the flue gases. A process analysis was performed which indicated that significant amounts of the waste heat contained in flue gases could be recovered in order to lower the final flue gas exhaust temperature to the design value (or below) of 189°C.

In a joint collaboration between Petroekmija and BD Heat Recovery, a process simulation of the primary reformer furnace was calculated and calibrated with actual operating data. This model was the basis for rating and evaluating the existing equipment, especially the two parallel DEKA® cast iron air preheaters (APH).

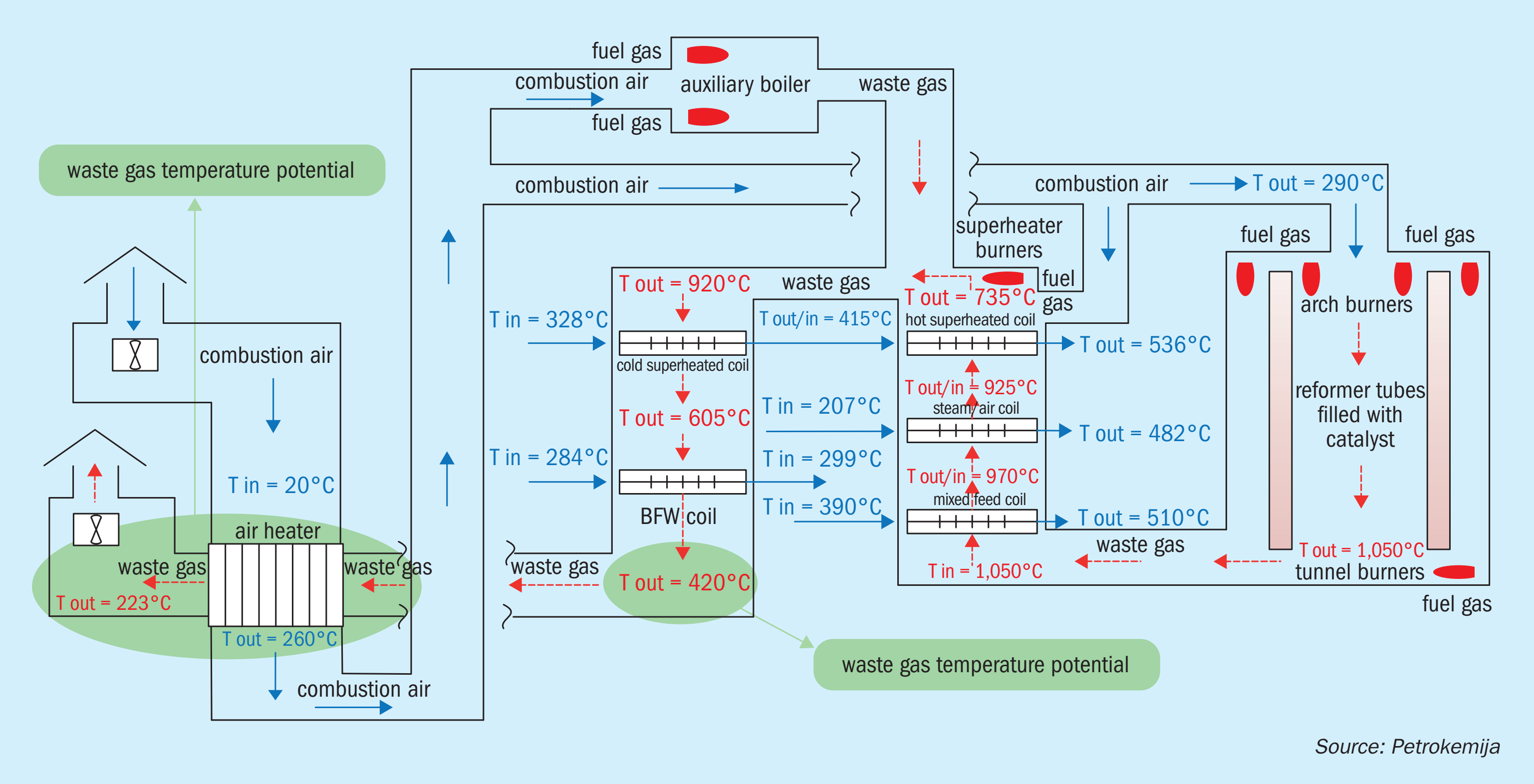
The DCS data readings before the retrofit showed the flue gases at the outlet of the primary reformer furnace still had a temperature of 223°C that could be further reduced in order to maximise performance, improve energy efficiency and reduce CO_2 emissions.

The process simulation included a pinch analysis and a heat exchange network (HEN) design of the primary reformer furnace to ensure further insight for the verification of the long-term energy conservation measures to simultaneously reduce the consumption of natural gas and thus the overall CO_2 footprint of the ammonia plant.

The pinch analysis and HEN synthesis was used to define the minimum energy requirement or maximum energy recovery (MER), respectively. It indicated that the hot flue gas streams with 605°C (after cold superheater coil) and 405°C (after the boiler feedwater coil) were ideal candidates for waste heat recovery. According to the obtained results from the analysis and synthesis procedure, these two temperatures present suitable heat sources for long-term energy conversation measures.

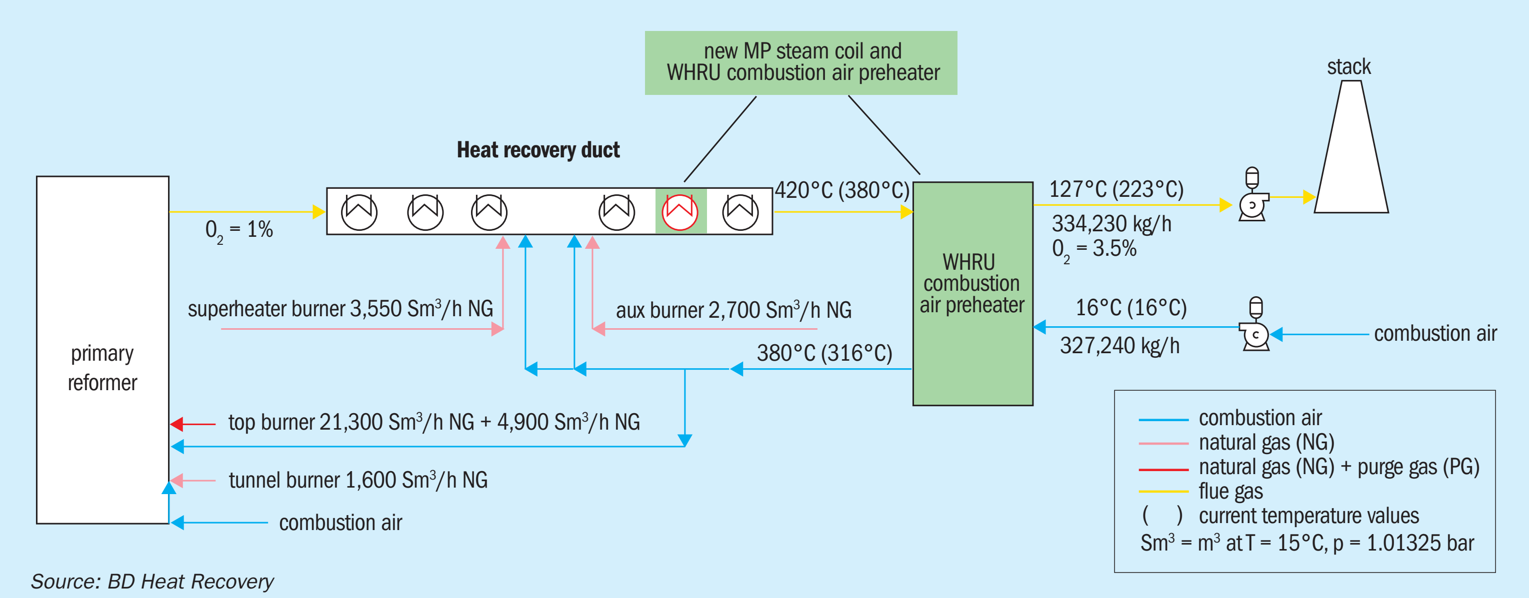
Taking into account both energy saving and capital cost targets, the long-term measures consider modification of the convection section of the primary reformer furnace by adding a new preheating coil for

Fig. 1: **Configuration of top-fired primary reformer furnace with temperature profiles of cold and hot process streams (hourly average results obtained from DCS)**



Source: Petrokemija

Fig. 2: **Block diagram with proposed long-term measures – locations of new MP steam coil and air preheater**



Source: BD Heat Recovery

medium pressure (MP) steam (40 bar) and by replacing the existing air preheater. It was thus concluded that a reduction in fuel gas consumption and CO_2 emission was possible. Based on the MER recovery findings the best location for the new MP steam heating coil was above the existing BFW coil.

At this location, the new heat exchanger can extract the remaining waste heat from the hot stream with the starting temperature of 605°C. This heat exchange coil will preheat the MP steam from the overhead of the process condensate before it mixes with the bulk of process steam from the MP steam header. This new heating coil will handle a mass flow of MP steam (40 bar) of 21.5 t/h with a starting temperature of 249°C thus providing a final steam temperature of 358°C.

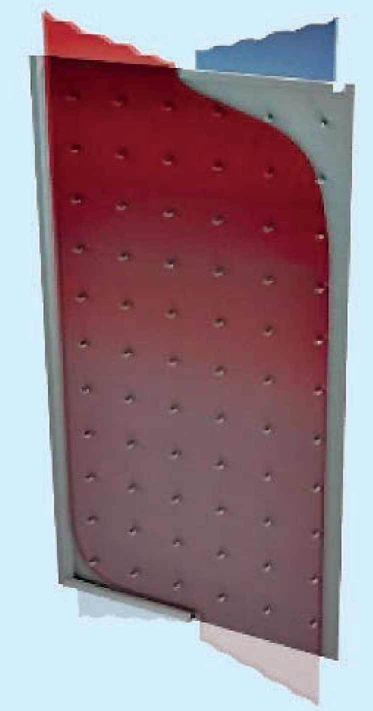
The original design of the combustion air preheater was able to handle waste gas from heavy fuel oil firing. For this reason, the last and therefore coldest set of heat exchange elements comprised glass tubes for resistance against acid corrosion. The future primary reformer furnace operation will be with natural gas firing only, creating an opportunity to improve the performance of the combustion air preheater. Replacement of the low-temperature elements and the glass tubes with high-temperature elements presents the most attractive technical solution to maximise the heat transfer surface. The new air preheater will preheat combustion air from ambient temperature to 380°C, while maintaining the same amount of combustion air in order to satisfy 100% production capacity. Fig. 2 shows the location of the two new heat exchangers in the retrofit design.

The hot stream after installation of the MP steam coil will have a final temperature of 420°C, which perfectly fits the target value of 420°C. The hot stream, after the installation of the new combustion air preheater, will have a temperature of 127°C, which is even better value in comparison with the target value of 120°C, thus increasing safety margins related to acid dew point and corrosion. With the installation of the new heating coils, predicted savings in fuel demand according to the performed modelling procedure will be at a level of 865 m^3/h with directly related reductions of CO_2 emissions by 0.029 t CO_2 for each t of NH_3 produced. This value presents savings of approximately 3% in comparison with the current performance data of the reference primary reformer furnace.

In order to minimise the amount of site work while still reaching the targeted performance, BD Heat Recovery proposed a new APH design based on a counterflow heat exchanger, a design where the flue gas and air streams are flowing vertically opposite to each another as shown in Fig. 3. The proposed design was accepted by Petrokemija.

Counter flow heat exchangers offer the most efficient way of exchanging heat between two gaseous media. The flue gas and air streams flow over the plates in counter flow to one another in a single stage, avoiding the need of a return duct and minimising the pressure drop. The heating surface consists of plates welded together and assembled into plate packs which are then assembled into a casing to form heat exchanger modules (HEM).

Fig. 3: **Counter flow heat exchanger**

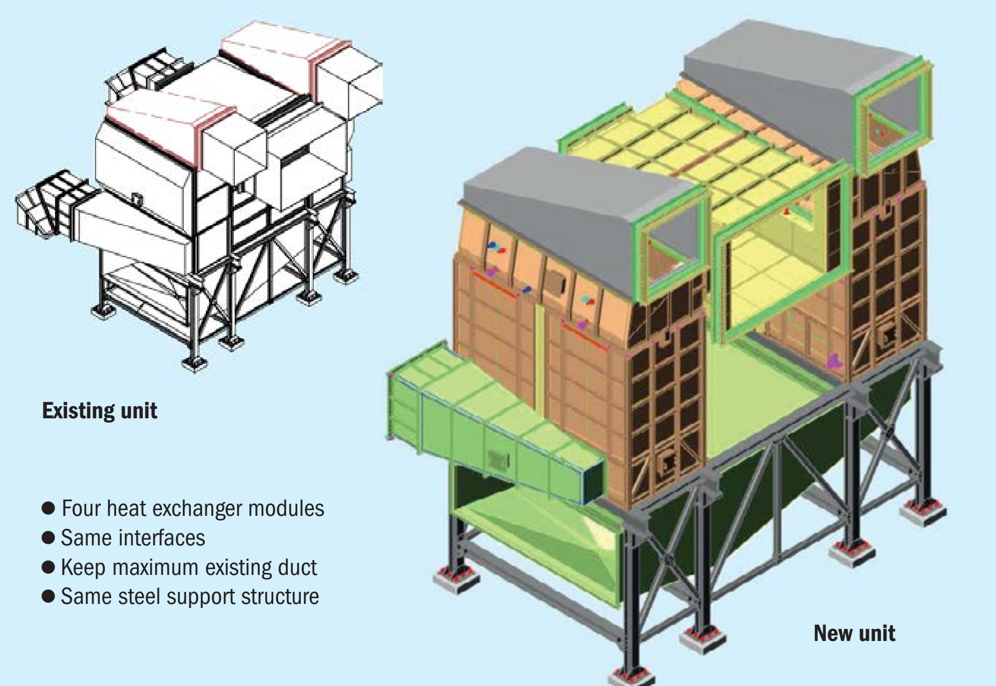


Source: BD Heat Recovery

The hot flue gas enters the unit via distribution hoods above the exchangers and flows vertically downward through the heating plates before being routed away from the unit via lower distribution hoods. The combustion air takes the opposite path, entering via the lower hoods, flowing vertically upward, before being routed away via the top hoods above the unit. Similar to the old APH, the new APH was built as two twin units, each of them made from two large heat exchanger modules.

In order to fully use the available installation space, the width of the plates was

Fig. 4: **New combustion air preheater arrangement**



Source: BD Heat Recovery

also adapted to fit the support structure of the old APH. The material of construction for the heat exchanger plates was SS304 in 0.9 mm thickness.

BD Heat Recovery designed the full system to re-use as much as possible any existing equipment such as flue gas inlet ducts or air inlet ducts. Also, the size of the delivered equipment was maximised to reduce the amount of site work and handling. Each delivered heat exchanger module had a weight of 43 t, was delivered by trailers "on demand" and immediately put into position on the existing steel structure.

Fig. 4 shows the arrangement of the new combustion air preheater which comprises four heat exchange modules, retains the same interfaces, maximises the use of existing duct and keeps the same steel support structure.

Results of retrofit measures

Project execution

After analysis, synthesis and modelling activities, Petrokemija and BD Heat Recovery agreed on contractual obligations in July 2020 regarding the delivery of engineering, procurement, fabrication, and installation of the new APH.

In parallel, Petrokemija initiated, independently from BD Heat Recovery, a procedure for fabrication, delivery, and installation of the new MP steam coil according to Petrokemija's "know-how" engineering services, which was based on the KBR BED package.

During the engineering phase of the project, special precaution has been taken to select suitable construction materials that would maximise the anticipated lifespan of the equipment. Based on the operating experience from both contractual partners, it was estimated that equipment will maintain adequate performance for a period of 15 to 20 years.

The installation procedure of both heat exchangers was done during the planned turnaround in January 2021. Including all necessary pre-assembly activities, the installation procedure took 40 calendar days.

The delivery schedule of the APH heat exchanger was less than six months from signing the letter of intent (LOI) to the final delivery on site.

Start-up procedure and analysis of process performance

The start-up procedure of the ammonia plant commenced on January 30, 2021. Steady-state production was achieved on February 6, 2021.

After stabilisation of the entire ammonia plant production process, a preliminary analysis of the process parameters related to the installation and performance of the new APH and MP steam coil was conducted. The analysis and performance evaluation were performed considering previous process parameters when the ammonia plant was operated with the old APH design and without an additional MP steam coil. The comparison procedure took all relevant process parameters into account, allowing for a precise evaluation of the achieved benefits.

The results showed that the installation of the new APH unit and additional MP steam coil reduced the fuel consumption by 834 Sm^3/h, representing energy savings of 0.51 GJ/tNH_3 and CO_2 emission reductions of 0.026 tCO_2/tNH_3, respectively. The total overall efficiency achieved was about 93%.

The modelling procedure based on pinch analysis and HEN synthesis was in excellent alignment with the practically obtained measured values. The efficiencies for both heat exchangers were also consistent with the designed values, thus satisfying the guaranteed performance predicted by the model.

Flue gas from the primary reformer is a major source of continuous atmospheric emissions from ammonia plants. The quantity of flue gas depends on the design and energy efficiency of the process; the main constituents are nitrogen, oxygen, carbon dioxide, water, carbon monoxide, oxides of nitrogen (NOx), oxides of sulphur (SOx), unburned hydrocarbons and particulates. Of greatest relevance to an ammonia plant is the NOx, which may be formed by the combustion of materials containing nitrogen or by reaction of atmospheric nitrogen and oxygen at high temperatures. In addition, due to higher temperature of the combustion air, the emission of NOx will increase in these favourable process conditions. This observation was made after the installation of the new APH heat exchanger. According to predictions from the model, one drawback of the project was the resulting higher emissions of NOx due to the higher temperature of combustion air.

In the event, after installation of the new APH heat exchanger the NOx emission increased by approximately 100 mg/Nm^3. Taking into account that even before installation of the new APH heat exchanger the NOx emissions were above the allowed limit of 230 mg/Nm^3, the next step will be the replacement of the originally installed arch burners by low-NOx burners.

Conclusion

This case-study demonstrated that before implementation of emerging near-zero technologies it is worthwhile for ammonia producers to consider implementation of proven technologies such as pinch analysis and HEN integration for designing retrofit options to conserve energy and reduce CO_2 emissions. ■

Editor:
RICHARD HANDS
richard.hands@bcinsight.com

Technical Editor:
LISA CONNOCK
lisa.connock@bcinsight.com

Publishing Director:
TINA FIRMAN
tina.firman@bcinsight.com

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Sales/Marketing/Subscriptions:
MARLENE VAZ
Tel: +44 (0)20 7793 2569
Fax: +44 (0)20 7793 2577
marlene.vaz@bcinsight.com
Cheques payable to BCInsight Ltd

Advertising enquiries:
TINA FIRMAN
tina.firman@bcinsight.com
Tel: +44 (0)20 7793 2567

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China Works, Unit 102,
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