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Number 385 September | October 2023

# nitrogen+syngas

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## Plant digitalisation
## Demand for syngas-based fuels
## African fertilizer update

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*Cover: Ready for takeoff.*
*Frank Peters / shutterstock.com*


# nitrogen+syngas

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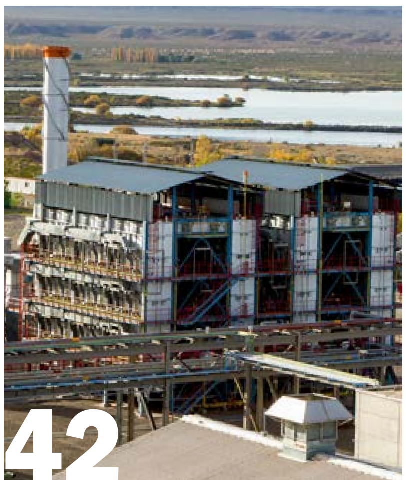
**NUMBER 385**
**SEPTEMBER | OCTOBER 2023**


**18**

## Syngas-based fuels

**Rapidly expanding demand for green derivatives**



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BCInsight

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# End of an era


> **Billingham was the birthplace of the UK ammonia industry...**

The closure of CF Industries' ammonia plant at Billingham, Teesside (see Industry News, page 8) marks the end of a long era for UK fertilizer manufacture. The facility was the last operating ammonia plant in the country, following CF's decision to permanently close its site at Ince in Cheshire in June last year. Going forward, Billingham will now rely on imported ammonia as a feedstock to run the nitric acid and 625,000 t/a ammonium nitrate plants on the site.

The decision is an economic one, of course. CF has long cited high UK natural gas prices as a barrier to competitiveness. Both sites were idled in September 2021 when gas prices soared, and only a government subsidy to secure $CO_2$ supplies for the food and drinks industry persuaded CF to reopen the Billingham ammonia plant. Billingham was the larger and more efficient plant, but a 2021 strategic review by CF found that ammonium nitrate sales to UK customers had fallen by almost 30% since the 2017-18 season due to intense competition from lower-cost imports, forcing CF to sell surplus AN on the international market at "unsustainably" low margins.

It is a sad end to a long history of ammonia production at the site. Billingham was the birthplace of the UK ammonia industry. It was established in the wake of the First World War to make synthetic ammonia for explosives, using the (at the time) novel Haber-Bosch process. The government sold the site in 1919 to Brunner-Mond, who developed the ammonia plant based on a copy of the BASF process at Oppau, using coke oven gas as a feedstock. Operations began at what was then a 24 t/d plant in December 1924, and three more units were completed by 1929 to take output at the site to just under 400 t/d of ammonia. In the meantime, Brunner-Mond was part of a major merger in 1926 with Nobel Explosives, the United Alkali Company and the British Dyestuffs Corporation, all of whom had a degree of shared ownership, to form Imperial Chemical Industries (ICI).

ICI improved the process by switching to a gasified oil and then later a steam reformed naphtha feed, but oil gasification necessitated the construction of an air separation unit which proved troublesome, and led to the first symposium on ammonia safety (a report on the most recent one can be found on pages 26-28) in 1955. In 1963 ICI developed a 360 t/d single stream naphtha fed ammonia plant at Severnside, but to move to larger plant scales it licensed MW Kellogg technology to build two 900 t/d plants at Billingham. The old steam reformers from the former ammonia plants were used for the Low Pressure Methanol process at Billingham in 1966, a 600 t/d plant. ICI also made developments in catalysts and ammonia process engineering at Billingham, eventually developing their own ammonia process, the Leading Concept for Ammonia, as well as later, in conjunction with Uhde, the dual pressure process.

In the late 1960s, ammonium nitrate capacity was added at the site, with a second AN plant being built in the 1970s. By now natural gas from the North Sea was being landed in the UK, and the Billingham plants were converted from naphtha to gas feed, and a fourth, larger (1,500 t/d) ammonia plant built – it is this plant that is now being retired. The last major investment at Billingham was a large nitric acid plant with a capacity of 1,000 t/d that started operation in 1985.

However, into the 1990s, the site was beginning to feel the cold winds of international competition, while gas supply from the North Sea was starting to decline. The three low pressure ammonia plants were shut down, as well as the oldest ammonium nitrate plant, and methanol production. ICI itself was broken up, to become, amongst other units, ICI Explosives (now Orica), ICI Katalco (now part of Johnson Matthey) and ICI Fertilizers, which was bought by Terra Nitrogen from the US in 1997. In the 2000s, Terra combined with Yara to produce the GrowHow UK business, which was in turn sold to CF Industries in 2010.

The closure of the final ammonia plant at Billingham is a symptom of the pressures that the wider European nitrogen industry faces, in the wake of the end of gas supplies from Russia and a shift towards more expensive LNG imports. How much of the industry will weather these current storms remains very much an open question. ■

*Richard Hands, Editor*

# Price Trends

**Market Insight courtesy of Argus Media**

## NITROGEN

In ammonia markets, the rate of buying inquiries has been rising, supporting a slightly firmer price environment, but producers report that they are sold out across most key supply regions. The limited spot f.o.b. availability has stalled trade, with only one sale confirmed from Bangladesh to India over mid-August. Indian buyers are looking for prompt cargoes, but most Middle East producers have nothing to offer. The supply outlook could improve in the weeks ahead as suppliers ramp up production where possible, but suppliers are in no rush to sell until a clearer picture of demand emerges for September.

Recent market drivers include:

- Limited supply – despite the steady rise in inquiries, sellers have very little additional ammonia to offer following the raft of production outages seen in the market over the past few months.
- European production rates – European plants are weighing up production strategies for the months ahead, with weak ammonia demand and high production costs creating a difficult decision for most producers in the region.
- Domestic Chinese markets – domestic prices surged in both the north and south in August, driven mainly by shutdowns of ammonia facilities and delays in start-up following plant turnarounds
- Indian buying – Marubeni has sold an 8,400 tonne Bangladeshi cargo to IFFCO for September delivery to Paradip. Marubeni has chartered the *Camila B* for the voyage.

Urea prices mostly fell again in mid-August, but the main development was the massive commitment of Chinese urea into India. India's IPL has confirmed purchase of 1.76 million tonnes of urea, of which more than 1 million tonnes is currently set to load from Chinese ports. This far outpaced expectations, and has exacerbated already bearish sentiment in most market players. By committing so much urea, China surpassed pre-tender expectations by around 80%, and with production margins currently high in most regions, the market will likely soften if exports continue at this pace.

Otherwise, market activity was generally slow, as importers and traders mostly waited for the resolution of the Indian urea tender before committing to new deals. Urea prices fell in most markets – by $15/t in the US, $30/t in Brazil, $20/t in Europe and $20/t in southeast Asia – under pressure from low demand and with traders increasingly set on securing liquidity through short-sales.

Fundamentals remain weak. Neither grain nor energy markets are providing, in the short-term, much support for either sentiment or fundamental market balance. ■

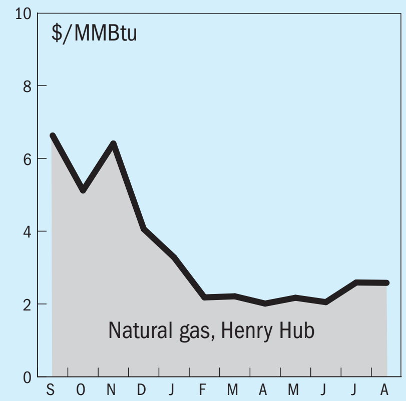
Table 1: **Price indications**

| Cash equivalent | mid-Aug | mid-Jun | mid-Apr | mid-Feb |
|---|---|---|---|---|
| **Ammonia** ($/t) | | | | |
| f.o.b. Black Sea | n.m. | n.m. | n.m. | n.m. |
| f.o.b. Caribbean | 260-310 | 270-340 | 330-400 | 550-590 |
| f.o.b. Arab Gulf | 290-320 | 210-260 | 250-320 | 570-600 |
| c.fr N.W. Europe | 380-410 | 355-365 | 385-410 | 620-660 |
| **Urea** ($/t) | | | | |
| f.o.b. bulk Black Sea | 340-400 | 220-285 | 250-335 | 320-380 |
| f.o.b. bulk Arab Gulf* | 346-400 | 240-316 | 300-375 | 300-355 |
| f.o.b. NOLA barge (metric tonnes) | 390-400 | 294-310 | 360-385 | 310-335 |
| f.o.b. bagged China | 370-395 | 270-340 | 330-370 | 355-410 |
| **DAP** ($/t) | | | | |
| f.o.b. bulk US Gulf | 573-600 | 468-506 | 627-699 | 646-678 |
| **UAN** (€/tonne) | | | | |
| f.o.t. ex-tank Rouen, 30%N | 302-324 | 253-283 | 275-310 | 392-403 |

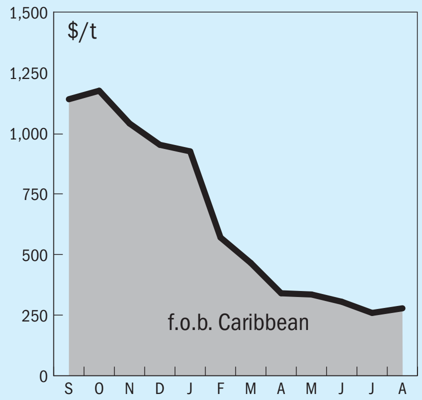
*Notes: n.a. price not available at time of going to press. n.m. no market. * high-end granular.*

## END OF MONTH SPOT PRICES

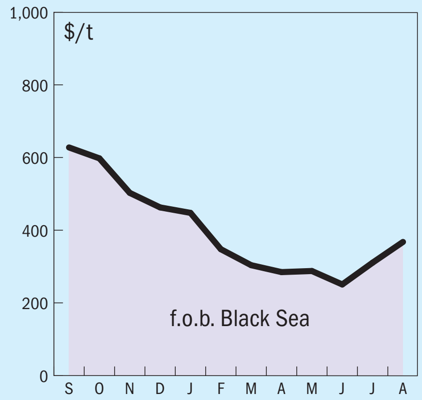
### natural gas



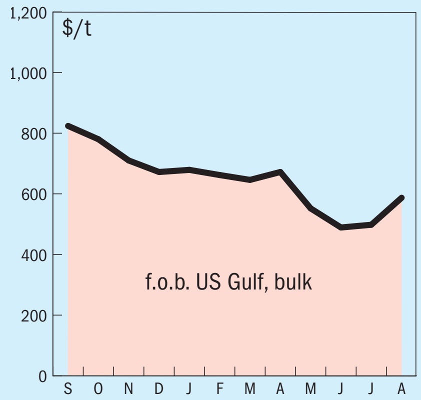

### ammonia




### urea




### diammonium phosphate









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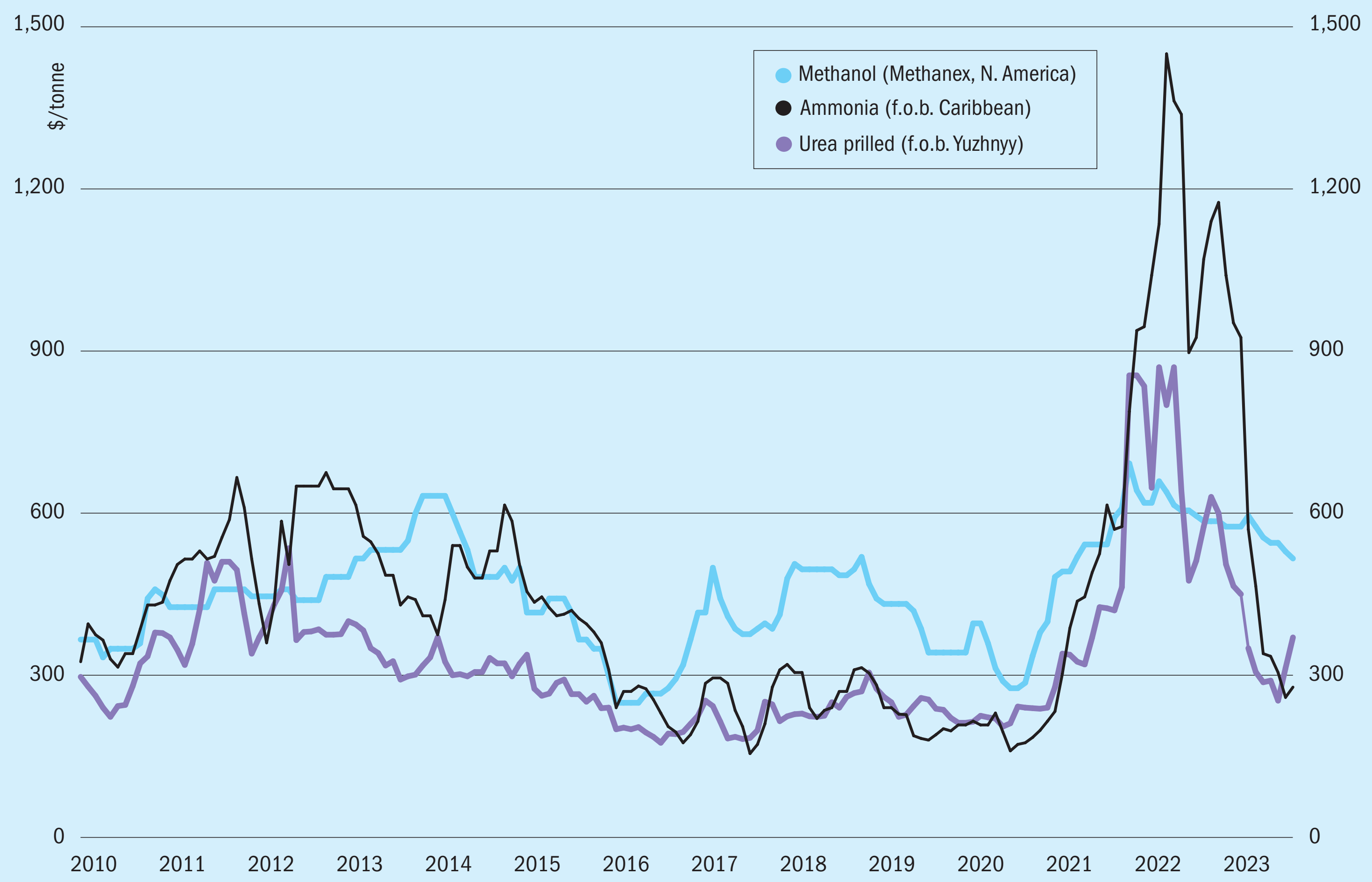
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52

# Market Outlook

**Historical price trends** $/tonne




*Source: BCInsight*

## AMMONIA

- Ammonia prices have now dropped by about 50% from their highs a year ago. Gas prices have fallen, particularly in Europe, and peak fertilizer application season is over in Europe and North America, leading to slackening demand., leading to slackening demand.
- High gas storage levels and supply diversification have reduced the risk of renewed stress in European gas markets in spite of some jitters over strikes in the Australian LNG industry. There is ample supply available from the US, though Trinidad continues to struggle with gas shortages.
- While there is some short-term firming to market sentiment, some of it caused by the end of the Black Sea grain export deal, and a general consensus that prices may have bottomed out, the global ammonia market still remains in a very cautious state, with neither buyers nor sellers wanting to instigate a spike in pricing which may cause further demand destruction.

## UREA

- Urea markets reached a low point in June and have been on something of a bull run since then, driven by supply cutbacks in Southeast Asia, Nigeria and Russia, as well as China's absence from international trade.
- These trends now appear to be reversing, with China selling a record volume to India and a return towards normal supply from Nigeria and Southeast Asia. As a result, the urea market is heading back towards a surplus of urea and prices have peaked. Chinese export controls have been eased slightly.
- There has been some support from buying in Brazil, but looking forward, demand looks unexceptional and sentiment among both traders and importers appears to be generally bearish.

## METHANOL

- Methanol bunkering operations have taken place in both Egypt and Singapore, though shippers have warned that it could take years for green methanol supply to meet demand. OCI Global, which is supplying green methanol for Maersk, has had a difficult quarter due to lower methanol prices.
- China has provided a floor for methanol prices over recent weeks and months, with coal-based methanol production the marginal producer. Chinese demand has been lacklustre as the Chinese economy remains sluggish. At the same time, new capacity coming on-stream within China is contributing to oversupply, and in the absence of global demand may impact upon global pricing.
- There is also new capacity coming onstream in Iran and the Geismar 3 Methanex plant in North America.
- In the longer term demand is still increasing faster than methanol supply, but in the second half of 2022 low gas prices and ample supply may see prices lower.

# Nitrogen Industry News

## UNITED KINGDOM

## CF Fertilisers to permanently close ammonia plant at Billingham

CF Fertilisers UK Limited, a subsidiary of CF Industries, says that it plans to permanently close the ammonia plant at its Billingham fertilizer complex in order to secure the long-term sustainability of its business in the UK. The Company intends to continue to produce ammonium nitrate (AN) fertiliser and nitric acid at the Billingham site using imported ammonia, as it has for the last 10 months following its decision to temporarily idle the plant in August 2022.

CF judges that producing ammonia at Billingham will not be cost-competitive for the long-term compared to importing ammonia, due primarily to projected high natural gas prices in the UK relative to other regions, and the impact of carbon costs. Additionally, shutdowns in recent years of industrial customers' UK operations that had consumed significant ammonia volumes for their businesses have created a supply-demand imbalance for ammonia production at Billingham. The company believes that there is "ample" global availability of ammonia for import, including from CF Industries' North American production network.

Closing the plant, the last ammonia unit operating in the UK, could result in up to 38 redundancies at the site, in relation to which CF says it will be entering into the required collective redundancy consultation process with its recognised union, Unite, and elected employee representatives. The company anticipates that some of the proposed redundancies might be avoided by redeployment opportunities. ■

### Study highlights fertilizer nitrogen losses to atmosphere

Some nitrogen fertilizer types spread on UK farmland are ending up in the atmosphere, with the worst offenders emitting on average 18% of the applied nitrogen fertilizer as ammonia gas into the air according to a study by researchers from the University of Birmingham. The study reviewed ammonia emissions from different synthetic nitrogen fertilisers. They found that uninhibited urea fertilisers, usually used to increase crop production, were the worst culprits for ammonia emissions. In some cases, the amount of fertiliser that ended up emitted into the atmosphere was 77%. Emissions from these types of fertilisers often exceed the expected current maximum emissions factor of 8% being used to estimate national ammonia emission inventory from agriculture. The data suggest that 34% of synthetic non-urea fertilisers studied are exceeding these thresholds, and in the UK, agriculture is the dominant source of ammonia emissions, accounting for around 85% emission annually.

Professor Sami Ullah from the University of Birmingham and senior author of the paper said: "Among plant available nitrogen species, ammonium in soils is a key nutrient for crops upon which our food security depends. The uptake efficiency of crops for nutrients including ammonium is relatively poor, ranging from 20% to 50% on average globally, so a substantial amount of the applied fertilizer is prone to losses from soils including ammonia volatilization into air."

The research team noted that urease and combined urease and nitrification inhibitors significantly reduced emissions, by 74.5% and 70%, respectively, compared to uninhibited urea fertilizers.

### Partnership for ammonia cracking technology

South Korea's power plant builder Doosan Enerbility Co. says that it has signed a research and development agreement with UK-based Johnson Matthey for ammonia cracking technology. JM plans to carry out studies into the development of an ammonia cracking model that could be paired with a hydrogen-fuelled power plant by the end of this year. The two companies intend to co-develop an integrated design technology connecting the ammonia cracking procedure with hydrogen combined power generation. They aim to apply this innovative approach to future hydrogen-based power production.

## CANADA

### Topsoe to supply ammonia loop for green hydrogen plant

Topsoe has signed an agreement with World Energy GH2 to license Topsoe's dynamic ammonia loop technology for Canada's largest renewable hydrogen projects, Project Nujio'qonik. Located in the Bay St. George region of Newfoundland and Labrador, Project Nujio'qonik was announced by World Energy GH2 in spring 2022 with an intended investment of US$12 billion to produce renewable hydrogen to decarbonize the hard-to-abate sectors globally. World Energy GH2 will supply 250,000 t/a of renewable hydrogen to global markets using wind power for production on the site, which is expected to begin producing hydrogen in 2025. Topsoe's ammonia loop technology will be used to generate up to 1,650 t/d of renewable ammonia on the site.

Henrik Rasmussen, Managing Director, the Americas, Topsoe, said: "We are very pleased to support World Energy GH2 in one of the world's first-to-market renewable hydrogen and ammonia production projects, highlighting our commitment to lead the development of the renewable hydrogen industry… we look forward to working with World Energy GH2 to deliver on its targets for production in 2025."

### Solex Thermal Science Inc. acquires Econotherm

Calgary-based Solex Thermal Science says that it has acquired Econotherm, a UK-based leader in waste heat recovery technology. Solex says that the acquisition expands its capacity to help customers reduce the primary energy consumed to produce industrial goods. The company has expertise in solid, liquid and gas heat exchange.

Econotherm is a leader in the design and manufacturing of heat pipes and exchangers for industrial waste heat recovery. The company focuses on difficult to recover heat that includes hot and/or dirty exhausts in industries such as automotive, metals, construction, food, mining, oil and gas, power generation and pharmaceutical. The company is also at the forefront of heat pipe research and development, having been recognized with green technology awards from Shell Oil and LLGA City Smart for its leading-edge developments.

"Solex's commitment to making a sustainable impact within the industries it operates aligns with our company's trajectory of being a world leader in today's circular economy. Having the support of Solex will allow us to expand the reach of our patented heat recovery solutions and create a positive impact in the world around us," said Mark Boocock, owner of Econotherm.

## AUSTRALIA

### Feasibility study on renewable ammonia

thyssenkrupp Uhde has been engaged by Ark Energy Corporation on behalf of the Han-Ho $H_2$ consortium to deliver a feasibility study to support the development of the Han-Ho project. The study will involve a comprehensive techno-economic analysis of the power-to-ammonia value chain using thyssenkrupp Uhde's proprietary RHAMFS® methodology. The goal is to evaluate the influence of various factors on the overall cost-effectiveness of the green ammonia plant and explore multiple scenarios to identify optimal plant designs. thyssenkrupp Uhde will also provide technology, engineering services and integration know-how for the green ammonia facility based on its own ammonia synthesis technology.

Thore Lohmann, Executive Director Fertilizer & Methanol at thyssenkrupp Uhde, said: "With new partnerships like this one with Ark Energy, we are building a sound business case for this groundbreaking green energy project and taking an important step towards climate-friendly production of green ammonia."

### Pupuk Kaltim reportedly in talks over Incitec Pivot purchase

Indonesian state-owned fertiliser company PT Pupuk Kalimantan Timur is reportedly in talks to acquire the fertiliser business of Incitec Pivot Ltd. Incitec Pivot has long sought to separate its explosives business, Dyno Nobel, from Incitec Pivot Fertilizers. The company has been close mouthed about the potential deal, but has said that it has "received a number of approaches for the potential acquisition of its fertilisers business".

Outside of the ammonium nitrate explosives plant at Moranbah, Incitec Pivot's main nitrogen asset is at Gibson Island near Brisbane. Gibson Island has the capacity to manufacture 300,000 t/a of ammonia, 280,000 t/a of urea and 200,000 t/a of ammonium sulphate. It also has a major phosphate hub at Phosphate Hill, Queensland, and superphosphate production at Geelong. Incitec Pivot sold its 880,000 t/a Waggaman ammonia plant in Louisiana in March to CF Industries. Pupuk Kaltim has five ammonia plants with a capacity of 2.7 million t/a and five urea plants with a combined capacity of 3.4 million t/a.

### Aboriginal partnership to develop green ammonia

A clean energy consortium is aiming to use solar energy in Western Australia to power electrolysers to produce 50,000 tonnes of green hydrogen a year. The East Kimberley Clean Energy Project would involve a solar farm development on approximately 2,000 hectares of land owned by MG Corporation near Kununurra, a town in far northern Western Australia located at the eastern edge of the Kimberley region. The solar energy produced (approximately 1 GW) would be combined with hydroelectric energy from the existing 30-MW Ord Hydro Power Plant at Lake Argyle (approximately 70 kilometres south of Kununurra) to power electrolytic hydrogen production facilities co-located with the solar farm development. Fresh water for the electrolysis process would be sourced from Lake Kununurra.

The hydrogen would be transported approximately 120 kilometres by buried pipeline to Balanggarra Country in Wyndham on the North-Western Australian coast, where it would be used in the manufacture of 250,000 t/a of renewable ammonia. The ammonia would then be used in the local agriculture and mining industries, as well as exported to nearby Asian markets. The project proponents have indicated the project would utilise existing infrastructure in the region including electricity transmission lines, roads, airport, and the Port of Wyndham.

The project developers are a new company – Aboriginal Clean Energy – set up via three indigenous owned entities; MG Corporation, the Kimberley Land Council and Balanggarra Aboriginal Corporation. Each will each have an initial 25% share in the company alongside climate crisis investment and advisory firm Pollination. A final investment decision is expected in the latter part of 2025 with post-commissioning hydrogen production operations scheduled for 2028-29.

## NETHERLANDS

### Collaboration on floating green ammonia plant

The OFFSET consortium, led by Netherlands-based project developer SwitchH2, and including partners BW Offshore Norway, MARIN, TU Delft, and Strohm, is partnering with thyssenkrupp Uhde on the development of an industrial scale floating green hydrogen and ammonia project, based on the proven concept of a floating production and offloading vessel (FPSO). In March 2023, SwitchH2 announced it had received Approval in Principle from DNV on its design principles for an FPSO which will produce ammonia offshore solely from renewable sources of energy. As part of the Approval in Principle process, BWO developed the topside arrangement, hull, and mooring system design for the FPSO with the engagement of thyssenkrupp Uhde via a technical concept study for the ammonia plant. The project consortium has received a grant of euro 3 million from the Dutch government in support of the project, which aims to have a floating hydrogen and/or ammonia production and storage facility connected to an adjacent wind farm by 2027.

"The green transformation is the biggest challenge humanity has ever faced, and we are proud to be one of the transformation enablers with our solutions and innovations at thyssenkrupp Uhde", said Dr. Cord Landsmann, CEO thyssenkrupp Uhde. "To stop climate change, we have developed technologies that make sustainability feasible for businesses, reduce the carbon footprint of industrial value chains, and accelerate the growth of renewable energy. This is exactly what motivated us to develop our green ammonia technology."

## GERMANY

### BASF splits off mobile emissions catalysts and precious metals services businesses

BASF has completed the carve-out of its mobile emissions catalysts and precious metal services businesses. The new company will be called BASF Environmental Catalyst and Metal Solutions (ECMS), and has global operations in 15 countries with more than 4,500 employees and 20 production sites. The ECMS business will continue to be reported as part of the Catalysts division in BASF's Surface Technologies segment.

ECMS produces mobile emission catalysts for gasoline, diesel and off-road vehicles, motorcycles, small engines and other applications. It is also a prominent supplier of precious metal products, trading and services and is the largest recycler of precious metals from spent automotive catalysts. The company's urban mine refines platinum group metals (PGMs) containing materials to a purity exceeding commercial grade industry standards that are fed back into manufacturing of new automotive and chemical catalysts. The recycling of precious metals emits 97% less $CO_2$ than refining primary or mined PGMs.

### Public hearing on new Hamburg ammonia terminal

Hamburg-based energy company Mabanaft says that it has reached another milestone in the planned construction of its ammonia import terminal in the port of Hamburg after presenting the necessary construction measures to Hamburg's environmental authority BUKEA (Environment, Climate, Energy and Agriculture Authority). The plans include building a tank for storing liquid ammonia at Mabanaft's existing Blumensand Tank Terminal. A HAZID risk analysis has also been successfully completed, examining possible nautical risks in the operation of the terminal as well as in the arrival and departure of very large gas carriers (VLGCs) at the terminal operating site.

Volker Ebeling, Senior Vice President New Energy, Chemicals and Gas at Mabanaft said: "The ammonia import terminal is the first step in building New Energy Gate, a terminal for sustainable hydrogen products that will enable Hamburg to import large amounts of climate-friendly energy."

## UNITED STATES

### MAN to supply compressors for green ammonia plant

Air Products and Chemical has awarded MAN Energy Solutions an order for six air compressor trains for use in an air separation unit in its Clean Energy Complex in Darrow, Louisiana. The complex will produce more than 750 million scf/d of blue hydrogen for Air Products' customers, which will be transported along a 700 mile pipeline on the US Gulf Coast, as well as blue ammonia for global hydrogen markets such as the transportation and mobility sectors. The facility will also capture and permanently store about 95% of its $CO_2$ emissions – over 5 million t/a – equivalent to the annual $CO_2$ emissions from more than 1 million passenger cars.


PHOTO: THYSSENKRUPP UHDE

*MAN RIKT compressor train.*

MAN's air-compressor trains will be deployed at the core of Air Products' air-separation unit where air will be separated into its primary constituents of oxygen and nitrogen. Both gases are needed for the production of hydrogen and ammonia.

Tamer Bayri, Head of Sales & Project Management Industrial Gases at MAN Energy Solutions, said: "We are thrilled to work with Air Products on this forward-looking project. This order reinforces our commitment to support our customers on their journey towards a sustainable energy-future with our expertise and state-of-the-art technology solutions. Our compressor systems are designed to meet the demanding needs of crucial air-separation processes exactly like this one in Darrow."

The Clean Energy Complex is expected to commence commercial operation in 2026.

### Nutrien halts work on low-carbon ammonia plant

Fertiliser producer Nutrien says that it has suspended work on a planned low-carbon ammonia project in Geismar, Louisiana. The company has called a halt to the project because of rising capital costs and "continued uncertainty on the timing of emerging uses for clean ammonia". It said it is prioritising "other capital allocation alternatives". Projected costs of around $2 billion increased by "around 15-20%" compared with initial estimates, according to Nutrien's president and chief executive Ken Seitz.

Nutrien had been aiming to take a final investment decision in 2023, with construction expected to begin in 2024 and "full production" to start in 2027. While the firm will continue to engage with partners on the technology and downstream side regarding the project and "evaluate opportunities", the decision to suspend the plans for now will mean a delay of "at least 24 months", Nutrien's president for nitrogen and phosphate Trevor Williams said. Provisions in the US' Inflation Reduction Act which sharply lift tax credits for sequestering $CO_2$ provide "a big improvement in terms of being able to try and justify" projects like the one planned in Geismar, Williams said. But this still "didn't get [the firm] over the hurdle in terms of the economics of the project at this point," he said.

## MEXICO

### Hy2gen announces plans for a renewable ammonia plant

Germany's Hy2gen says that it is planning to construct a 200 MW renewable ammonia production plant in Campeche, Mexico. The project, named MARENGO, is expected to initially produce 180,000 t/a of renewable ammonia for customers in the European Union. A cooperation agreement has been signed with local development partners, and the project will now move on to feasibility studies and FEED studies, during which essential construction data and information on the operation of the production plant will be collected. These studies are expected to be completed after 24-36 months. Assuming that the project moves forward, construction of the plant will then begin, with first production expected by 3Q 2028.

"MARENGO will play an important role in the production of renewable ammonia for the European Union," said Hy2gen CEO Cyril Dufau-Sansot. "This is mainly due to the ideal conditions at the site location, such as constant wind and many hours of sunshine. MARENGO's electricity needs will therefore be secured by a 415 MW wind farm and a 230 MW solar farm."

## BRAZIL

### Unigel idles Laranjeiras plant

On August 11th Unigel indefinitely suspended operations at its nitrogen fertilizer plant in Laranjeiras. According to the company, the decision was taken due to the high price of natural gas. Unigel says that it has made efforts to make the production of nitrogen fertilizers viable and "continues to establish dialogues with agents and public authorities and negotiate conditions with the main gas suppliers, in favour of solutions for the challenging situation that surrounds the chemical industry and the national production of fertilizers". The plant has a production capacity of 650,000 t/a of urea, 450,000 t/a of ammonia and 320,000 t/a ammonium sulphate, making it the largest national producer of nitrogen fertilizers remaining in Brazil after the closure of Petrobras' plants over the past few years.

## AFRICA

### Stamicarbon to build two 4000 t/d urea plants

Stamicarbon says that, following last year's award of a license and process design package to design a 4000 t/d urea melt and granulation plant, it has secured a second license contract for an identical capacity and design plant with the same customer at an undisclosed location in sub-Saharan Africa. The bundle includes the correspondent proprietary equipment contracts to deliver the high-pressure equipment and the fluid bed granulation unit for the two trains of the plant. The world-scale integrated ammonia and urea complex will thus have a capacity of 4,600 t/d of ammonia and 8,000 t/d of urea in two production trains. This grassroots project, which is expected to be operational in 2026, aims to address the growing demand for high-quality fertilizers in the region and, thanks to the plant's strategic location, globally.

The urea plants will use Stamicarbon's proven pool condenser with MP Flash design bringing significant energy consumption reduction, and the granulation plant will use Stamicarbon's fluid bed granulation technology. The plant design includes an integrated off-gas acidic scrubbing system that reduces ammonia emissions to a minimum, and salts reworking technology, an innovative concept that eliminates the waste water stream. The high-pressure equipment for both synthesis sections will be in durable duplex stainless steel Safurex®.

"We are glad to have secured this licensing and proprietary equipment contracts for this grassroots complex that will support agriculture, create local jobs and address the growing demand for high-quality fertilizers across the Sub-Saharan region and other parts of the world. We look forward to building a long-term relationship with our new customer over the coming years and watching this exciting project grow," says Pejman Djavdan, CEO of Stamicarbon.

## FRANCE

### Air Liquide and KBR to offer low-carbon ammonia and hydrogen technologies

Air Liquide, through its Engineering & Construction Division, will work with KBR to offer fully integrated low-carbon ammonia solutions based on autothermal reforming (ATR) technology. Air Liquide is a world leader in ATR technology, one of the most suitable solutions for large-scale production of low-carbon hydrogen, which is then combined with nitrogen to produce low-carbon ammonia using carbon capture techniques. These solutions will be integrated with KBR's ammonia technology, to contribute to the development of a global low-carbon hydrogen market as, when transformed into ammonia, hydrogen can be easily transported over long distances. Since 1943, KBR has licensed, engineered, or constructed over 250 ammonia plants worldwide.

In the longer term, Air Liquide and KBR say that they will work together to contribute to the development of low-carbon hydrogen as a key enabler of the energy transition. Ammonia can be easily transported over long distances and a global supply chain infrastructure is already in place for the production, transport and utilisation of ammonia at large scale. Once transported, ammonia can be converted back into hydrogen to contribute to the decarbonization of industry and mobility. In March 2023, Air Liquide announced the construction of an industrial scale ammonia cracking pilot plant in the port of Antwerp, Belgium to convert ammonia into hydrogen.

Michael J. Graff, Executive Vice President, Air Liquide Group, said: "Through this new offering, Air Liquide and KBR will combine their renowned respective expertise to provide efficient, reliable and competitive solutions for the production of ammonia and help the sector engage its low-carbon transition."

## CAMEROON

### Yara Cameroon acquired by NJS Group

Yara International has finalised an agreement to sell its 65% majority stake in Yara Cameroon to NJS Group, which has been the minority shareholder since the company's inception in 1995. Once this transaction is completed, NJS Group will become the sole shareholder of the company with the objective of optimising its offerings for the agricultural sector, currently focused on controlled livestock development.

To strengthen their collaboration, Yara International and NJS Group have concluded an exclusive distribution agreement for premium NPK fertilizers, YaraMila, and YaraLiva Nitrabor Calcium Nitrate. As a result, Cameroonian farmers and agricultural retailers are assured of future supply of these key products. As an essential part of this agreement, Yara International ASA will provide technical and operational support to NJS Group, ensuring a solid platform for future growth.

## JAPAN

### Agreement on green hydrogen and ammonia development

Japanese power consortium JERA has signed a memorandum of understanding with Saudi Arabia's Public Investment Fund. (PIF). The MoU will drive cooperation between the two parties, to explore opportunities for the development of green hydrogen projects and derivatives such as ammonia. JERA is looking towards the energy-rich MENA region as a promising production base for green hydrogen and ammonia. According to the company, to achieve its 'JERA Zero $CO_2$ Emissions 2050' objective, JERA will work with leading companies in Japan and overseas to establish and expand supply chains for hydrogen and ammonia. Meanwhile PIF is advancing Saudi Arabia's 2060 Net Zero target, and exploring investments across sectors including green hydrogen, renewable energy, energy efficiency and waste management.

Japan is reportedly providing assistance in the construction of an ammonia plant planned by Saudi Aramco, via trading houses Mitsubishi Corp. and Mitsui & Co. Saudi Aramco aims to produce as much as 11 million t/a of ammonia a year by 2030 with the addition of the new plant, using carbon capture and storage to lower the carbon intensity of production.

## UNITED ARAB EMIRATES

### Feasibility study complete for green ammonia project

Brooge Renewable Energy Ltd says that it has successfully completed a feasibility study for its green ammonia project in Abu Dhabi. The proposed project would establish an export-focused green ammonia production facility with capacity of 1,950 t/d, in two phases, with Phase I commissioning 300 t/d for delivery to Europe and Asia. The company says it expects to gain competitive advantage from favourable renewable energy prices and the lower freight cost to key end-markets.

"We are extremely pleased to announce the successful completion of the Feasibility Study for our Green Ammonia Project," said Lina Saheb, Interim CEO of Brooge Energy Limited. "With our early mover advantage and strategic location, we are confident that our export-focused green ammonia production facility will not only meet the rising global demand for green hydrogen carriers, but also contribute significantly to the UAE's and the world's net-zero targets. We remain committed to driving sustainable solutions that benefit both our environment and the global economy."

## UKRAINE

### Russia withdraws from Black Sea grain export deal

Russia has declined to extend the Black Sea grain export deal. Dmitry Peskov, spokesperson for Russian president, Vladimir Putin, said that the UN-brokered agreement had "essentially stopped" and that Russia would no longer be cooperating. The deal, which had run for 12 months from July 2022, had allowed the export of 33 million tonnes of grain via the port of Odessa and had helped contribute to a 17% drop in the price of wheat and a 26% fall in the price of corn on global markets. However, Russia had said that unless exports of Russian fertilizer, particularly ammonia, were included in the deal, and that financial restrictions on the export of Russian fertilizer were lifted, it would not continue with the deal. Other conditions included an end to sanctions on the Russian Agricultural Bank and the resumption of supplies of agricultural machinery and parts, and lifting restrictions on insurance and reinsurance. A possible contributary factor to Russia's decision was an attack on the Kerch Straits bridge to the Crimean peninsula in the week leading up to the deadline by Ukrainian unmanned naval drones.

Ukraine will now be forced to export most of its grains and oilseeds through its land borders and Danube ports, driving up transportation costs.

## INDIA

### Deepak to expand nitric acid capacity

The board of Deepak Fertilisers and Petrochemicals Corp Ltd has approved a plan to expand nitric acid capacity at Dahej, in Gujarat at a cost of $235 million. The expansion will include a 300,000 t/a weak nitric acid plant, and two concentrated nitric acid plants with a combined capacity of 150,000 t/a, according to a company statement. The plants will be built within the company's existing site at Dahej. Production is tentatively set for 2025-26.

Grupa Azoty's ammonium nitrate plant.

PHOTO: THYSSENKRUPP UHDE

## POLAND

### New AN neutralisation plant

Poland's Grupa Azoty has selected thyssenkrupp Uhde to supply a new ammonium nitrate neutralisation plant at Tarnow. Grupa Azoty is the second largest EU-based manufacturer of nitrogen and compound fertilizers. The new ammonium nitrate neutralisation plant will be based on the natural circulation process and produce liquid ammonium nitrate (AN). For this project, thyssenkrupp Uhde will be responsible for the licensing, basic engineering and supply of the process equipment as well as technical consulting services for the detailed engineering, construction, and commissioning. The process is based on proven *uhde*® technologies which form the basis of thyssenkrupp Uhde's ammonium nitrate technology portfolio, and is characterised by a high circulation rate and a very low reaction temperature compared to other technologies, which operate at >180°C. With these chosen operating parameters, a high safety level is achieved by design.

Dr Cord Landsmann, CEO thyssenkrupp Uhde said: "This project for Grupa Azoty marks another milestone for us. It's a big step towards a more sustainable chemical industry. We are proud to say that we were the only licensor who could offer a referenced technology which is able to use low-pressure gaseous ammonia as feedstock without requiring an ammonia compressor."

# Syngas News

UNITED STATES

## Green methanol plant for Louisiana

SunGas Renewables Inc. has formed a new subsidiary, Beaver Lake Renewable Energy, LLC (BLRE), to construct a new green methanol production facility in central Louisiana. The project will have a capacity of 400,000 t/a of green methanol, using gasified biomass, specifically wood fibre from local, sustainably-managed forests as feedstock. The methanol will have a negative carbon intensity through sequestration of the nearly 1.0 million t/a of carbon dioxide produced by the project, which will be executed by Denbury Carbon Solutions. The methanol will then be used as a clean marine fuel by A.P. Moller–Maersk, which is building a fleet of methanol-powered container vessels.

SunGas Renewables anticipates that BLRE will require approximately $2 billion to construct the project at the former International Paper facility in Rapides Parish. A front-end engineering and design study on the site is planned to begin in October. The company expects to make a final investment decision in August 2024, with construction expected to begin in late 2024 and commercial operations commencing in 2027.

Emma Mazhari, Head of Energy Markets at Maersk, said, "A.P. Moller–Maersk is excited to be partnering with SunGas Renewables, which is pioneering a truly large-scale pathway to green methanol with its Beaver Lake Renewable Energy facility. We would like to thank SunGas Renewables for showing great leadership and for its commitment to the green transition of energy. This is helping Maersk to deliver valuable services to our customers and is aligned with our aim to reach net zero greenhouse emissions by 2040. Together, as pioneers in the field, SunGas and Maersk are driving a much-needed transition in a heavy pollution industry. We hope that work can be accelerated further in the years to come."

"Using biomass from sustainably managed forestry along with carbon capture allows our project to generate green marine shipping fuel while simultaneously removing carbon from the atmosphere. This new low-carbon marine fuel facility also helps strengthen communities and create sustainable economies right here in Rapides Parish, Louisiana," said Robert Rigdon, CEO of SunGas Renewables. "As we continue our mission to make a meaningful impact in the energy transition, we look forward to collaborating with all our project partners and the State of Louisiana to construct and operate this important project. This incredible effort happening right here in Pineville will be an innovative and industry leading low-carbon energy solution that will help fuel a better world." ■

DENMARK

### Clariant catalyst selected for renewable methanol project

European Energy has selected Clariant´s methanol synthesis catalyst MegaMax for its green methanol project. Located in Kasso, Denmark, the facility is scheduled to start operations by the end of 2023. It will have the capacity to produce 32,000 t/a of methanol from carbon dioxide. MegaMax was chosen to deliver high activity and stability under the challenging conditions of $CO_2$-to-methanol conversion.

European Energy was founded in 2004 with the goal of driving the green transition and developing sustainable, fossil-free energy solutions. The company has major investments in solar and wind energy projects, as well as power-to-X and carbon capture technologies, and builds 1,000 MW of renewable energy annually. A large portion of the plant's annual yield is already allocated to the maritime giant Maersk for powering its first-ever carbon-neutral fleet. The remaining green methanol will be supplied to the Lego Group and Novo Nordisk.

Georg Anfang, Vice President Syngas and Fuels at Clariant Catalysts, commented, "We are proud to be part of this pioneering project with European Energy. Clariant Catalysts has been developing Power-to-X technologies, including green methanol, for over a decade. As a substitute for maritime bunker fuel, green methanol has a huge potential to be a key component of the energy transition to decarbonize the transport sector."

Anders Brendstrup, Vice President at European Energy, added, "We are very pleased to have Clariant on board. Their renowned expertise and advanced products are a perfect match for our vision to drive the green energy transition. We see many advantages in our partnership, not only for this ground-breaking project but also for future ventures."

UNITED KINGDOM

### Ørsted and ESVAGT sign second contract for methanol-powered vessel

Ørsted and ESVAGT have signed an agreement for a sister vessel to the world's first methanol-powered service operation vessel (SOV), which was announced in 2022. The SOV will be ready for launch in 2026, where it will operate out of Ørsted's UK East Coast Hub on a 10-year contract, maintaining offshore wind turbines. It will be powered by dual fuel engines, capable of sailing on renewable methanol, which will lead to a carbon emissions reduction of approx. 4,500 t/a. Ørsted is developing a 50,000 t/a renewable methanol facility, FlagshipONE in Sweden, which is expected to be operational in 2025, and expects to supply its own methanol for both of the SOVs. Several other maritime companies have placed orders on methanol-powered vessels, demonstrating that the demand for green fuels is materialising rapidly.

Mark Porter, Head of Operations Europe at Ørsted, said: "As the world leader in offshore wind, Ørsted will continue to look for the best green alternatives to fossil fuels. E-methanol is a strong match for our SOVs, and we're very pleased that we, along with ESVAGT, will soon welcome the second methanol-powered vessel to our fleet." Søren Karas, Chief Strategy & Commercial Officer at ESVAGT, added: "ESVAGT is deeply committed to continuously innovating to deliver lower emission solutions. We are looking forward to bringing the first methanol powered SOVs to the market".

Over the past two years, Ørsted has built up a diverse portfolio of green fuel projects, three of which focus on producing green methanol for maritime transport. As well as FlagshipONE in Sweden, projects include 'Project Star' on the US Gulf Coast, which will supply 300,000 t/a of methanol for A.P. Moller–Maersk's fleet of zero-emissions vessels, and the 'Green Fuels for Denmark' project in Copenhagen, where Ørsted is working with major Danish players in heavy transport, including shipping.

## AUSTRALIA

### Solar methanol project

Australian solar power developer Vast has contracted with global design and manufacturing firm Contratos y Diseños Industriales (CYD) to facilitate early design work on Vast's VS1 project, a 30 MW concentrated solar power (CSP) plant at Port Augusta in South Australia. CYD will begin early design work using a virtual model to simulate the construction and operation of the project's thermal energy storage tanks, which contain molten salt. Vast and CYD have been collaborating on the development of new thermal storage tank designs for the VS1 project. Vast's CSP technology, demonstrated at a pilot plant in Jemalong, uses modular arrays of solar towers and receivers to capture and store energy from the sun for electricity or heat. The Vast technology uses sodium as a heat transfer fluid and claims improved system efficiency, reducing costs.

Vast has previously appointed Worley's Advisian to complete basic engineering and front-end engineering design. The VS1 project is budgeted at A$203 million, but has received an A$65 million grant from the Australian Renewable Energy Agency (ARENA) as well as a A$40 million pledge from ARENA and Germany for a proposed solar methanol facility and hydrogen electrolyser alongside the VS1 plant. The VS1 solar power project is expected to be operational by 2024.

## BELGIUM

### Honeywell and ZoneFlow complete steam reforming pilot project

Honeywell International Inc. and ZoneFlow Reactor Technologies say that they have successfully conducted pilot plant testing of the ZoneFlow Reactor in ZFRT's large-scale pilot plant at the Université Catholique de Louvain in Louvain-la-Neuve, Belgium. The testing validated increased steam reforming capacity by at least 15% in terms of feed flow compared to conventional state-of-the-art pellets, with no higher methane slip and without increasing the maximum tube skin temperature or pressure drop. This increased production of hydrogen allows for the steam methane reformer to convert hydrocarbon feeds such as natural gas or naphtha and steam into syngas.

In 2021, Honeywell UOP and ZoneFlow Reactor Technologies, LLC signed a joint development agreement to grow and commercialize the ZoneFlow Reactor technology. This technology can provide a significant improvement in the productivity and cost-effectiveness of steam methane reforming for hydrogen and syngas production.

"The combination of Honeywell's domain expertise and ZoneFlow's Reactor technology is geared to provide high value creation for both new and existing steam methane reforming units. There are over 800 steam methane reforming units worldwide for hydrogen generation and a similar number employed for ammonia and methanol production. The successful testing can allow for significant capital savings for new steam methane reforming plants and higher productivity for existing plants," said Ted Faiella, vice president and general manager of Equipment, Honeywell UOP Process Technologies. "As ZoneFlow's reactors can increase hydrogen production with existing assets, this ready-now technology can play a major role in the energy transition as refineries look to burn hydrogen instead of natural gas to lower their carbon emissions."

Louvain University has also been testing a biomass gasification process developed by EQTEC using a steam-oxygen technology to convert grade B waste wood - lower-quality wood waste which can be challenging to gasify as it typically consists of lower-grade or contaminated wood which may contain non-reactive materials such as glass or metal that must be removed from the fluidised bed to avoid low-efficiency reactions. EQTEC says that the Biogaz Gardanne project shows that steam-oxygen gasification technology can be applied at commercial scale on plants seeking to produce advanced biofuels.

## TRINIDAD & TOBAGO

### Restart unlikely for Titan plant

Hopes for a restart of Methanex's mothballed Titan methanol plant on Trinidad have faded. Methanex has wholly owned the Titan plant since 2003, and idled it in March 2020 as methanol demand fell due to the covid pandemic. But the company said in 2021 that the plant would remain idled "indefinitely" until it could source natural gas feedstock for it on "commercially acceptable" terms, following negotiations with the Natural Gas Company of Trinidad & Tobago (NGC). There were indications earlier in the year that these negotiations might be bearing fruit. However, both parties have gone silent on the matter and former energy minister Kevin Ramnarine recently told local press that he does not see Titan returning to operation at present. Methanex has also indicated it was considering relocating the facility to a brownfield site such as Geismar, Louisiana, Medicine Hat Alberta, or Egypt.

Methanex continues to operate the 1.8 million t/a Atlas plant on Trinidad, in which it owns a 63% stake, producing around 1.0 million t/a in 2022 and likely a similar amount this year, although there is an ongoing tax dispute with Trinidad's Board of Inland Revenue concerning certain fixed price methanol sales contracts from 2005-2016.

## CANADA

### Enerkem and Technip to collaborate on waste-to-fuel technology

Technip Energies and Enerkem Inc. have signed a memorandum of understanding to enter into a collaboration agreement aimed at accelerating the deployment of Enerkem's technology platform for biofuels and circular chemical products from non-recyclable waste materials. Since 2016, Enerkem has been operating a commercial demonstration scale facility at Edmonton, Alberta, Canada.

Technip Energies will contribute its expertise in engineering, technology integration and project delivery to support projects developed by Enerkem. This partnership will enhance Enerkem's project delivery capacity and speed. Furthermore, the collaboration will focus on strategic efforts to optimise design elements and industrialise the approach through the replication of Enerkem's designs for future projects. To expedite the deployment of its technology, Enerkem intends to establish a Development Company (DevCo). The purpose of DevCo is to acquire sites and secure relevant permits for the replicable methanol biorefinery design, supporting the production of bio and low-carbon fuels, as well as circular chemicals.

Dominique Boies, CEO of Enerkem, stated: "We are excited to partner with Technip Energies to accelerate the deployment of Enerkem's technology in Europe, North America, and the Middle East. Technip Energies' extensive expertise will enable Enerkem's clients to benefit from projects speed to market and cost efficiencies, supporting their decarbonisation efforts and sustainability goals." ■

Norwegian chemical shipping company Stolt-Nielsen says that **Niels G. Stolt-Nielsen** will step down from his role as CEO on September 1, 2023, after 23 years as Chief Executive Officer. He will be succeeded as CEO by **Udo Lange** and will assume the role of Chairman of the Board of Stolt-Nielsen Ltd, the company announced. Lange has more than 20 years of experience in the international trade industry, with expertise in freight forwarding, express and parcel logistics and airline catering. He was most recently president of Healthcare, Logistics and Americas International at FedEx Express, leading a team of more than 50,000 employees across 80 countries. He was also part of the FedEx Senior Management Committee which sets the strategic direction of the circa $90 billion revenue enterprise and has held several other senior roles at FedEx since joining in 2015.

Stolt-Nielsen's Stolt Tankers unit aims to reduce its carbon intensity by 50% (relative to 2008 levels) by 2030, have at least one carbon-neutral ship in the fleet by 2030, and run a carbon-neutral business by 2050. As part of this strategy, Stolthaven Terminals and Stolt Tankers are exploring the potential of ammonia as a greener alternative to traditional petroleum-based marine fuels to support the ongoing transition to low and zero-carbon energies.

PetroVietnam Fertilizer and Chemicals Corporation (PVFCCo) has appointed **Le The Dong**, formerly head of the Technical Department, as the new Deputy Plant Director, and **Le Thuc An**, formerly Deputy Workshop Manager NPK as the new Deputy Head of the Production and Business Department. The appointments were made at a ceremony at the Phy My urea plant attended by Le Cu Tan, Deputy Secretary of the Party Committee and CEO of PVFCCo; Ta Quang Huy, Deputy CEO of PVFCCo; Le Trong Dinh Chi, Plant Director, and representatives of the departments of PVFCCo.

Nikola Corporation has announced that **Michael Lohscheller** is stepping down as the company's president and chief executive officer and is leaving the Board of Directors. **Stephen Girsky**, the chair of the company's Board of Directors has been announced as Lohscheller's successor. **Steve Shindler** will be taking Girsky's former position as the chair of the board for the company.

Under Lohscheller's leadership, the Nikola Corporation moved forward in its ambition to become a zero-emissions transportation leader, including the launch of the Class 8 hydrogen fuel cell truck.

The Fertilizer Institute (TFI) has announced the consolidation of several industry-supported organisations into the FERT Foundation, which will be dedicated to ensuring that education, research and training is conducted under a single umbrella. The new foundation will bring the work of the Fluid Fertilizer Foundation (FFF), Foundation for Agronomic Research (FAR), and Nutrients for Life Foundation (NFLF) together and ensure that the industry's resources are used for maximum impact.

Fertilizer education will continue under the Nutrients for Life program name. Training will operate under the Ford West Leadership Academy. Research will combine priorities of the Fluid Fertilizer Foundation and the Foundation for Agronomic Research. The new Foundation will be a separate 501(c)3 organization, and will be a private foundation, serving the needs of the fertilizer industry. TFI members will direct its activity.

"The aim of the FERT Foundation is a world in which fertilizers are understood and appreciated, scientific research supports advocacy for sustainable fertilizer use, and an engaged, informed and diverse workforce serves a thriving industry," said TFI President and CEO Corey Rosenbusch. "By leveraging economies of scale and more closely aligning objectives, these organizations will better serve the industry than could the existing patchwork of standalone organisations." ■

## Calendar 2023/2024

### SEPTEMBER

**10-15**
Ammonium Nitrate/Nitric Acid conference, VARNA, Bulgaria
Contact: Sam Correnti, DynoNobel, Karl Hohenwarter, Borealis
Email: sam.correnti@am.dynonobel.com, karl.hohenwarter@borealisgroup.com, annaconferencehelp@gmail.com
Web: annawebsite.squarespace.com

**14-15**
2nd International Conference, Ukrainian Fertilizer Market, LVIV, Ukraine
Contact: Chem Courier
Email: conf@fert-ua.com
Web: www.fert-ua.com

**25-26**
World Methanol Conference, VIENNA, Austria
Contact: David Coates, OPIS
Tel: +1 713 305 0116
Email: dcoates@opisnet.com

### OCTOBER

**9-11**
Global Syngas Technologies Conference, SAN DIEGO, California, USA
Contact: Global Syngas Technologies Council
PO Box 18456, Sugar Land, TX 77496 USA
Tel: +1 713 703 8196
Email: info@globalsyngas.org

**17-19**
AFA Technical Conference, MUSCAT, Oman
Contact: Arab Fertilizer Association
Tel: +20 2 23054464
Email: afa@arabfertilizer.org
Web: https://annual.arabfertilizer.org/

### NOVEMBER

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

### DECEMBER

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

### FEBRUARY 2024

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

### MARCH

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

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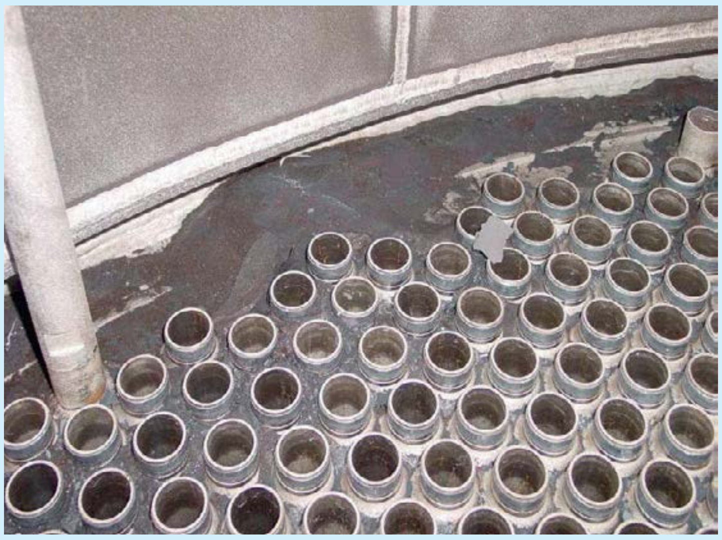
# Plant Manager+

## Problem No. 69 Impact of ammonia catalyst fines on urea plant

**Rohit Khurana and Umesh Jainker of KBR presented a technical paper on this topic during the 2013 Asian Nitrogen + Syngas Conference. It can be found in the UreaKnowHow.com E-Library with the title: "Replacing ammonia plant catalyst with maximum efficiency and lowest cost". The paper addresses the importance of de-dusting catalyst beds before commissioning and the serious impacts on the plant if not performed thoroughly. Many ammonia plants have faced problems related to the plugging of exchangers, pipe choking, pressure drop increase of the downstream catalyst beds and separators or foaming in the $CO_2$ removal section which could be caused by the presence of catalyst dust. Most of these problems have led to either decrease in the efficiency of the plant or operation at lower throughputs. The paper presents the critical steps and procedures for proper dedusting of the catalyst beds before commissioning. In addition, the foaming problem in the $CO_2$ removal section associated with catalyst dust is discussed signifying the importance of cleaning the $CO_2$ removal system and solution. The role of filters in the $CO_2$ removal section was also emphasised.**

**Furthermore, catalyst dust can also create problems in the urea like scaling of the HP stripper tubes and on the top tubesheet of the HP stripper (refer to picture), leading to clogging of the liquid divider holes, which is very critical in HP strippers with 25-22-2 tubes as it can lead to active corrosion and tube rupture. In the low-pressure rectifier, catalyst dust can also cause fouling of the heater and even of the internals of the rectifier column itself.**



**Nour of El Delta Fertilizers in Egypt kicks off this round table discussion:** What problems can be expected if ammonia catalyst fines pass from the ammonia section to the high-pressure urea plant? Are there chemical reactions and what are the expected compounds? Is erosion possible with these fines in the liquid dividers of the HP stripper and corrosion? Do these fines cause scale formation on the tube wall and tube sheet in heat exchangers?

**Majid Esmaeilzadeh from CCM in Iran replies:** Are you sure that the fines are iron oxide? Have you confirmed it by taking a sample and doing lab analysis. From where did you take the sample for analysis?

**Nour replies:** Yes I am sure, the fines were found in the filter before the ammonia preheater.

**Suresh from Nagarjuna Group in India joins the discussion:** The problem may be caused by the slip of iron catalyst fines/catalyst heaps through the ammonia reactor mainly due to failure of the Johnson screen in the ammonia converter basket. Some plants have collected iron catalyst heaps at the HP ammonia feed booster pump suction, so it is better to inspect the screen inside the ammonia converter, but, it is a difficult task.

**Girish Prakash of Yara in India shares his valuable experiences:** I fully agree with Suresh about the source of iron catalyst fines and in fact we faced the problem around 2001-02. We faced two phenomena at that time: (1) the colour of the urea prills changed to dull white with a tinge of brown colour instead of the normal crystalline white and (2) frequent cavitation problems in the ammonia booster pump (due to choking of strainers).

**Waqqar Ahmed of Fauji Fertilizer Company Ltd. In Pakistan also joins the discussion:** To cater for this type of problem we have a strainer and filters in the liquid ammonia line before the ammonia receiver vessels in the urea plants.

**Nour replies:** Thank you for your reply Girish. Did you also notice any effect in the stripper? Did the stripper outlet temperature increase? Did the heat transfer in the first stage of the evaporation section decrease? How long did you continue with catalyst fines fouling?

**Les Farbotko (retired) from Incitec Pivot in Australia shares his valuable experiences:** We do not have a filter on the ammonia line to our urea plant - it goes straight into the ammonia storage drum, where some seems to settle out on the bottom (behind a raised weir on the pump suction nozzle). I have sometimes worried whether this catalyst dust is in the reduced state and may get hot when exposed to air, but we haven't seen anything like this, because we usually steam out first, which would oxidise the dust. Similarly, any dust that is carried forward out of the ammonia drum would be oxidised by contact with $CO_2$ and $H_2O$ in the reactor or other downstream vessels. Has anyone seen any spontaneous heating of catalyst dust when filters etc. have been opened up? Catalyst dust may also contribute to wear on the packings of the HP $NH_3$ pumps.

# Fuel uses for syngas derivatives

Low carbon production is attracting considerable attention to using syngas derivatives as fuels, but there are considerable logistical and commercial barriers to overcome.

Decarbonising the fuels used for vehicles and power production is of prime concern for tackling climate change. Renewable energy and battery technology play a part, but for many vehicles, especially ships and aircraft, liquid fuels remain the most efficient means of propulsion. Using hydrogen derived from low carbon sources is a possibility, but while it is possible to generate hydrogen directly via electrolysis or partial oxidation of natural gas with carbon capture and storage, hydrogen is a difficult substance to use for vehicle applications because of its very low density, even when compressed or cooled to cryogenic temperatures. Various approaches have been tried for using hydrogen as a vehicle fuel, from fuel cells to using metal hydrides as a carrying medium, but for the moment it is other syngas derivatives like ammonia, methanol and Fischer-Tropsch hydrocarbons which are looking like the most viable ways of converting renewable hydrogen into widely used fuels.

## Maritime fuel

Much of the interest is coming from potential uses as a fuel for shipping. The International Maritime Organisation (IMO) originally set a goal of reducing total greenhouse gas (GHG) emissions from international shipping by 50% by 2050, compared to 2008 levels. However, this year it adopted new, more stringent targets to reduce emissions by 40% by 2030 compared to 2008, have 5-10% of all shipping be zero carbon by that time, and to be carbon neutral as close to 2050 as possible. Given the lead times on building and deploying ships and their length of service, this has seen the shipping industry scrambling to pick winners among the various candidate fuels as soon as possible.

At the moment methanol seems to have a clear lead in this field. Methanol is no stranger to being used as a shipping fuel. Methanex subsidiary Waterfront Shipping, which ships methanol around the world, investigated using some of that methanol as a fuel on cost grounds, and began operating a duel-fuelled tanker in 2016. It has now built or converted 18 vessels to run on methanol. This has given methanol a head start as a green fuel, as the engines to use it are already commercially available (and require less modification than fuels like ammonia). Proman have also now taken delivery of four methanol fuelled tankers and have two more on order.

But undoubtedly the greatest boost to methanol as a shipping fuel has come from its adoption by Danish shipping giant Maersk, which is responsible for 14% of world cargo transport. In 2021 Maersk decided to acquire a methanol fuelled carbon neutral container vessel, and then later that year added another eight large (16,000 ten-foot equivalent unit – TEU) container ships at a cost of $175 million each. Last year it ordered an additional six 17,000 TEU methanol dual-fuel vessels, and the total has now risen to 19 ships, with delivery between 2023 and 2025. Each ship will require 35,000-40,000 tons of methanol annually, or a total of 500,000 t/a of low carbon methanol. The company says that by 2030 it is aiming to run 25% of its 700+ vessel fleet on renewable methanol, which will take its annual requirement to 6 million t/a. Maersk says that it has picked methanol because it is a mature technology as regards shipping engines.

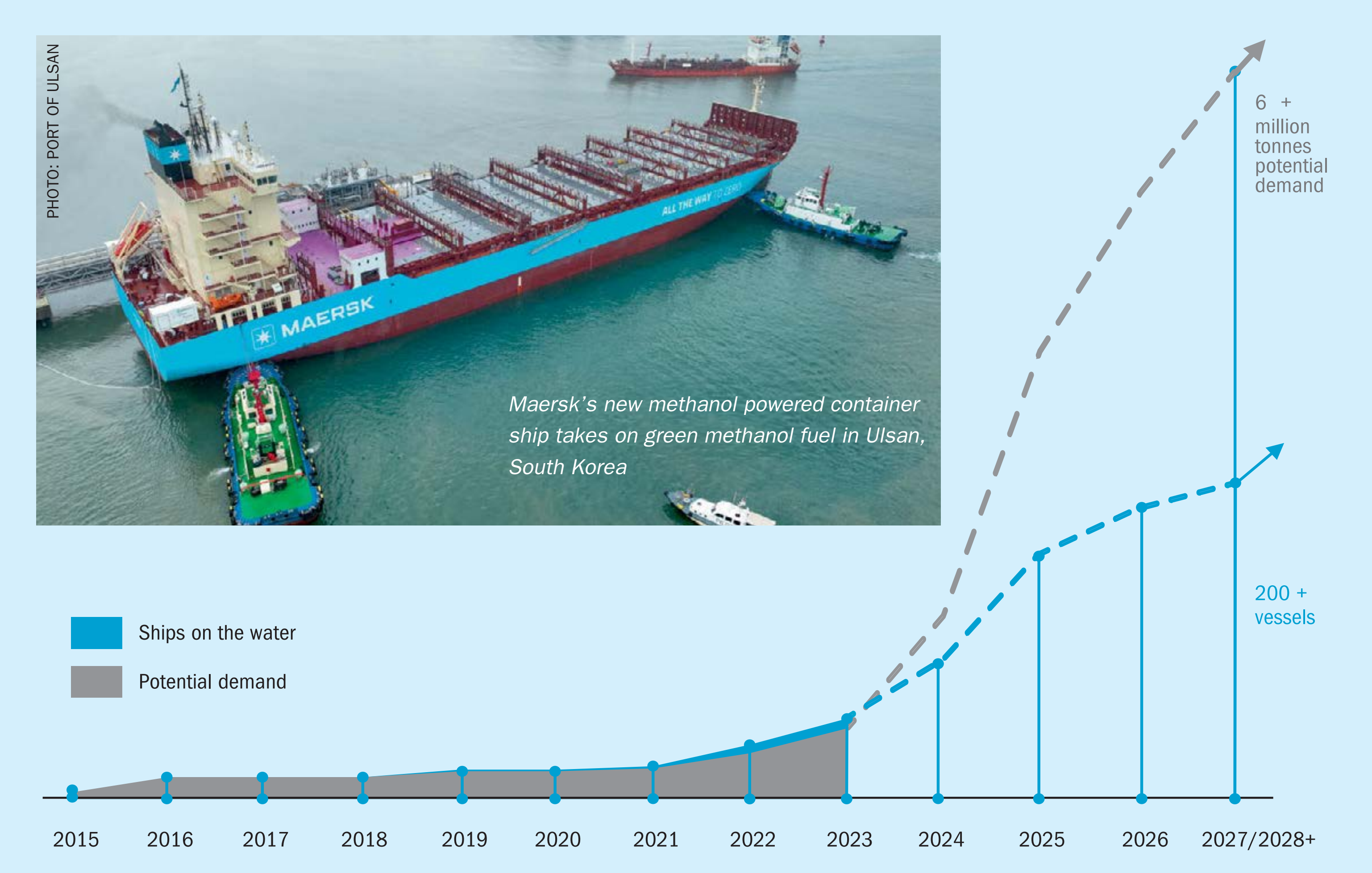
Sourcing this amount of low carbon methanol is a potential issue, which has led Maersk to begin looking for strategic partners to supply them. It has now secured agreements with ten methanol producers, including Proman, Orsted, European Energy, Wastefuel, and SunGas Renewables, with the intent of sourcing at least 730,000 t/a of green methanol by end of 2025. Methanex believes that demand for low carbon methanol could be 3-6 million t/a by 2027 (see Figure 1).

## Ammonia

There has been much discussion of using ammonia as a maritime fuel, and considerable research into its potential. Engine manufacturer Wärtsilä has been working on four-stroke ammonia internal combustion engine designs, and MAN Energy Solutions is working on a two-stroke ammonia engine. Japanese trading house Itochu and Dutch oil storage and terminal operator Vopak have conducted feasibility studies on the development of ammonia supply infrastructure for use as a marine fuel for vessels in Singapore, and Japanese shipping company NYK Line, shipbuilder Japan Marine United Corporation (JMU), and ClassNK have been developing an ammonia-fuelled ammonia gas carrier that would use ammonia as the main fuel. MOL and Mitsui also recently announced that they had received approval from Class-NK for the design of a large ammonia-powered bulk carrier. At present, however, there are no commercially available ammonia shipping engines, and ammonia has barriers to its adoption as a marine fuel.

In theory, ammonia burns cleanly to produce nitrogen and water. In practice, however there are several issues with ammonia combustion. Firstly, ammonia has a very high ignition temperature. It is possible to overcome this by mixing it with conventional fuels such as gasoline, diesel, LPG, etc whose combustion can supply heat to ignite the ammonia. This can

Fig 1: **Potential methanol demand for marine fuel**




*Maersk's new methanol powered container ship takes on green methanol fuel in Ulsan, South Korea*

*Source: Methanex*

reduce the need to engine modification. However, it does reduce ammonia's green credentials. Ammonia combustion does also produce lower power. Ammonia has a lower flame speed than traditional fuels which restrains temperature diffusion in the cylinder during the combustion stroke and causes the power reduction. These two aspects combined; high ignition temperature and low flame velocity lead to a slower chemical reaction rate which can lead to ammonia being discharged from the exhaust without burning. The common way to enhance the chemical reaction rate of ammonia combustion is to use a promoter in an ammonia-air mixture.

Beyond this, however, there are also often side reactions which lead to NOx formation in ammonia combustion. The biggest issue is $N_2O$ formation, as nitrous oxide has a global warming potential 265 times that of $CO_2$. Currently, $N_2O$ emissions are not regulated by the IMO, but they will need to be if ammonia is to become a widely used shipping fuel. There are various strategies for reducing NOx formation well known to nitric acid producers and removal of nitrogen oxides from an exhaust stream is already a well understood and proven technology, but it does add extra cost and complexity to ammonia-based ships.

The shipping industry is also concerned about safe handling of ammonia during bunkering operations. Ammonia in gaseous form is highly toxic if breathed in, and in order to maintain it as a liquid it must be cooled and stored below -33°C at atmospheric pressure or compressed to around 10 bar (raising the boiling point to about 25°C), or some combination of the two, increasing both the dangers and costs of its transport and storage.

Maersk, whose push for methanol has been behind much of the early lead for that option, did say a couple of years ago that it considered ammonia a potential option, but more recently it has appeared to get cold feet. At a recent shipping industry conference, Maersk Group head of future fuels Maria Strandesen, said: "Ammonia is still on the 'perhaps list' for us. It is by no means off the table, but we are not yet comfortable enough to order the first pilot vessel to run on ammonia."

In spite of these issues, some are still optimistic for ammonia's use as a shipping fuel if green/blue production can be scaled up and costs reduced. Ammonia process licensors are working on conversion and revamping of existing plants from grey to green production, and Yara Clean Ammonia have suggested that shipping could become a magnet for green ammonia supplies in the same way that it has green methanol, while the International Energy Agency (IEA) has suggested that ammonia's use for shipping could reach 130 million t/a tonnes by 2070 – on the same scale as its use for fertilizer. At the moment, however, methanol is the clear leader.

## Road vehicles

Aside from some abortive experiments with ammonia as a vehicle fuel in the 1920s and 30s, most demand for road fuels from syngas-derived products has come from two sources; Fischer-Tropsch hydrocarbons, and methanol. Fischer-Tropsch fuels were pioneered by South Africa's Sasol, where there is still considerable production, and took off for a while in the 1990s as a use for stranded gas resources, including large plants in Malaysia, Qatar and, somewhat less successfully, Nigeria and Trinidad. But the rapidly growing LNG market became the preferred use for new gas finds and since then only Uzbekistan has completed a GTL plant.

Methanol, conversely, after a false start in California, achieved a degree of market penetration as a road vehicle fuel in China, where coal-producing provinces saw it as a way of extending expensive gasoline pools. Methanol as a blendstock represents around 10% of Chinese fuel demand. Experiments with converting methanol to gasoline (MTG) using ExxonMobil's process were also tried in New Zealand and China but did not catch on more widely.

Now that the focus is back on low carbon vehicle operation, there has been renewed interest in using green hydrogen and captured $CO_2$ to make green methanol or synthetic diesel for road vehicle use, but little practical movement so far, and battery or battery-hybrid vehicles remain the most popular option for decarbonising road transport.

## Aviation fuel

Aviation is recognised as one of the most difficult sectors to decarbonise. As with shipping the cost of individual airliners means that they are often kept in service almost continuously for long periods in order to recover and amortise this cost. An aircraft, unlike road vehicles, cannot be electrified, certainly not for long haul flights – in order to store the same energy that an airliner can carry in its fuel tanks, it would need batteries that weight 30 or so times the weight of aviation fuel, while hydrogen fuel tanks would take up most of the fuselage as well as the wings even if it were liquid. The assumption therefore is that aircraft will be using liquid hydrocarbon-based fuels similar to the ones they currently use for the foreseeable future. This leads to the concept of so-called sustainable aviation fuels (SAF). The main way that SAF is produced at the moment is via what are known as hydrotreated esters and fatty acids (HEFA), which has come to be known as 'biojet'. Around 2 million t/a of capacity is already operational or under construction. However, although HEFA is the most widely used SAF pathway today, it is regarded the least scalable one in the long term because of the limitation on sufficient vegetable oil feedstock. A recent industry report suggested it might only be capable of providing 10% SAF by 2050 due to feedstock limitations. For large scale decarbonisation other options are needed.

Renewable methanol is a possibility for aircraft but again the lower energy density means that the fuel tanks would have to be larger. At the moment, the main alternatives to biofuels are Fischer-Tropsch synthesis or gasification of lower carbon solid feedstocks such as municipal solid waste (MSW), or biomass, e.g. from paper mills or other plant processing. Current International Civil Aviation Organisation (ICAO) projections are that alcohols and Fisher Tropsch pathways will for about 40% of the remaining total and the other 50% from 'Power-to-Liquid' ($CO_2$ and renewable hydrogen), identified as being the most scalable in the future in terms of feedstock availability.

## Power generation

Outside of vehicle applications, the other major fuel application is for power generation. This has been of particular interest in Japan, where there are plans to introduce ammonia into the fuel mix for thermal power generation to cut $CO_2$ emissions. As part of its Green Growth Strategy, the government is targeting ammonia imports either for conversion back to hydrogen and nitrogen (using ammonia as a hydrogen carrier) or by burning ammonia directly in power production. Pilot studies have successfully burned ammonia in coal-fired power stations at up to 20% of the feed and there have been subsidies to demonstration projects via IHI, JERA, Chiyoda and MHI. Japan wants to use this to try and prolong the life of its coal-fired power stations, which generate around 30% of its electricity. India and South Korea have also shown some interest in similar schemes.

The strategy has attracted criticism, not least from Bloomberg New Energy Finance (BNEF). A study last year pointed out that the cost of imported green or even blue ammonia could push the cost of power generation at such facilities higher than that for offshore wind at high levels of blending (50% or more). As with ammonia combustion in vehicle engines, there also are NOx emissions to deal with through some kind of scrubbing process, though part of the ammonia feed could be diverted to a SCR system. The Centre for Research on Clean Energy and Air also calculates that ammonia co-firing will increase emissions of particulates, especially PM2.5, by up to 160%.

Nevertheless, work continues. JERA, responsible for 30% of Japan's power generation, is looking to overseas partnerships with the likes of Yara for blue ammonia supply from Australia. There is also research on the use of ammonia-fired gas turbines. Mitsubishi Power, part of Mitsubishi Heavy Industries (MHI), has begun development work on a 40 MW 100% ammonia powered gas turbine system. The company says that it is targeting commercialisation in or around 2025. IHI is also partnering General Electric in a similar scheme.

Japan's Green Ammonia Consortium says that it expects 1% of Japan's electricity to come from blue and green ammonia combustion by 2030, potentially rising to 10% by 2050. JERA says that it will convert its 1 GW Hekinan coal-fired power station in Aichi, central Japan, to a 20% ammonia feed during 2024-25. By 2030, Japan hopes to be importing an extra 3 million t/a of ammonia for power generation.

## Costs and availability

While safety and environmental concerns and some of the technical challenges in developing ammonia engines are factors that could delay its adoption, they are not insurmountable obstacles, though they explain why methanol has had such a head start. However, the wider use of green and blue methanol, ammonia and F-T liquids depends very much upon two factors; cost and availability.

Cost of manufacture is obviously highest for green production and depends upon the cost of the solar and wind electricity being used and the electrolysers. Platts estimates that the current cost of green ammonia production is between $750-800/t delivered c.fr to Japan/South Korea. A year ago this was below the cost of production, but ammonia prices have fallen dramatically this year and are currently less than half of that. In the absence of a gas price crisis caused by a major European war, financial viability for green ammonia currently depends both upon a premium for green production over grey and possibly regulatory or government incentives like the US Inflation Reduction Act. Costs of production will continue to come down as electrolysers become

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

PHOTO: NESTE

*Refuelling an aircraft with sustainable aviation fuel.*

cheaper and green production is able to take advantage of economies of scale – costs have already dropped remarkably - but that in turn depends upon there being sufficient guaranteed demand for green ammonia. There seems no short term prospect of that emerging from maritime demand at present, but possibly Japan's ammonia blending programme may give sufficient impetus, even if it means that Japanese electricity consumers may end up paying the premium for it.

Blue ammonia may be a more realistic prospect. CRU estimates that the costs of carbon capture and storage for ammonia to be between $20-45/t, depending upon the close availability of a suitable reservoir for carbon storage, which ought to be easily covered by current EU carbon costs or US IRA production incentives.

While methanol already has an established a rapidly growing demand for low carbon production, it too has not been without its own problems. Maersk recently completed fuelling of its new Agility container ship in Ulsan, South Korea with green methanol produced by OCI Global in the Netherlands, and OCI says that it is in the process of gaining permits for methanol bunkering in various locations along the ship's route to Copenhagen, including Singapore, Egypt and Rotterdam. However, falling methanol prices are now reportedly below OCI's cost of production, with a small net loss reported in the company's recent Q2 results. OCI has stressed the importance of long-term cooperation between producers and consumers over green methanol supply, and presumably this means long term guaranteed price contracts.

Finally, however, there is an open question as to whether sufficient green or blue ammonia or methanol will be available to meet some of the higher end projections for demand out to 2050, which are for tens of millions of tonnes of both green ammonia and methanol. Even if there were enough renewable energy available to feed this production, just as ammonia production must currently compete with the power industry for natural gas and coal feedstocks, so in future it might have to compete with the power industry for renewable electricity. Blue production can help to bridge the gap, but the long term path ahead remains an uncertain one. ■

# Africa fertilizer update

Prior to the covid pandemic, sub-Saharan Africa had been the fastest growing market for new fertilizer demand. However, the combination of pandemic related disruption, followed by the dislocations caused by the war in Ukraine, have pushed up prices and led to falling demand across the continent.

*A farm at Vioolsdrift, South Africa.*

An estimated 140 million people across Africa face food insecurity, according to UN figures. The continent's chronic food insecurity has been amplified in recent years by drought, especially in the Horn of Africa, itself exacerbated by climate change. The current crisis in the continent however has mainly come about as a result of high food prices. Weather-sensitive domestic food production results in heavy reliance on imports, with some 85% coming from outside the region, although this tends to overstate the import dependence of smaller countries. In fact four countries; Nigeria, Angola, the Democratic Republic of the Congo (DRC), and Somalia, account for most of the region's net agricultural import position. The rest of the countries in the region are actually marginally net agricultural exporters. Even so this is a worrying situation for a region with so much arable land.

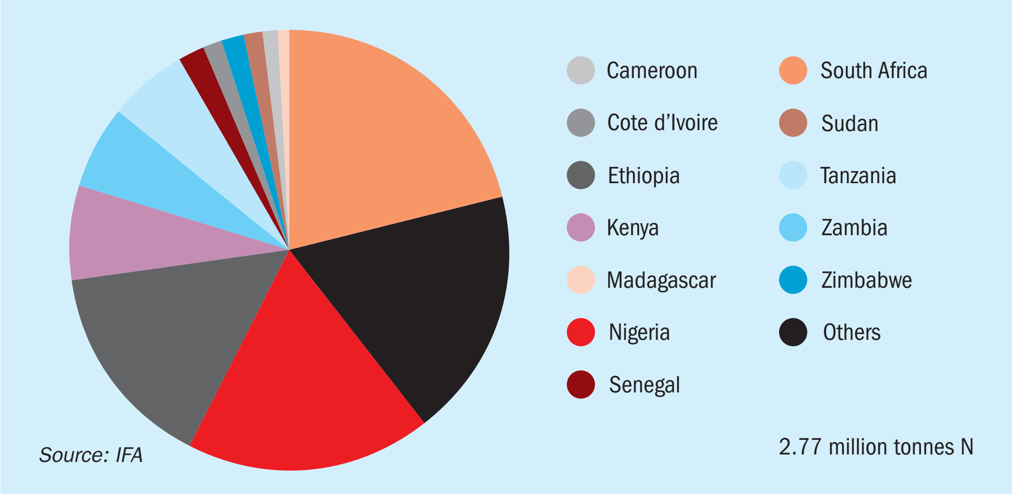
Fertilizer prices have played a part. Fertilizer prices have tripled since early 2020 and remain volatile, putting a stable supply of fertilizer out of reach of many small farmers. Fertilizer exports from Belarus and Russia – important fertilizer suppliers for Africa – have been disrupted by the war, while some other exporting countries have restricted supply through export taxes, bans and licensing requirements, in part to protect their own farmers. Food shipments via the Black Sea Grain Initiative have helped to ease some supply challenges, but Russia's withdrawal from the agreement in July means that this important lifeline has now closed.

## Fertilizer demand

The region has vast amounts of arable land and extensive agricultural production (albeit with low yields) but soil fertility is low – the major increase in food production that the region needs to feed its projected population increase over the next 20 years will need to come from increased fertilizer use. Fertilizer application rates have been on a steady increase in the region, averaging around 4.5% year on year during the 2010s, and around 7% in 2017-2020, although they remain low by global standards. Sub-Saharan Africa has an average fertilizer nutrient application rate of 22 kg/ha, compared to a world average of 146 kg/ha (and closer to 400 kg/ha in some countries, such as China and Chile). This has nevertheless more than doubled since 2006, but still falls way short of the 50 kg/ha target set by the Abuja Declaration in 2006. Figure 1 shows total nitrogen fertilizer consumption for the region in 2020, with Ethiopia, Nigeria and South Africa the main consumers.

One reason for low fertilizer application rates is the hand to mouth existence of many farmers in the region, who cannot afford to buy fertilizers until they have sold their crops. Around 70% of farmers in the region are smallholders. The International Finance Corporation has launched a $6 billion Global Food Security Platform to improve credit access to address liquidity constraints in the private fertilizer supply chain, and there have been ongoing efforts to improve fertilizer markets in Africa. In Kenya, for example, a World Bank program providing fertilizer e-voucher subsidies helps eligible smallholder farmers purchase fertilizer from private retailers at a subsidized rate,

Fig 1: **Nitrogen consumption in sub-Saharan Africa, 2020**








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

increasing productivity by more than 50%, enhancing crop diversification, and building private sector capacity. Nevertheless, much more needs to be done to improve Africa's food productivity.

## Infrastructure

Poor roads and ports are another problem. Ports are often not able to handle larger vessels, so capacity to handle fertilizer shipments is limited, while poor transport networks and often long queues to cross borders increase the time taken to ship fertilizers inland and bump up costs from the international baseline. Again there are development programs to try and improve this, but it remains a structural impediment to greater use of fertilizer in Africa.

## Supply

With domestic demand limited, many producers have been forced to look at export markets. Africa produces approximately 30 million t/a of fertilizer of all types, roughly twice as much as it consumes. But in spite of this, nearly 90% of fertilizer consumed in Sub-Saharan Africa is imported, mostly from outside the continent. This reflects inefficiencies in shipping and port costs, distribution chains, information availability and other trade frictions.

There are currently 19 fertilizer manufacturing plants in sub-Saharan Africa outside of South Africa, out of which five are nitrogen plants, concentrated in Nigeria, as well as an ammonium sulphate plant in Madagascar and an ammonium nitrate plant in Zimbabwe. There are also nine locations producing phosphate rock, SSP, DAP and other phosphate-based fertilizer compounds in Kenya, Tanzania, Zimbabwe, Burkina Faso, Mali, Senegal and Togo. Outside of this, there are four lime supplements and micronutrients plants.

## Natural gas

Development of nitrogen fertilizer capacity has hitherto been largely dependent upon exploitation of natural gas reserves. African natural gas production is concentrated in the north of the continent, especially Egypt and Algeria, while Sub-Saharan Africa produces only one third of the continent's gas output, around 60% of that represented by Nigeria. Other significant regional producers are Angola and Mozambique, with smaller volumes coming from the Democratic Republic of Congo, Tanzania, Côte d'Ivoire and Equatorial Guinea. However, Sub-Saharan Africa continues to see new gas discoveries and development and has been a major focus for exploration and production by international majors. Much of this centres around the potential for LNG development. The global LNG market continues to expand rapidly, especially since Europe has not been able to import natural gas by pipeline from Russia, and LNG developments continue to proceed apace.

LNG production in southern Africa is dominated by the longest established producer, Nigeria, which exported 19.6 bcm of gas as LNG in 2022. Angola was the next largest producer, with an LNG liquefaction capacity of 5.2 million t/a at a facility which has been operating since 2013, owned by BP, Chevron, Eni, Sonangol EP, and TotalEnergies. Since 2007 Equatorial Guinea has also operated a 3.7 million t/a LNG plant at Bioko Island, and in Cameroon, Golar LNG started operations via a 2.4 million t/a capacity floating LNG (FLNG) platform in 2018, although production only runs at 1.4 million t/a as new gas fields are tapped.

Floating LNG plants have proved an answer to some of the infrastructure problems that bedevil the region, as they can be constructed elsewhere and sailed into position. The Republic of Congo is playing host to the new $5 billion Tango LNG project. Eni is developing the offshore Marine XII project using two floating LNG plants which will process gas from the Nenè and Litchendjili fields. The first FLNG vessel is expected to begin production in December this year and the second in 2025, taking production to 3 million t/a. In Gabon, independent oil company Perenco made a final investment decision in February 2023 to bring on stream a 700,000 t/a floating LNG unit at the Cap Lopez Oil Terminal by 2026.

But there is also plenty of onshore development as well. In late December 2019 Nigeria made a final investment decision to go ahead with a major expansion of its Bonny LNG plant via a new 7th train which will increase capacity by 4.2 million t/a, as well as debottlenecking of existing capacity to add a further 3.4 million t/a. Overall, Nigeria's LNG capacity will increase by 35% to just over 30 million t/a by 2024.

In Angola, Eni and its partners have made a final investment decision to develop the Quiluma and Maboqueiro gas fields, which will include a connection to Angola's existing LNG plant, allowing production of an additional 4 bcm of LNG by 2026.

TotalEnergies' Mozambique LNG project will commence exports by 2027, with other LNG schemes following, including ExxonMobil's Rovuma LNG which is to consist of two 7.6 million t/a liquefaction trains on the Afungi Peninsula.

In Equatorial Guinea, Marathon Oil is developing the 3.7 million t/a Punta Europa LNG plant on Bioko Island, while BP is pursuing developments in Mauritania and Senegal. The Greater Tortue Ahmeyim (GTA) export facility will become the deepest African LNG project, with gas coming from two deep offshore natural gas fields, Tortue offshore Mauritania, and Ahmeyim offshore Senegal. Originally scheduled to begin production in 2022, the project has been delayed to 2024 by the covid pandemic. It now aims to produce 2.3 million t/a of LNG from the start of 2024.

In Tanzania, the $30 billion Lindi LNG project, backed by TotalEnergies and Norway's Equinor, will develop gas from deepwater resources through a 10 million t/a plant. And South Africa could see its first LNG project. South African helium and natural gas producer Renergen has launched the first phase of the Virginia Gas Project in the Free State province. The facility is expected to have a capacity of 50 t/d of LNG, increasing to about 680 t/d in the second phase.

Overall, LNG export infrastructure capacity in the region is expected to rise to about 110 million t/a by 2030, and to more than 175 million t/a by 2040.

## Other feedstocks

There is still some nitrogen capacity in South Africa based on coal gasification, using Sasol technology. Sasol operates a 300,000 t/a plant at Sasolburg and two trains at Secunda with another 250,000 t/a. The Secunda facility is based on coal gasification, while Sasolburg uses the off-gases from the large scale Fischer-Tropsch plant, which used to run on coal but since 2004 has been converted to run on natural gas. From this AEL manufactures 420,000 t/a of ammonium nitrate for explosives use using ammonia sourced from Sasol, as does mining company Omnia, which has nitric acid, AN and CAN facilities at Sasolburg. Sasol has plans to switch Secunda to imported natural gas, possibly from the Rovuma project in Mozambique, in the medium term.

Zambia likewise developed coal-based capacity, including 100,000 t/a of ammonia production at Kafue, operated by Nitrogen Chemicals of Zambia (NCZ), as well as downstream nitric acid, ammonium nitrate and ammonium sulphate production. Most of this capacity has been closed down, but the AN plant was re-started in 2013 using ammonia imported from South Africa.

On the renewables side, Zimbabwe operated an electrolysis-based ammonia plant at Kwekwe using electricity from the Kariba Dam, but this closed in 2015 due to the high electricity costs involved. Sable Chemicals continues to run nitric acid and ammonium nitrate production at the site using ammonia imported from South Africa and produced 50,000 t/a last year.

## Renewables

There is considerable interest in the region, as there is elsewhere, in switching to renewable feedstocks. Sasol has conducted a feasibility study on building a 600 MW green hydrogen hub at Boegoebaai using a combination of wind and solar energy, with an option to expand into downstream renewable ammonia and methanol production. Likewise Omnia is conducting a feasibility study on using solar power to generate 100,000 t/a of ammonia for its feed, while in Zimbabwe, Sable Chemicals has discussed switching to renewable ammonia production, with a feasibility study on building 400 MW of solar powered hydrogen production.

Hive Energy in South Africa has plans for up to 780,000 t/a of renewable solar based ammonia production at Nelson Mandela Bay with a 1.3 GW solar array. The project is a joint development with Linde, with a price tag of $4.6 billion and a start-up date initially targeted for 2026, though almost certain to slip.

Elsewhere, MET Development has proposed a 200,000 t/a renewable ammonia plant at the Oserian Industrial Park, next to Lake Naivasha in Kenya, with a downstream urea plant based on Stamicarbon technology. The electricity grid in Kenya has a high renewables penetration, with about 90% of the energy derived from solar PV, wind, hydro and geothermal. Kenya has an "overcapacity" of electricity, with about 500 MW of installed capacity currently considered surplus to requirements.

## Nigeria

Nigeria has had a long history of domestic nitrogen production, beginning in 1987 with the National Fertilizer Company of Nigeria (Nafcon) plant, which operated 500,000 t/a of gas-based ammonia-urea production at Onne, near Port Harcourt in the east of Nigeria. The company suffered from financial and operating problems throughout the 1990s however, and Nafcon was sold on in 2005 to Egypt's OCI group, becoming Notore Chemical Industries. Notore refurbished the plant and reopened it in 2010. A subsequent debottlenecking project increased capacity to 430,000 t/a of ammonia and 750,000 t/a of urea in 2013.

Several projects to build new nitrogen capacity followed, but delays in gas allocations and difficult financing slowed development. The first new project to be commissioned was the Indorama Eleme Fertilizer and Chemicals Ltd facility at Port Harcourt, River State, developed by Indonesian chemical giant Indorama Corp. Toyo Engineering and Daweoo Nigeria built the plant using KBR ammonia technology for the 2,300 t/d ammonia plant and a Toyo license for the 4,000 t/d urea plant. The facility was commissioned in 2016, and a second, identical ammonia-urea train was completed in 2021, bringing capacity to 2.6 million t/a.

Outside of Indorama, the major development has been the $2 billion Dangote complex in the Lekki Free Trade Zone east of the capital, Lagos, next to a refinery and petrochemical plant run by the same company. The Dangote project has been a huge one, consisting of two 2,200 t/d Topsoe-designed ammonia plants feeding two 3,850 t/d Saipem urea plants, for a total of 2.5 million t/a of urea capacity. Completion of a gas supply pipeline pushed back the original start-up date, and covid added more delays, but the plant was finally fully commissioned in March 2022.

The Dangote complex takes Nigeria's urea capacity to 5.8 million t/a. This is considerably ahead of domestic consumption, although that has been rising as more fertilizer becomes available. Nigeria consumed 550,000 t/a of urea in 2016, but after the Indorama plant started up this rose to 750,000 t/a in 2017 and 1.7 million t/a in 2021. Nevertheless, both Indorama and Dangote rely upon export sales.

## Other projects

A few years ago there were a number of other nitrogen schemes proposed for the region, but outside of Nigeria no plants have actually been commissioned. Indian fertilizer producers have been interested in developing urea projects based on African gas for export to India, but difficulties in developing the projects and the rise of domestic capacity in India based on imported LNG have largely killed these schemes off. An Indian project for a 1.2 million t/a urea plant in Ghana was cancelled in 2014, as was a similar one in Gabon. Plans have also been floated for ammonia-urea plants in Cameroon, Tanzania, Mozambique and Angola, but so far none have made it past the design stage.

In Ethiopia, a 300,000 t/a coal-based urea plant that was to have formed part of a fertilizer complex being developed with Chinese assistance at Yayu remains only part complete. Meanwhile in 2021 phosphate giant OCP announced its involvement in a $3.7 billion gas-based ammonia-urea unit for Dire Dawa in Ethiopia with a capacity of 3,200 t/d, as well as downstream NPK production. However, the project has not progressed beyond the feasibility study stage. At present there are no active nitrogen projects under construction in sub-Saharan Africa.

## A temporary setback?

Promising improvements that had been taken in the development of fertilizer demand and production in sub-Saharan Africa have taken a step backwards with the covid pandemic and the dislocations to fertilizer and food markets caused by the war in Ukraine. Nevertheless, the gas developments that would be the basis for new nitrogen production in the region continue to progress apace. The success of Dangote and Indorama in Nigeria show that the development of domestic fertilizer production does lead to an increase in domestic fertilizer demand – urea consumption in Nigeria has more than tripled in just a few years. OCP continues to be forward thinking in this regard, developing partnerships and joint venture companies with local firms across the region. The region's potential for sustainable fertilizer production via renewables is also apparent and, indeed, local solar or wind power can overcome infrastructural deficiencies in gas or power distribution networks. It can only be hoped that the current crisis is just a temporary setback, and that Africa continues to develop as both a destination for fertilizer investment and demand. ■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# Ammonia Safety Symposium

*Below: The 2023 AIChE Ammonia Safety Committee. Front: Eugene Britton (CF Industries), Taylor Archer (Clariant), Ashutosh Shukla (FFI), Mohamad Noueiri (Yara), Dorothy Shaffer (BakerRisk), Venkat Pattabathula (SVP Chemical Plant Services), Marc Gilberston (East Dubuque Nitrogen Fertilizer), Seshu Dharmavaram (Air Products), Ahmed Esmael Rahimi (Qatar Fertiliser Company), Ameet Kakoti (Haldor Topsoe A/S). Back: Harrie Duisters (OCI NV), Klaus Noelker (thyssenkrupp Industrial Solutions AG), John Brightling (Johnson Matthey), Umesh Jain (KBR), Federico Zardi (Casale SA), Samuel Okulaja (Nutrien).*

PHOTO: AICHE

**Venkat Pattabathula**, a member of the AIChE Ammonia Safety Committee, reports on the American Institute of Chemical Engineers' Safety in Ammonia Plants and Related Facilities Symposium, held in Munich, Germany, from 20-24 August 2023.

The Ammonia Safety Committee is dedicated to improving the safety of plants that manufacture ammonia and related chemicals, such as urea, nitric acid, ammonium nitrate, and methanol. The conference's objective is to improve the safety performance of the ammonia industry. This is achieved by sharing information on incidents, safety practices, and technology improvements in presentations and open discussions.

From 20-24th August 2023, 360 engineers from more than 30 countries and 100 companies attended the AIChE's 67th Annual Ammonia Safety Symposium at The Westin Grand Hotel in Munich. Attendees who participated in the Symposium included plant managers, production managers, safety managers, process/reliability engineers, and everyone responsible for the safety and performance of ammonia plants or handling facilities, to hear worldwide experts discuss the latest advances in safe production and use of ammonia, case studies, and lessons learned at these symposiums.

## Zero accident vision

This year's keynote speech; Zero Accident Vision – What would it take? was presented by Volker Andresen, Sustainability Director of the International Fertiliser Association (IFA). Volker started his speech with a universal truth: "nobody wants to get hurt."

He began with a brief history of workplace safety, from the divine protection sought by stone age hunters and gatherers to the first known set of employment laws to ensure safety and prevent workplace accidents, dating to ancient Egypt. In the modern era, at the beginning of the industrial revolution, the English Parliament passed the first factory work regulations in 1802, setting limits on working hours and establishing minimum standards for hygiene, health, and worker education. However, it was a century until checks were made that the laws were being adhered to, when in 1898 Sir Thomas Morrison Legge was appointed the first British medical factory inspector. After World War One, the International Labor Organisation (ILO) was established in 1919 under the Treaty of Versailles to promote social protection, workers' rights, and the improvement of working conditions globally. Yet according to the ILO in 2023, work still kills more people than wars globally.

Turning to the ammonia industry, Volker said that the International Fertilizer Association, founded in 1927, remains the only global fertilizer association, with a mission to promote the efficient and responsible production, distribution and use of plant nutrients. It has 470 members from 80 countries across the entire fertilizer value chain. IFA's member and stakeholder surveys confirm that safety is on everybody's mind. Safety (including security) is the number one driver of the industry's reputation. To improve the overall reputation, stakeholders need to believe that this industry is committed to creating global best practices in product safety and security. In 2018, the two-year IFA 2030 scenario planning reconfirmed the importance of safety and security for keeping our industry's license to operate in the 2020s.

IFA's surveys suggest that the main occupational safety issues include: lLack of personal protective equipment; inadequate procedures and controls; insufficient training (especially of contractors); poor internal communications; fatigue, stress, distractions; and human errors, including complacency. Meanwhile the main process safety issues include: insufficient process safety procedures; poor process safety controls; inadequate hazardous material storage and handling; improper segregation of incompatible chemicals; equipment failure and malfunction; and lack of emergency preparedness.

IFA members formally agree on the 12 Safety, Health, and Environment (SHE) Principles:

- Striving for zero harm
- Demonstrating company leadership and management commitment
- Setting annual objectives, targets and key performance indicators
- Complying with local laws and embracing global best practices

Members have developed IFA's Safety Handbook to benefit the entire fertilizer industry; it is 58 pages long and available in English, Arabic, Chinese, Spanish and Portuguese. Its first chapter describes the major principles behind positive safety management: PDCA – Plan, Do, Check, Act – and successful execution; POPMA – Policy, Organisation, Planning, Measuring, Auditing.

Since 2001, IFA has also published its annual safety benchmarks. These are 100% voluntary, confidential and free, and include Lost Time Injury Rate and Total Recordable Injuries and can help measure the effectiveness of safety management systems and compare them against the industry's best safety performers, allowing companies to develop organisation-specific key performance indicators. Members can participate online in English, Chinese, and Russian.

Online education includes webinars with IFA Green Leaf Award winners and safety and security classes of IFA's Sustainable Fertilizer Academy. In-person education includes security workshops with organisations like the US Army in sub-Saharan Africa and the roll-out of a chemical identification test kit with pocket wizard, which IFA helped the World Customs Organization to develop. Written education includes IFA's Safety Handbook and a product security poster campaign for its retailer and distributor network in Sub-Saharan Africa.

So how can we turn a zero accident vision into reality? Safety expert advice includes making the 'Must Win Battle', led by senior company staff. Companies should apply existing best practices and systematically melt the "accident iceberg" – an acknowledgement that for every incident that is recorded, there are many near misses which perhaps are not but from which key learnings can be taken. Companies should build partnerships with everyone involved; employees, contractors, first aiders, firefighters, and regulators. Complacency is the enemy!

Volker concluded by noting that technology is now bringing unprecedented opportunities for sefty improvement via areas such as robotics and automation, collaborative robotics, smart wearable technology, sensor-based hazard detection, AI-based safety analytics and Virtual Reality training sessions, and allows for new out of the box thinking, such as drone inspections for hazard elimination, the introduction of smart traffic safety sensors. Some companies have used a safety blackboard to report incidents anonymously with no names mentioned. Safety is not a destination, but a never-ending journey.

## Safety incidents

The key safety-related papers were:

### Secondary reformer outlet transfer line rupture

On February 17, 2022, the Dyno Nobel Plant in Waggaman, LA, experienced a rupture of the Secondary Reformer outlet transfer line of its 2300 t/d KBR ammonia plant. Fortunately, there were no injuries from this incident. This loss of containment resulted in a significant fire, damaging adjacent equipment and instrumentation. This paper reviewed the incident and the troubleshooting of the other front-end reactor effects and remedies undertaken to repair the transfer line and restart the plant.

It was determined through the extensive root cause analysis that the failure was ultimately caused by a liner weld that had failed and, when inspected and tested, appears to have been originally of poor quality, with some lacking full penetration depth. Analysis revealed that hot cracking likely occurred in the extension welds during fabrication. Additionally, deviations were made from the original liner slip joint design drawings, such as the mating direction of the sliding joint being found reversed from the design drawings.

The refractory layer in the middle segment was also found to have undergone alkali hydrolysis throughout its entire thickness. Alkali hydrolysis is a reaction in which the cement that binds the refractory is converted into carbonates in water and $CO_2$, causing cracking and decreasing strength and stability. It was determined that after installation, the refractory had not been adequately protected from atmospheric $CO_2$ and had not dried for months until commissioning. It was also noted that there had been extensive delays in the dry-out process during plant commissioning of the bubble alumina refractory material after pouring. This delay left the refractory in a state where rapid deterioration permitted a gas path to form to the pressure shell and exposed the shell to temperatures well over the design conditions.

The transfer line was rebuilt to the intended design with more rigorous QA/QC controls to ensure a higher liner standard and refractory installation.

### Failure of secondary reformer due to top dish head rupture

After more than 41 years of trouble-free service, a fire jet with an explosion occurred due to loss of containment from a secondary reformer top dish head at Fauji Fertilizers. A crack in the pipe base metal allowed the premature entry of air into the flammable process gas environment ahead of the burner, where it ignited, causing failure of the refractory, exposing the metal surface to high temperatures of burning gas, resulting in a dish-head rupture. The dish head was restored by welding an insert patch, three-dimensionally formed from a carbon steel plate, using in-house resources and plant production was resumed in just 15 days.

Secondary reformers' failures are rare in the industry, and the risks associated with such failures are normally very high. The explosion at FFC resulted from a weld crack in the air inlet pipe of the burner. This crack formed a passage that let air into the reformer, ahead of the burner, where flammable process gas ignited, and this failed the refractory, thus exposing the metal surface to very high temperatures above the design values and eventually resulting in loss of containment. The failure's root cause was weakness in the design, which the designer improved in later years at new plants. However, this improvement was not carried out on this ~41-year-old equipment due to a lack of communication and documentation sharing. Learning from the incident, a robust action plan was developed to address vulnerable areas and mitigate risks associated with ageing plants, including improved liaison with the process licensor and document sharing, RBI and PSM systems implementation and establishment of an Asset Reliability and Integrity department.

## Mixed feed reheater manifold and piping failures

A significant failure occurred on the mixed feed reheater (B-901) 304H stainless steel outlet piping system at Nutrien number 3 ammonia plant in Point Lisas, Trinidad in July 2022. This paper explored the failure of the piping and presented an analysis of the causal factors. The effects of creep, sigma phase embrittlement and solidification cracking are examined, and the lessons learnt were highlighted.

During start-up operations a hissing sound was heard near the mixed feed reheater. Insulation was seen dislodged from the area where the hissing sound was being emitted, prompting an immediate plant shutdown. Further investigation revealed multiple cracks on the mixed feed reheater outlet manifold and associated outlet piping from B-901 to the B-701 primary reformer. Repairs and partial replacement were conducted on the failed sections to return the plant to production, with the intent of a complete replacement during the October 2022 turnaround.

Type 304H stainless steel is widely used in the industry and has shown good performance overall. However, it is recognised that 304H stainless steel is susceptible to sigma phase embrittlement after prolonged periods of high-temperature operation. Detailed review and selection of electrode specification is necessary to ensure the produced ferrite content is within the recommended electrode specification to avoid sigma phase embrittlement and solidification cracking. The presence of the sigma phase is directly related to reduced creep ductility, as was observed in the failures. Solidification cracking can be prevented during welding with adequate quality control.

The failures have brought awareness to the importance of adjusting inspection test plans to capture all potential damage mechanisms adequately. Inspection test plans for in-service operation and fabrication/repair activities should be provided. Emphasis should be placed on inspection and possible asset replacement to mitigate against these damage mechanisms in aging facilities.

## Two-phase flow in a high-speed compressor

The centrifugal air compressor of the ammonia plant at the MOPCO site in Egypt consists of high pressure and low pressure stages which had a damaging effect on the two-phase flow of the high-pressure stage due to a malfunction in the intercooler of the high-pressure section. A full investigation into the incident determined that improper assembly of the third intercooler bundle during a major overhaul in June 2014 led to damage to sealing strips so that hot gas could bypass the bundle rather than flow through it. The malfunction of the mechanical condensate trap prevented the condensate from flowing outside the cooler; this then caused carry-over of condensate with the gas flowing towards the compressor fourth stage suction, i.e. two-phase flow affecting the HP rotor behaviour established a high shaft vibration at average rotor speeds, which was thought to be imbalanced during the preliminary analysis.

Corrective actions included inspection of all compressor minor and major parts. All clearances were measured and adjusted to tolerance ranges. The intercooler stage bundle was replaced with a new one and the intercooler stage shell cleaned and painted using a new heavy-duty paint. The mechanical trap was replaced with a large sized and capacity one (1 inch to 2 inches) with a sight glass and electronic sensor connected to the DCS to ensure the trap was always in service. It was also added to the preventive maintenance plan for mechanical traps, which is checked weekly. MOPCO also replaced the level switch with an advanced high-sensitive type to ensure accuracy, replaced the journal bearing NDE side with a new pad and replaced the entire HP rotor.

## Hydrogen plant relief line failure

On May 7, 2010, a relief line piping failure associated with the low temperature shift converter (LTSC) in Chevron's Pascagoula refinery occurred. This event happened during a shutdown of the hydrogen plant to address mechanical issues with the gas turbine downstream of the LTSC. To maintain temperatures in the LTSC and shorten startup duration, the startup line was used to vent the heat-up gas to relief downstream of the reactor. The line failure was attributed to fatigue caused by an unusual failure mechanism; acoustic-induced vibration due to the line not being designed for the full gas flow rate. This event highlights the importance of having and following well-written procedures, recognising and mitigating risk, and completing thorough risk assessments through the management of change process.

The operator training program was updated to include acoustic induced vibration awareness and the risk associated with venting full process flow through atypical vent locations. Cautions were added to the normal startup and shutdown procedures to warn against routing full process flow through these vent lines. These lines were also locked closed (due to the low frequency of these valves being used) and tagged with the same warning.

## Unprecedented catalyst migration problem

In August 2021, the 2,000 t/d ammonia plant of Petrokimia Gresik in Indonesia experienced an increasing pressure drop on the synthesis loop, from 6.3 $kg/cm^2$ to 8 $kg/cm^2$. Ammonia converter basket breakdown was causing unprecedented catalyst migration to some synthesis-loop equipment and increasing pressure drop, most notably on the unitised chiller tube annulus. The plant rate was reduced to 75% and at risk of getting lower than the turn-down rate. The ammonia converter basket was then repaired, and many methods and efforts were made to remove the migrated catalyst from the equipment, especially the chiller tube annulus.

Much effort was required to remove the catalyst trapped in the annulus of the unitised chiller. The most effective method after several attempts was a combination of water circulation with air blowing using an air compressor. Limited cleaning access for the synthesis loop heat exchangers caused residual catalysts to remain in the dead-zone area. This residual catalyst could migrate to downstream equipment and cause further blockages. Good teamwork between the operations team, process engineers, and maintenance team was the key to successfully achieving rapid fabrication of the cone strainer and its smooth installation. Close monitoring of the delta pressure cone strainer is necessary to determine the program for cleaning the strainer as soon as needed. mitigation for catalyst migration of ammonia converter to downstream equipment should be provided for the new ammonia plant.

Next year's Symposium will be in San Diego, CA, USA, on 8-12 September 2024. ■

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# Incentives for green production

*Solar array at Baofeng Energy's 450MW green hydrogen project, China.*

PHOTO: BAOFENG ENERGY

The US Inflation Reduction Act has been a major step in terms of incentivising green syngas production, and has encouraged other governments to look at their own regulatory regimes.

The passage in August 2022 of the US Inflation Reduction Act (IRA) is one of the largest public investment proposals in US history, and has been a game changer in terms of subsidies for green chemical production. The act establishes new incentives for low carbon hydrogen production and other technologies such as carbon capture, and allows for up to $369 billion in federal tax incentives for green energy investments.

As well as lowering the cost of renewable electricity, of particular interest to the syngas industry are the IRA's tax credits for green hydrogen production, via the so-called provision 45V. Qualifying hydrogen production facilities can obtain a ten-year production tax credit of up to $3/kg beginning from the date that facility begins operation, though it is worth noting that the credits expire in 2033, so only facilities starting this year would gain the full ten years. The full $3 is also only available for production that results in less than 0.45kg $CO_2$ per kg hydrogen in terms of life cycle emissions, with lower subsidies of $1/kg, $0.75/kg or $0.60/kg for more polluting technologies, up to a cap of 4kg $CO_2$/kg hydrogen, and also depends upon labour and wage standards being met.

The act also establishes a 45Q tax credit for facilities using carbon capture, utilisation or storage (CCUS), i.e. so-called blue hydrogen which lowers the thresholds at which projects can gain credits, in the case of industrial facilities from 100,000 t/a down to 12,500 t/a. There is also a section 48 which allows for investment tax credits (ITCs) for hydrogen producing facilities, again subject to how green the production is.

Many in the industry have said that it makes the US the best place to invest in green technology now, with the cost of green hydrogen production becoming possibly as low as $2/kg – the US Department of Energy has set the target for the green hydrogen price at $1/kg by the end of this decade.

## Europe

The passage of the IRA initially caused some consternation in Europe, used to leading on environmental matters, where regulators have preferred to use carbon pricing and emissions limits as a way of forcing industry to go green (though often driving it overseas). The European Commission published its REPowerEU plan on 18 May 2022, which sets a target to increase the EU's renewables share of power generation to 45% by 2030. The plan has an ambitious low-carbon hydrogen production target of 10 million t/a, with an additional 10 million t/a of imports by 2030. Refining and ammonia and methanol production are likely to be the major producers or consumers of green hydrogen, though these only represent around 5 million t/a of hydrogen production in the EU, so the 20 million t/a target envisages a large scale switch in other industries as well. The EU has allocated €41billion as part of the REPowerEU plan to switch from fossil fuels to alternatives and €27billion to develop key hydrogen infrastructure.

## Elsewhere

India has also seen green hydrogen as a way of reducing its reliance on coal, and is said to be preparing a $2 billion incentive programme for the green hydrogen industry, aiming to reduce the production cost by 20% over the next five years. The Strategic Intervention for Green Hydrogen Transition (SIGHT) programme reportedly allocates $540 million for electrolyser manufacturing for five years and $1.6 billion for green hydrogen and green ammonia production for three years, with a production incentive of approximately $1/kg hydrogen. In February the government announced plans for India to make 5 million tonnes of green hydrogen annually by 2030, roughly equivalent to all of India's current production for refining, fertilizer and steel manufacture.

But rather than private incentives, other countries are simply pushing government money into projects. Saudi Arabia is moving ahead with its NEOM project, which will include 1 GW of electrolyser capacity, via the backing of the Saudi sovereign wealth fund as well as a firm offtaker (co-developer Air Products). And perhaps the most striking example is China, where around 1 GW of electrolyser capacity will be built this year alone. China does have the cheapest cheapest electrolysers in the world, and is also the world's largest hydrogen producer, responsible for around one third of global hydrogen production (33 million t/a in 2020, most of it from coal and only 1% from renewables). The Chinese central government has set a production target of 100-200,000 t/a of renewable hydrogen per year by 2025, with renewable share of hydrogen production rising to approximately 15% by 2030 via the Mid-and-Long-Term Hydrogen Industrial Development Plan (2021-2035). The plan aims to achieve this by scaling up and increasing the productivity of Chinese production, facilitated by "supportive electricity prices" and the establishment of technical standards. It is believed that government support for hydrogen projects currently runs at around $10 billion per year. ■

# Can SAF really help the sector transition to net zero?

*It is becoming increasingly clear that SAF will play a significant role in helping the aviation sector achieve net zero.*

PHOTO: ISTOCK/DONGFANG ZHAO

Sustainable aviation fuel (SAF) is increasingly seen as a vital tool in the aviation sector's transition to net zero. These drop-in fuels, which can be derived from bio and renewable-derived syngas, are used to dilute the fossil-derived components of fuel and are fully compatible with existing fuel infrastructure. This positions SAF as a convenient and rapid route towards decarbonisation. However, questions remain around its ultimate viability at scale and whether it really can be the 'silver bullet' aviation leaders are looking for. We spoke to **Paul Ticehurst** from Johnson Matthey (JM) to shed some light on SAF and the future role of syngas in aviation.

**Could you give a brief introduction to yourself, including your role at JM and your background?**

My name is Paul Ticehurst, and I am a Senior Business Development Director at Johnson Matthey. I have over 25 years of experience developing process-based projects and working throughout Europe and the US which I use to inform my current role, where I have commercial responsibility for Fischer-Tropsch CANS™ technology and Johnson Matthey's HyCOgen™ reverse-water gas shift reaction.

**In your own words, what recent events are shaping the aviation industry's approach to meeting net zero?**

The aviation industry's journey towards achieving net-zero emissions is being shaped by several influential factors.

The two biggest drivers, in my opinion, are target-orientated sustainability goals and evolving public perspectives.

For instance, in 2022, the International Air Transport Association (IATA) approved a resolution aiming to achieve carbon-neutral status across the global air transport industry by 2050. This significant commitment is a key step towards net zero, as the IATA represents roughly 300 airlines, covering around 83% of total available seat miles in air traffic[1].

According to the IATA's strategy, SAF will contribute around 65% of this reduction of emissions, with the rest being made up of new technologies and incremental infrastructure changes[1].

*Paul Ticehurst*

PHOTO: JOHNSON MATTHEY

Additionally, the general public's attitude towards flying is helping to galvanise airlines towards adopting increasingly ambitious sustainability targets. Manifesting in trends such as 'flight shaming', where activists are encouraging people to consider the carbon impact of their flying, an increasing number of people are seeking climate-conscious ways to fly.

Overall, these drivers are impacting the entire aviation sector and steering airlines, fuel producers, and governments towards a more rigorous approach to making flying more sustainable.

**SAF only makes up around 0.03% of total aviation fuel use. How can airlines expect to meet the IATA's net-zero targets by 2050? Can SAF technologies really make up this shortfall?**

Momentum for SAF is rapidly picking up steam across the world and several major


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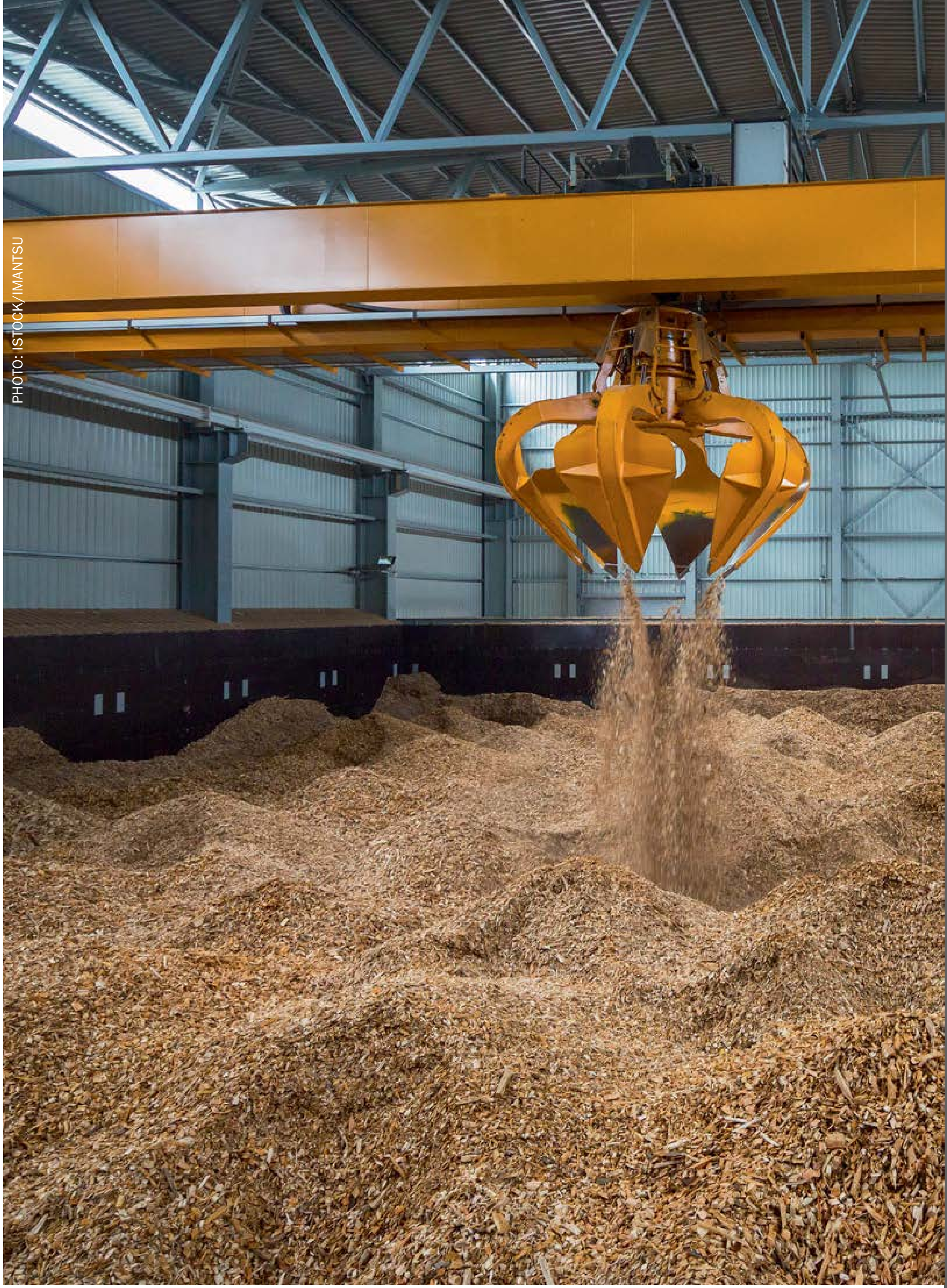


PHOTO: ISTOCK/IMANTSU

economies have set ambitious targets for adoption. For example:

- The US is aiming for 10% SAF usage by 2030 and 100% by 2050[2].
- The UK is aiming for 10% by 2030 and 75% by 2050[3].
- The EU is aiming for 5% by 2030 and 63% by 2050[4].

Meeting these targets will only be possible if much-needed investments are made to build the infrastructure and supply networks to support SAF at scale. Looking at the current market, exciting opportunities for growth are emerging, for example, adoption in major travel hubs such as London's Heathrow Airport, the first UK major airport to integrate SAF into its fuel distribution. Additionally, governments are taking proactive steps to support their SAF targets by implementing effective financial incentives. Here, policy makers can accelerate production by bridging the cost gap between SAF and traditional fossil jet fuel.

In the US, the Inflation Reduction Act (IRA), provides a new combination of grants and tax credits to incentivise SAF production. In particular, the IRA makes SAF eligible for two separate tax credits that can be redeemed successively. The first is a two-year SAF blender's tax credit (BTC) based on the Sustainable Skies Act. After the BTC ends in 2024, SAF will be eligible for the new Clean Fuel Production Credit until it expires at the end of 2027.

Many individual states such as California and Oregon also have additional tax breaks to incentivise low carbon intensity SAF. Across the Atlantic, the EU is enacting non-compliance penalties for failing to use SAF from 2025 onwards. The amount they are required to supply starts at 2% of their overall fuel consumption in 2025 and reaches 70% by 2050[5].

**What role will syngas-based technologies play in the aviation sector's transition to net zero?**

By utilising the Fischer-Tropsch (FT) process, producers can convert syngas into synthetic crude, which can then be further upgraded into SAF. This syngas can be derived from a wide range of sources, including waste biomass and municipal solid waste. Technologies also exist to convert electrolytically produced (green) hydrogen and captured carbon dioxide into syngas – providing another route to SAF for fuel producers.

The wide range of feedstocks that can be utilised with these technologies enables a flexible pathway to SAF. Allowing fuel producers to tailor plant development to the local feedstock availability and environment. For example, the Fulcrum Sierra BioFuels waste-to-fuels Plant in Nevada utilises gasification to produce syngas from household rubbish that would otherwise be destined for landfill[6]. Conversely, the Repsol and Aramco plant in Bilbao, Spain, will become one of the world's first to use green hydrogen and carbon dioxide. This approach is enabled by a catalysed process by HyCOgen™, a reverse water gas shift technology developed by JM[7].

**What is your response to reports saying that current feedstock supplies are inadequate to meet SAF mandates across the world?**

Some SAF technologies, such as hydroprocessed esters and fatty acids (HEFA), rely on volatile feedstock markets. However, the feedstock flexibility that FT has will most likely benefit its users in the near future. The ability to utilise green hydrogen, for example, will spur green hydrogen-derived SAF as the fuel inevitably becomes more widespread. SAF projects can even drive green electricity generation in some cases; for example, the EU has 'additionality rules' that state green hydrogen is only classified as 'green' if the electricity used to produce it is derived from new renewable capacity.

Furthermore, organisations such as the World Economic Forum have also found that enough sustainable feedstock supplies – including municipal solid waste, agricultural residues, and cooking oil waste – exist to reach SAF production

*Syngas can be produced from a wide range of feedstocks, such as biomass or municipal solid waste, making FT largely feedstock agnostic.*

levels of 500 million tonnes annually by 2030 and meet projected demand[8]. From a feedstock perspective, the future of SAF is secure.

**In your opinion, are there any additional measures that could help the sector achieve its ambitious targets?**

Currently, the key obstacle for project developers is driving confidence in SAF. As a relatively new sector, financiers are often reluctant to invest in projects until it has been proven more extensively. In the meantime, governments need to instil confidence in the sector. To stimulate growth, governments could potentially underwrite the risk being taken on by banks. An approach that has been suggested in UK consultations on the subject[9]. Additional financial incentives would also be valuable in pushing the sector towards more widespread adoption and helping to stimulate the creation of a SAF economy. As it stands, SAF is poised to grow incredibly quickly – it just needs a show of confidence.

**When selecting a technology partner for a SAF project, what key considerations should project developers consider?**

Working with an expert partner in syngas is very valuable, especially for smaller or less experienced developers. Simply being able to rely on comprehensive technical and commercial expertise during plant deployment is often critical to its long-term operations and profitability. Furthermore, when using a technology like FT which may involve utilising an unfamiliar feedstock, being able to ensure aspects like optimal conversion performance is fundamental. Working with partners who have proven experience in the sector can also help shore up confidence in new projects.

Some smaller developers may also find integrated solutions, such as JM's HyCOgen™/FT CANS™ technologies, that align better with their priorities. This integrated, end-to-end solution turns over 95% of captured carbon dioxide into high quality synthetic crude oil, ready for upgrading to SAF[7].

In the pursuit of a net-zero future, the aviation industry faces big decisions and potential hurdles. However, these obstacles are not insurmountable. In fact, by leveraging the appropriate technologies and fostering close collaboration across the value chain, the widespread adoption of sustainable aviation fuel is highly achievable. Working together, the aviation sector has the potential to shape a better, connected tomorrow. ■

## References


1. Net-Zero Carbon Emissions by 2050. https://www.iata.org/en/pressroom/pressroom-archive/2021-releases/2021-10-04-03/ (accessed 2023-07-12).
2. FACT SHEET: Biden Administration Advances the Future of Sustainable Fuels in American Aviation. The White House. https://www.whitehouse.gov/briefing-room/statements-releases/2021/09/09/fact-sheet-biden-administration-advances-the-future-of-sustainable-fuels-in-american-aviation/ (accessed 2023-07-12).
3. Pathway to Net Zero Aviation: Developing the UK Sustainable Aviation Fuel Mandate.
4. Fit for 55 and ReFuelEU Aviation. EASA. https://www.easa.europa.eu/en/light/topics/fit-55-and-refueleu-aviation (accessed 2023-07-12).
5. New law agreed to cut aviation emissions. European Commission - European Commission. https://ec.europa.eu/commission/presscorner/detail/en/ip_23_2389 (accessed 2023-07-12).
6. Johnson Matthey and bp's innovative FT CANS technology successfully produces product for Fulcrum's Sierra waste-to-fuels plant. matthey.com. https://matthey.com/fulcrum-sierra-23 (accessed 2023-07-12).
7. HyCOgen FT Cans Aramco Repsol. matthey.com. https://matthey.com/hycogen-ft-cans-aramco-repsol (accessed 2023-07-12).
8. All Aircraft Could Fly on Sustainable Fuel by 2030, Says World Economic Forum Report. World Economic Forum. https://www.weforum.org/press/2020/11/all-aircraft-could-fly-on-sustainable-fuel-by-2030-says-world-economic-forum-report/ (accessed 2023-07-12).
9. Sustainable Aviation Fuels Mandate - Summary of Consultation Responses and Government Response.

# Optimise fertilizer production by plant digitalisation

Plant digitalisation can contribute to increase the profitability of chemical plants by optimising performance of operation as well as maintenance. Available digital products range from visualisation of plant data for increased transparency to closed-loop AI controllers based on digital twins.

**Kathrin Rodermund, Johannes Dammeier, Johannes Franz, Sascha Wenzel (thyssenkrupp Uhde)**

Digitalisation is a large field of unlimited possibilities. It is not surprising that it can mean different things to different people. Commercial experts look at accounting, order management, warehouse management and other elements, mostly covered by modern ERP systems. Engineers are interested in operating data and their optimisation or are developing new ways for designing plants. Others may be looking from different perspectives. However, all areas of digitalisation have one thing in common: new applications, more powerful computers, and better network connections, even in remote locations, offer ever increasing possibilities of digitalisation.

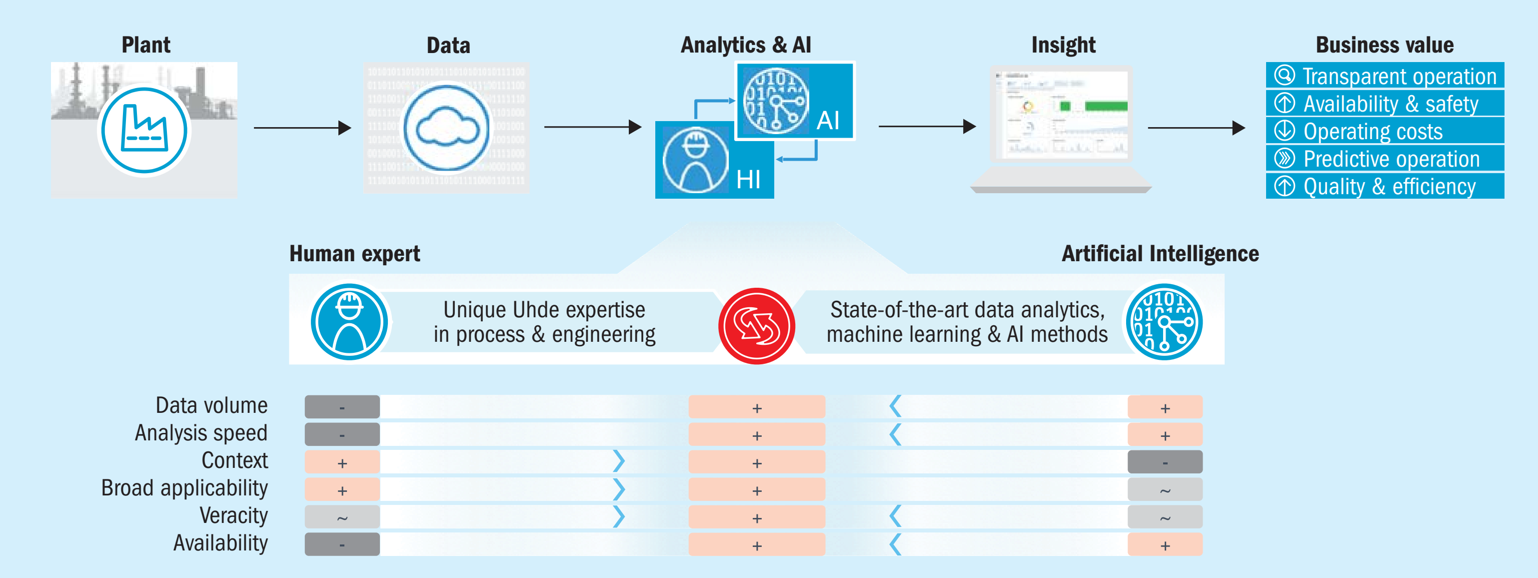
McKinsey expects that chemical companies can improve their end-to-end EBITDA by 8.5 to 16% by applying digital technologies[1].

However, there are also some critical issues which must be mentioned. Of course, data security is an important topic to be discussed as cybercrime is increasing every year. In addition, digitalisation can be disappointing for customers, especially when it comes without domain expertise. The simple use of algorithms does not solve customer problems in most cases. It usually needs domain experts to interpret data and consult customers on how to optimise their operation, which is not surprising in a very complex environment in which typically several hundred signals must be processed.

thyssenkrupp Uhde has been active in plant digitalisation for more than 15 years and in chemical process technologies as well as engineering and construction for more than 100 years.

Today, thyssenkrupp Uhde offers a wide range of digital products which help its customers to maximise production, reduce raw material and energy consumption as well as effectively lower emissions. In addition, digitalisation can significantly improve plant availability and safety.

Fig. 1: **Combination of human and artificial intelligence leading to optimal results**




*Source: tkIS*

Digital products can be divided into four categories (Fig. 1):

1. **Data analytics and consultancy:** This includes service products like remote condition monitoring of the plant, regular reporting with thyssenkrupp Uhde expert advice and root cause analysis of issues.
2. **Digitalised maintenance:** This covers methods to detect wear, predict failures and the remaining lifetime.
3. **Predictive operation:** These products support personnel to operate the plant to increase production rate, availability and product quality, while lowering consumption figures.
4. **Performance optimisation:** While digital products from category 3 are still "open-loop", leaving the final decision whether to follow the suggestions with the operators, products within this cluster automatically optimise plant performance without involvement of operators.

Many of the products from categories 2 to 4 are based on a "digital twin". However, what is a digital twin and how can it help customers?

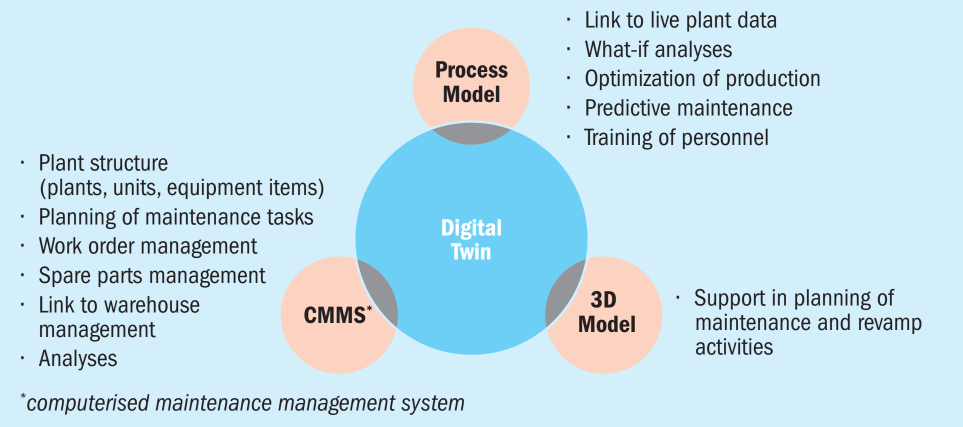
By definition, a digital twin is a virtual representation of a physical object that should describe this object in a precise manner. Digital twins can be found in the fields of science, medicine, engineering, pharmaceuticals, sports, and many more.

A digital twin of a chemical plant may cover the following elements (refer also to Fig. 2):

- **Process model:** This model describes the process behaviour of the plant and is typically either based on a process simulation (white box) or an empirical, mathematical (black box) model. Such models help to optimise plant performance.
- **3D model:** Typically developed during the engineering phase, this model represents the exact geometrical representation of the plant and can be used for planning of maintenance and revamp activities.
- **Maintenance management model:** Typically, this is available in all modern CMMS applications and contains equipment information like data sheets, spare parts, equipment history, planned maintenance tasks, etc.

thyssenkrupp Uhde is able to provide all of the above-described models and combine them to generate one common digital twin of a chemical plant. Alternatively, it is also possible to focus on single elements only, e.g., the process model.

Fig. 2: **Possible elements of a digital twin**




*Source: tkIS*

In the following sections, some examples of digital products applied in customer projects are described.

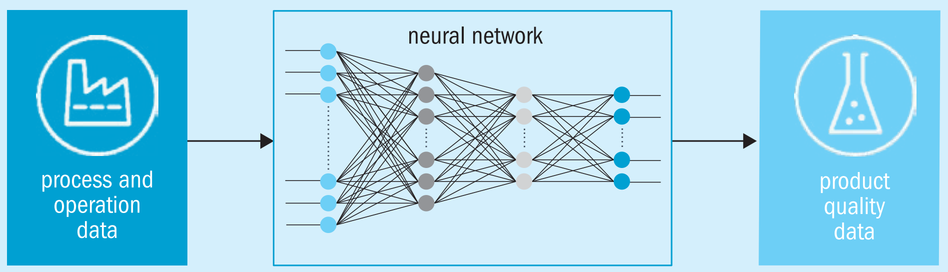
## Product quality prediction in CAN granulation

tk Uhde and Tech Center Control Technology (TCCT), thyssenkrupp's competence centre for data analytics and AI, have jointly developed a method for quality prediction in CAN granulation to solve the problem of the accumulation of off-spec material in this complex process with a large recycling loop during the time-consuming laboratory analysis. State-of-the-art machine learning algorithms like neural network models were used to develop the AI (Artificial Intelligence) tool. The neural network was trained with historical data to predict the main quality parameters of the solid nitrate fertilizer: nitrogen content, humidity and hardness.

After initial training, the tool was rolled out and implemented together with a fertilizer producer in a tk Uhde pugmill granulation plant. It predicts the main quality parameters almost instantaneously, based on live process data coming from the DCS, and thus works as an online AI soft sensor. If recent laboratory data are available, the AI tool is even capable of providing a forecast for the main product quality data for the upcoming two hours if the process conditions remain unchanged. Comparisons with laboratory test results show a high accuracy of the model in continuous operation of the plant. 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, thus maximising the yield of the production facilities.

All AI soft sensor data as well as the process data are visualised in web dashboards which are full customisable and can be adapted to the customer needs. They allow the process data and predictions to be queried and analysed at any point of time.

Fig. 3: **Principle of an artificial neural network**




*Source: tkIS*

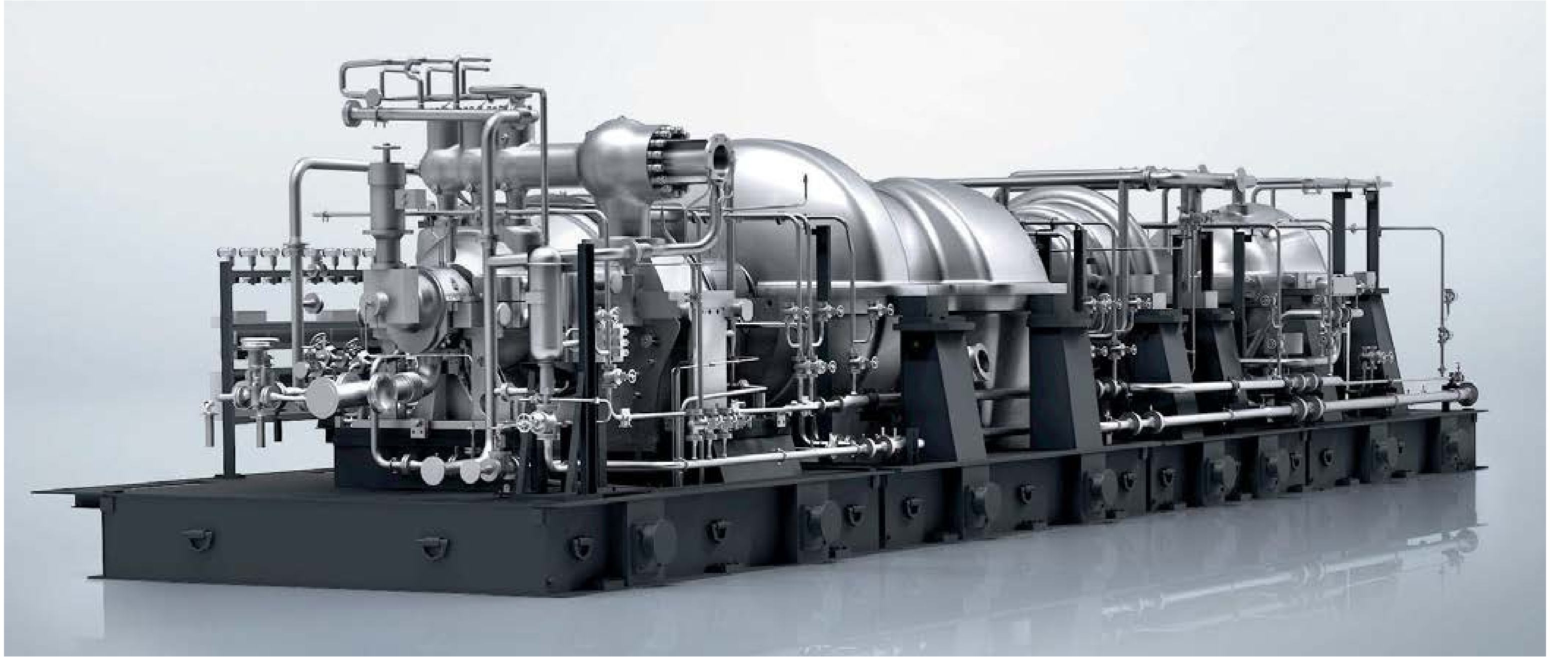


PHOTO: MAN ES

*Fig. 4: "NAMAX" nitric acid compressor train.*

## Co-operation with MAN Energy Solutions regarding nitric acid plants

In nitric acid plants, the compressor train is not only an exceptionally complex piece of equipment, it is also deeply integrated into the nitric acid process. Therefore, aiming at a higher degree of autonomy and optimised operating points of nitric acid plants, it is advantageous to optimise the compressor train controls and plant controls together.

Uhde has constructed nitric acid plants for almost a century, now. Today, Uhde is a global market leader in nitric acid technology, offering capacities of up to 2,000 t/d of nitric acid (100%). Since the 1950s, Uhde has built and commissioned more than 130 plants. MAN ES is a global market leader for nitric acid compressor trains (Fig. 4) equipping the majority of new-built nitric acid plants. MAN ES has proven its expertise in autonomous operation in the field of unmanned sub-sea turbocompressors. Moreover, during the pandemic, MAN ES has gained experience in remote commissioning. For these reasons, MAN ES and Uhde are perfect partners for the development of autonomy solutions for nitric acid compressors trains and plants.

A joint task force has been set up, which is currently combining rigorous physical relations and real-life data with AI methods and digital controllers. The task force consists of process and machinery experts as well as process simulation professionals and data scientists.

thyssenkrupp Uhde and MAN Energy Solutions (MAN ES) have joined forces to use artificial intelligence to support plant operation, considering product price and resource costs, energy efficiency, maintenance aspects as well as process stability. The focus of the development is a higher degree of autonomous operation considering the above-mentioned goals for efficiency and stability.

## Digital products for new fertilizer complex

tk Uhde provided various digital products to support the operation and maintenance of a new fertilizer complex just recently started up in the Middle East, i.e., an operator training simulator, remote performance monitoring including online dashboards and regular reports (Fig. 5) as well as digital twins for the various plants.

The digital twins are based on process models which are either based on a process simulation (white box digital twin) or on artificial neural networks (black box) which first must be trained and verified based on plant data.

Typically, white box digital twins are applied for Uhde's proprietary technologies for which process simulations have already been used to design the plants. These process simulations will then be further enhanced by adding design parameters from the engineering phase like equipment and piping dimensions, pump and valve curves, etc.

Black box digital twins can also be applied for very complex systems in which not all relations are exactly known, e.g., for prediction of product parameters when producing solid particles (refer to quality prediction in CAN granulation).

The digital twins will be applied for testing of new process parameters to run "what if" analyses. They also offer anomaly detection to make the operators aware of any potential problems.

## AI controller for aromatics extraction

In the following example one of the newest developments in plant digitalisation is described. Although it has been applied in aromatics extraction, an important petrochemical process, similar systems may also be used for fertilizer applications.

tk Uhde's Morphylane technology is one of the leading aromatics extraction technologies in the world which can be used to produce high purity benzene and toluene from feedstocks like reformate, pyrolysis gasoline or coke-oven light oil.

To further enhance its performance, tk Uhde, TCCT and German refinery Holborn have jointly developed a digital twin which can be used to adjust relevant process parameters like the solvent flow rate and temperatures depending on the feed to this very complex system. The digital twin is based on an artificial neural network which has been trained and verified based on process data from the real production plant. Its machine learning algorithms continuously improve the model with time.

In a first phase, the digital twin has been operated in an open-loop

Fig. 5: **Online dashboards and regular reports support customers in day-to-day operation and maintenance**


*Source: tkIS*

arrangement for some time, offering guidance to the operators who still needed to adjust the set-points in the control system manually. Now, it is even possible to close the loop, i.e., the AI controller may automatically adjust the mentioned process parameters in the control system to optimise production. Manual operation is only required under very special circumstances, making this digital product a very powerful tool to increase profitability and help operators in their daily work.

## Conclusion

A wide range of digital products are available to maximise production, reduce raw material and energy consumption, and to effectively lower emissions. Digitalisation can also significantly improve plant availability and safety.

The level of digitalisation depends on the complexity of the process technology applied. Often, it is sufficient to focus on the most complex systems within a plant. However, due to the increased speed of modern computers and software, it is already possible to model complete plants as well.

Finally, the combination of state-of-the-art simulation software often supported by machine learning techniques and domain expertise avoids frustration during the execution of digitalisation projects. With the help of process technology experts, the development and application of digital products becomes much more efficient. ■

## Reference

1. "End-to-end digital transformations for chemical companies", McKinsey (2020).



# A digital twin across the plant lifecycle

TOYO's digital twin concept combines its unique digital twin at both the project execution stage and the commissioning stage, and when used in conjunction with its proprietary process simulator it can predict the whole plant lifecycle.

In 2016, Toyo Engineering Corporation (TOYO) launched a digital transformation service named DX-PLANT® in the field of chemical and industrial plants by leveraging IoT and big data analysis technology. Through the development of DX-PLANT®, TOYO has provided unique solutions featuring various fields and reported its progress in previous issues of *Nitrogen+Syngas*. In this article, TOYO addresses recent updates to TOYO's digital twin concept across the total plant lifecycle for fertilizer plants.

TOYO's service is characterised by the realisation of a comprehensive digital twin across the entire plant lifecycle spanning from the engineering, procurement, and construction (EPC) phase to the operations and maintenance (O&M) phase. In line with the "Advanced EPC Operation" strategy of its mid-term management plan, TOYO is working diligently to execute digital projects through the digitalisation of EPC operations. The EPC digital twin has been created for implementation of advanced work packaging (AWP) in projects.

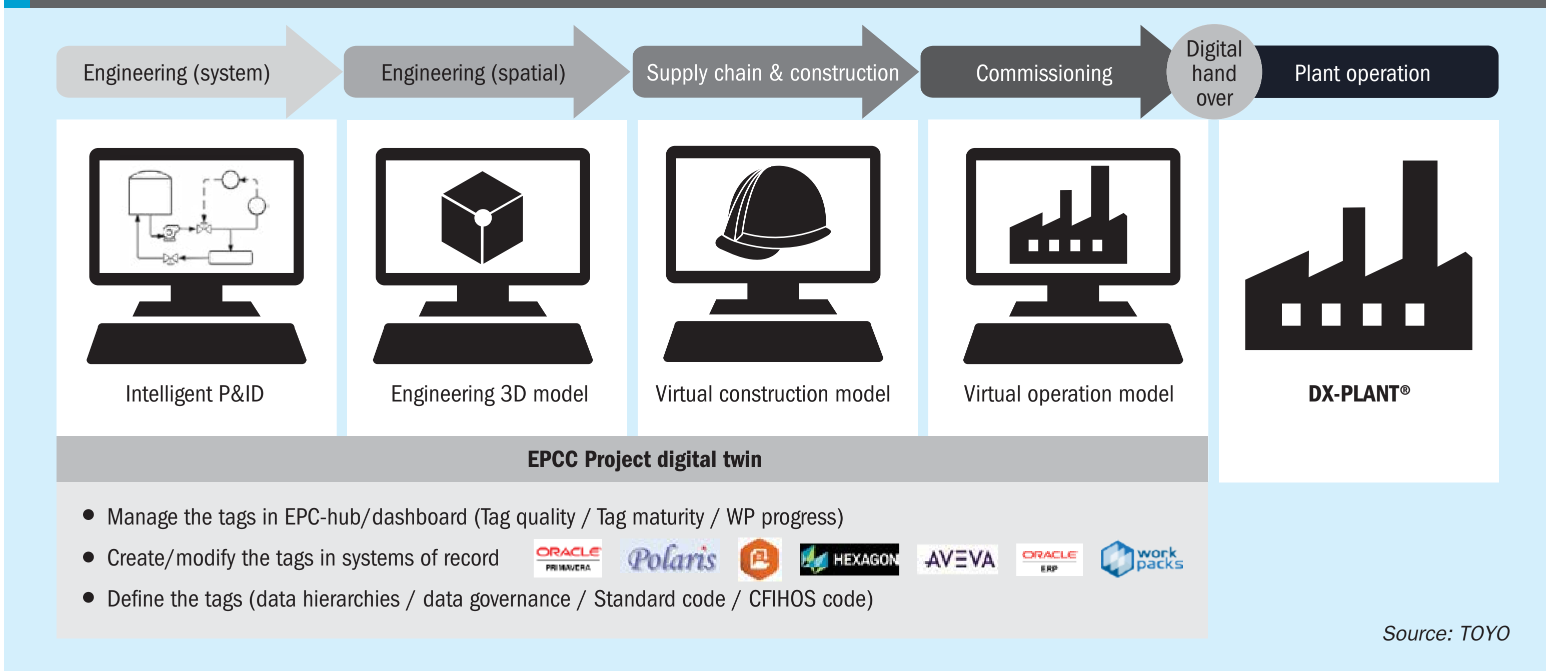
The EPC digital twin is based on the EPC-hub that integrates data from various systems related to EPC execution. The EPC digital twin enables TOYO to optimise the project as a whole, to make project execution more resilient through agile replanning in response to unexpected irregularities, and to realise future predictions. As an EPC contractor as well as a urea process licensor, TOYO believes that it will be able to provide the EPC digital twin to its clients as an asset model as described in the following section.

TOYO's digital twin in the EPC phase transitions and grows during various phases of the project, such as basic design, detail design, procurement/construction and commissioning phases, and after the project is completed, the digital twin created during the EPC phase will be handed over to the O&M phase digitally. TOYO has already developed its own DX-PLANT®, which is the digital solution for the O&M phase, and the EPC digital twin created during the EPC phase will be integrated into DX-PLANT® and utilised during the O&M phase (see Fig. 1).

The use and transition of the EPC digital twin in each phase is described below:

- During basic design, various process systems and components are digitised using an intelligent P&ID (2D) in which the process system information is set up as a digital twin to perform necessary studies and maintain design consistency.
- At the time of layout design during detail design, verification and examination are conducted on the digital twin (engineering 3D model), which is based on the basic design phase digital twin (intelligent P&ID) providing consistency.
- In the procurement and construction phases, the digital twin created in the design phase is further developed into a virtual construction model that is linked to the project schedule. In this

Fig 1: **TOYO's digital twin from EPC phase to O&M phase**




*Source: TOYO*

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



digital twin (virtual construction model), the design document schedule, procurement schedule, and construction schedule are integrated into a so-called "4D model", and study and verification of the plans are repeated virtually on the digital twin (4D model) for alignment.

- In the pre-commissioning and commissioning phases, the digital twin developed from the virtual construction model is used to plan, verify, and review test blocks, taking into account actual construction progress, which is not possible with 2D models.
- The digital twin data created through to project completion is then digitally handed over, reducing the end user's cost and schedule for "information handover to operation".

Structured in this way, the EPC project digital twin is utilised by TOYO as an integrated project management tool to optimise the project.

The structure and TOYO's approach for the digital twin in O&M is as follows.

First, TOYO defines the digital twin as consisting of an asset model and an operation model, comprising a physical model and a data driven model.

The asset model manages the design information including the 3D models necessary for O&M and data such as maintenance records. The asset model is based on the digital twin created during the EPC phase, and further developed with e.g., maintenance records or information during the O&M period.

The operation model reproduces the plant operation virtually. It consolidates the operation data in a virtual space and then utilises the data with the physical model, which consists of a process simulator developed during the EPC phase. Using a process simulator enables remote monitoring support or performance monitoring. In the early stages of plant operation, insufficient operation data are available, therefore applications such as predictions from plant operation data cannot be developed.

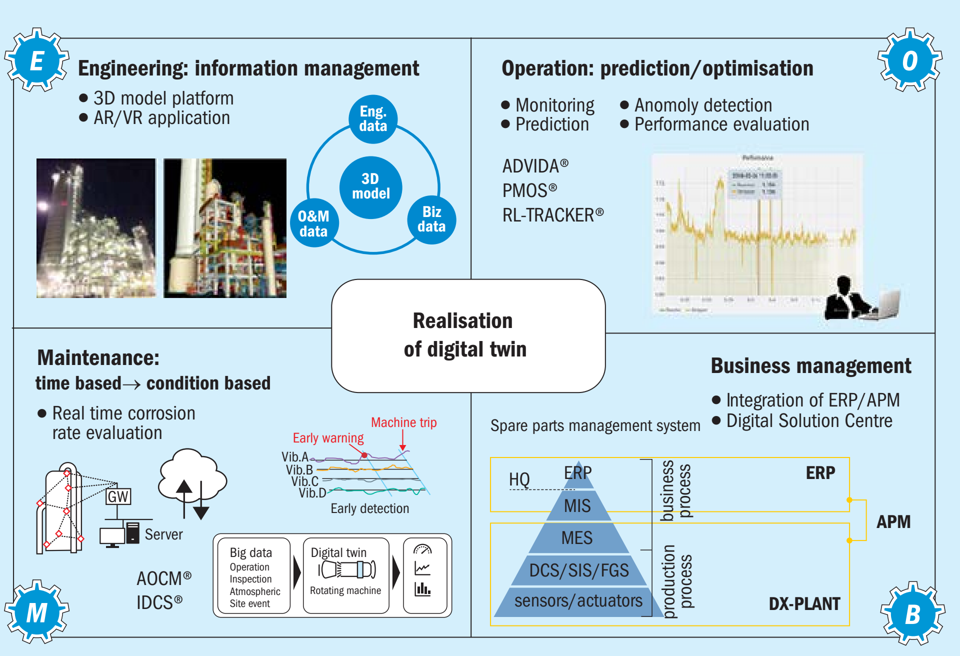
However, once sufficient operation data has been accumulated in the operation model, it is possible to create a data-driven model to fine tune the process simulator to fit the simulation to the operating plant, create an anomaly detection system and soft sensors. In other words, it is the completion of the operation model (hybrid) and digital twin.

It should be noted that TOYO tailors its proprietary process simulator for each urea plant as a result of the engineering. It can be used to trace plant conditions very accurately and enables a reliable digital twin to be handed over to the owner even when sufficient operation data is not available. After accumulating data, it can become the true precise digital twin.

TOYO's system can be used for single or multiple plants. By utilising TOYO's digital twin for multiple plants, it is possible to compare the performance of a plant with others for its evaluation, identification of issues, and to make improvements in a shorter timeframe.

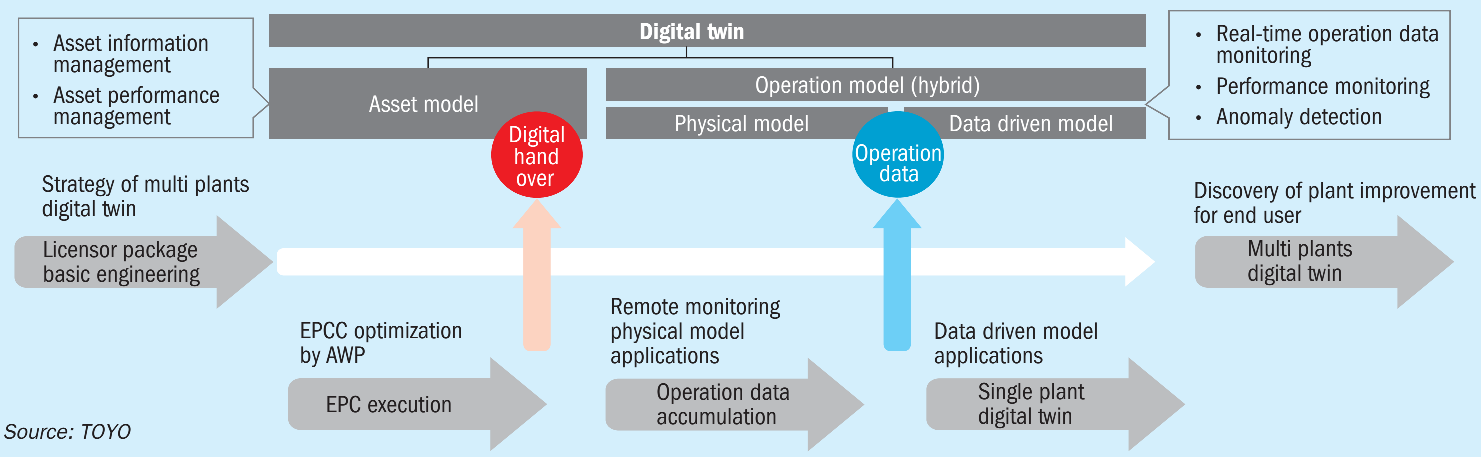
In this way, TOYO optimises EPC through the EPC digital twin, seamlessly handing over the digital twin to O&M, and realises O&M improvements using the digital twin as a process licensor. ■

Fig 2: **DX-PLANT® concept**




*Source: TOYO*

Fig 3: **Realisation of a digital twin across the plant lifecycle**




*Source: TOYO*

# Digital tools reshaping urea plant operations

With the growing global demand for food and the rise in ecological challenges, there's a pressing need for a more sustainable and environmentally-friendly approach to fertilizer production. Achieving a sustainable increase in plant load and operational margins through improved operations is a demanding task. **Luc Dieltjens** and **Ali El Sibai** of Stamicarbon discuss how a plant can effectively address these challenges with digital tools to optimise the process.

## Model-based process optimiser: A powerful digital tool

The model-based process optimiser is undoubtedly one of the digital tools that can substantially enhance plant operations and consequently refine the overall performance of chemical processes. By relying on a robust model and by utilising an efficient solver, the optimiser computes the optimal operating conditions with respect to a defined objective function (e.g., maximising productivity, minimising energy consumption) and under the existing process constraints/disturbances. Clearly, this demands, as a first step, a comprehensive assessment of the plant's condition, process control, and dynamics.

Stamicarbon, nitrogen technology licensor of MAIRE Group, combined these "standard" aspects of a process optimiser with its own process control solutions. The result is a unique process optimiser, Stami Digital Process Optimizer, that acts like an autopilot for the urea plant and can therefore consistently achieve an efficiency boost ranging from 2–5%, contingent on local conditions.

## Stami Digital Process Optimizer: The principle

All urea stripping plants are characterised by a high degree of interaction among the process variables. Any change at the back end will affect the synthesis and vice versa. These are typical control characteristics for plants incorporating multiple recycles. The dehydration of ammonium carbamate to urea and water is slow, necessitating large retention times in the reactor, typically around one hour. This reactor hold-up is referred to as 'pure dead time' in the process. Dead time is the property of a physical system whereby the response to an applied disturbance is delayed in its effect.

The Stami Digital Process Optimizer combines the advantages of a multivariable, model-predictive control (MPC) system with the non-linear optimisation capability of a urea process modelling tool. It uses a model of the urea process to predict the behaviour of the plant several hours into the future. Given the safety and operating limitations, as well as the quality specifications of the process, the system calculates the optimal adjustments to be made. It then implements these adjustments by sending minor changes to the setpoints of key process variables in the distributed control system (DCS). This ensures urea producers benefit from enhanced operational reliability, guaranteeing continuous and consistently optimal operation.

The basic principle of an MPC system is to utilise existing knowledge of the process transfer characteristics. By understanding the relations between manipulated variables, measured disturbances, and controlled variables, the process can be continuously driven to the desired operating conditions. Using data-driven dynamic models derived from step-testing, the MPC controller stabilises the process operation and pushes it as close as possible to process limits, such as synthesis pressure.

Stami Digital Process Optimizer builds upon the process monitor that calculates key performance indicators (KPIs) such as plant load, ammonia emissions, energy consumption, and soft sensor key variables. These soft-sensor key variables provide additional process information which is not measured or cannot be measured, such as stripper tube load, stripper efficiency, and ammonia emissions. These soft sensor key variables have been included in the MPC design as control objectives.

The process optimiser directly anticipates the effects that disturbances have on the process outputs that are controlled as soon as these disturbances are observed. It then steers the process to new operating conditions. Conversely, a traditional feedback control system like a PID controller first needs to observe the effects of disturbances at the controlled process outputs before it can start counteracting these disturbances.

The architecture of the process optimiser system is shown in Fig. 1. Without this system, corrective actions are left to the discretion of the operators. The process optimiser automates operator handling and drives the urea plant to an optimised operating point by integrating real-time optimisation (RTO) and MPC.

The plant model calculates not only the KPIs and soft sensor key variables but also the real-time optimiser values. Optimal conditions for the process at a steady state are determined by the RTO, while the trajectory to be followed, as predicted using a linear dynamic model obtained through a plant step test, is managed by the MPC. Given the typical complexity (high degree of interactions and recycles) of a urea plant, the MPC is an invaluable tool to achieve the optimal, stable operating point efficiently.

Once the desired stability is reached, the MPC will be used to maximise the $CO_2$ flow without breaching any operating constraints, ensuring the highest possible production capacity at all times.

## Customer experiences

A process optimiser project has been executed on a urea plant with Stamicarbon's LAUNCH MELT™ pool reactor design, which currently operates at a capacity of 1,400 t/d. The customer sought opportunities to enhance the urea plant's operation without significant equipment modifications. The process optimiser was chosen as the optimisation tool. This urea plant is intricately integrated with two melamine plants and an ammonium nitrate plant, adding layers of complexity and challenges to the project. The project provided numerous insights, lessons, and best practices beneficial to all involved.

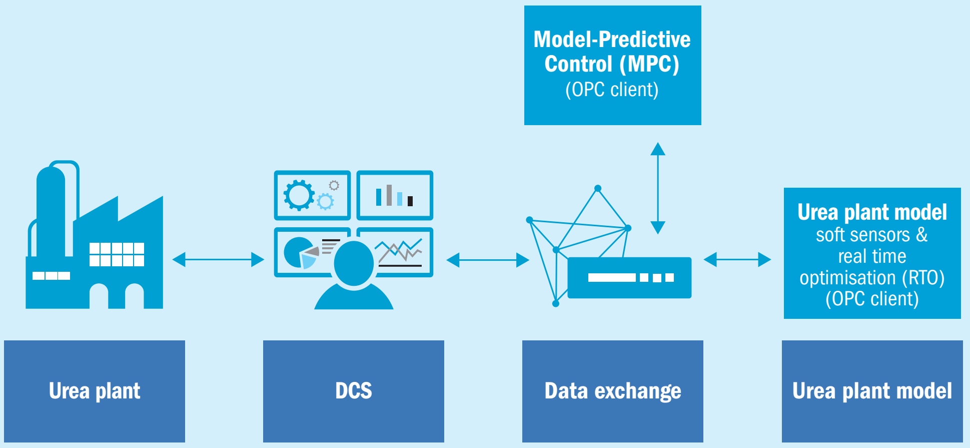
### Current operation is not always optimal

The first lesson learned was that the accuracy of a plant model depends on how well it's constructed. Given the urea plant's expansive operating window, the model had to be robustly programmed to encompass all operating scenarios, using historical data as a basis. At certain junctures, the model's predictions and trends diverged from the customer's established experiences and practices. This led to in-depth discussions between the process engineers of the customer and Stamicarbon. Through these deliberations, it became evident that the urea plant wasn't being operated optimally. The insights from these discussions enabled the customer to enhance urea production.

### Implementation can take time

The implementation phase of this project took longer than expected due to several reasons. Firstly, differing opinions among the process engineers regarding optimal operation took time to reconcile. Secondly, some critical instruments weren't functioning correctly, which impacted the implementation of the control strategy in the MPC controller. Lastly, for the step tests to be carried out, the plant needed to operate at nominal conditions. Coordinating the right resources, ensuring their availability, and aligning with the necessary plant conditions proved to be more complex than anticipated.

Fig. 1: **Stami Digital Process Optimizer architecture**




*Source: Stamicarbon*

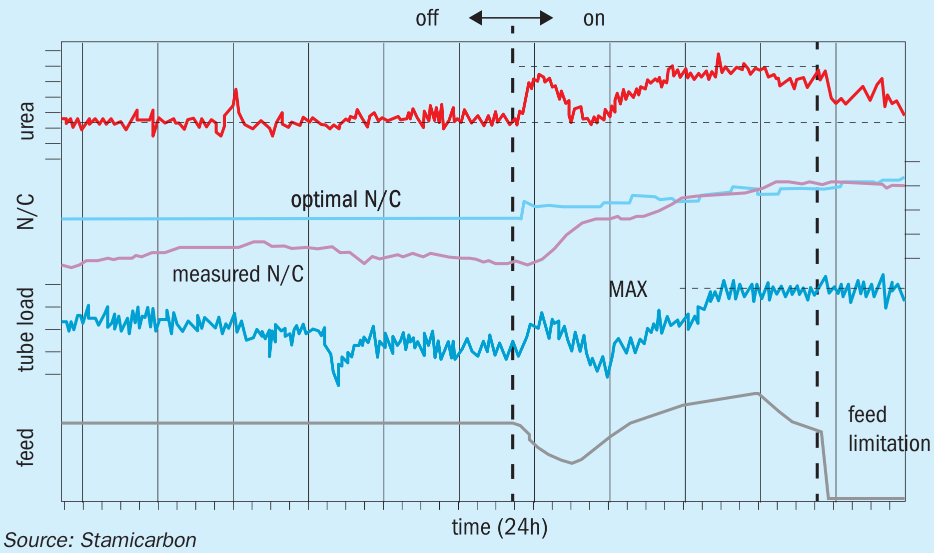
### Results

The Stami Digital Process Optimizer calculates the ideal N/C ratio in the pool reactor, which the MPC then uses for anticipation. Because of an improved yield in the reactor, the overall production capacity rises. Additionally, there are gains from reducing variations in the N/C ratio when the optimiser is active (see Fig. 2). The stripper tube load, continuously calculated by the plant model, has the lowest specific energy consumption at its maximum. This tube load is set as a constraint in the MPC, meaning it shouldn't exceed a certain limit. The MPC directs it towards this maximum.

An optimisation goal might be to maximise load or, considering feedstock constraints, to minimise energy use or some other objective function. Typical benefits of the process optimiser include a 1-5% rise in production, a 1-3% drop in specific energy consumption, an increased on-stream factor, and reduced manual oversight due to fewer interventions by operators. For the afore-mentioned project, the Stami Digital Process Optimizer achieved a 4% production boost and a notable reduction in energy costs. The results from deploying the Stami Digital Process Optimizer surpassed expectations in terms of both plant performance and knowledge acquisition.

The process model becomes especially powerful for plant optimisation when paired with an MPC. Implementing the Stami Digital Process Optimizer requires no hardware modifications, nor does it necessitate plant shutdowns – it's solely a software extension. To ensure data security Stamicarbon has been certified in the information security standard ISO 27001. ■

Fig 2: **Impression of the process performance**




*Source: Stamicarbon*

# Efficient and proven ammonia cracking at scale

Large-scale ammonia cracking for conversion of ammonia to hydrogen is a proven technology with decades of industrial experience. Topsoe shares its experience within ammonia cracking and presents an improved and highly energy-efficient (96%) ammonia cracking technology, H2Retake™, developed based on Topsoe's proven technology and industrial experience.

Ammonia has, for a long time, been identified as the energy carrier and storage medium of the future. But only recently, has it become a reality. Up until now, oil and fossil fuels have been the dominant media for global scale energy export, import and storage. However, the industrial transition, driven by the global ambitions to limit greenhouse gas (GHG) emissions, and the continuous reduction of renewable electricity costs are changing the landscape. Carbon-containing energy carriers and fuels will co-exist with ammonia, but due to the scarcity of sustainable carbon, they are not fully scalable and will only be available in applications allowing for higher pricing compared to the cost of ammonia as an energy carrier.

## Introduction to ammonia cracking

The ammonia supply chain is robust and scalable. More than 20 million tonnes of ammonia are already being traded and transported across the globe. Mega-scale blue ammonia projects involving carbon capture and sequestration are currently being contracted, bringing high volumes of low carbon intensity ammonia to the market. Simultaneously, the market for green ammonia, based on renewable electricity, is developing with many mega-scale projects in the pipeline.

Ammonia cracking is the enabling technology for using ammonia as an energy source for applications driven by energy in the gas form. Applications of hydrogen or cracked gas ($H_2/N_2$) from ammonia will include:

- substitution of conventional hydrogen in all existing industrial hydrogen applications and their future analogues, for example biorefineries;
- natural gas replacement in industrial applications such as gas turbines, gas engines, gas furnaces and boilers, as well as partial substitution in natural gas grids;
- future hydrogen applications such as hydrogen for road transportation.

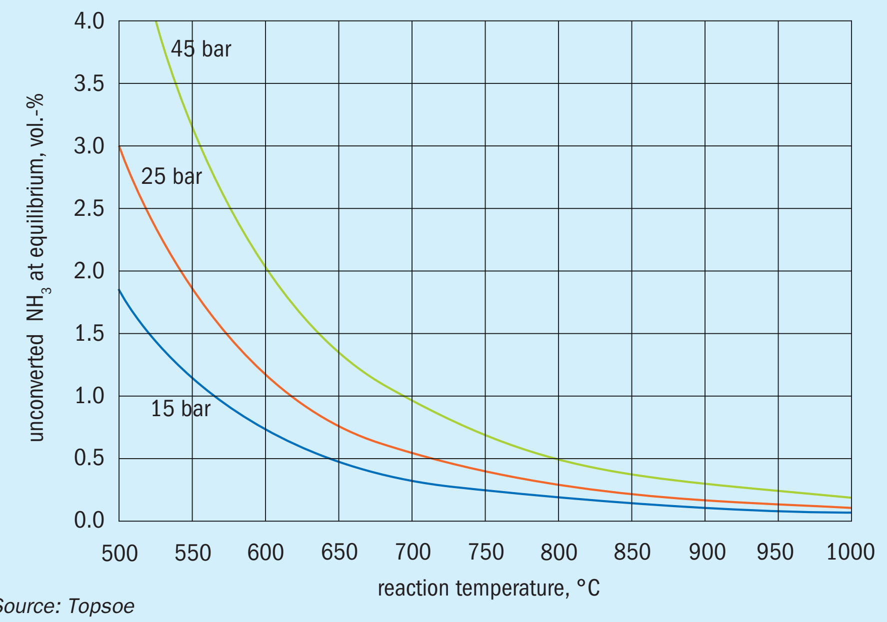
Ammonia cracking can be:

- centralised, and large to mega-scale with hydrogen transported to the end-use in extended hydrogen grids, as planned in Europe;
- decentralised, large-scale and co-located with large hydrogen off-takers possibly via local hydrogen grids;
- small-scale decentralised for example at hydrogen filling stations.

## Ammonia cracking theory

Ammonia is transported and stored as a liquid, typically at atmospheric pressure and -33°C. The first step in an ammonia cracking plant involves preheating and evaporating the ammonia. Evaporation of liquid ammonia requires 23 kJ/mol.

Fig. 1: **Dependence of equilibrium conversion of ammonia on temperature and pressure**




*Source: Topsoe*

1 47 2 48 3 49 4 50 5 51 6 52 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

Cracking of ammonia to nitrogen and hydrogen is an endothermic reaction limited by chemical equilibrium.

$$NH_3 \rightleftharpoons 0.5\ N_2 + 1.5\ H_2$$

$$\Delta H_{reac,\ 25°C} = 46.2\ kJ/mol_{NH3}$$

The endothermicity and the stoichiometry of reaction above means that ammonia cracking is favoured at high temperatures and low pressures. This is clearly observed in Fig. 1, which shows the dependence of the equilibrium conversion of ammonia on temperature and pressure.

Unconverted ammonia will leave the reactor as ammonia slip. In practice, the maximum temperature is limited by construction materials and cost. The optimal pressures are typically around 25–45 bar which will eliminate the need for a hydrogen compressor in many cases.

From these considerations, it is evident that the most basic layout for an ammonia cracking process includes at least the following steps:

- vaporisation and preheating of the raw ammonia feed;
- catalytic decomposition of ammonia;
- removal of unconverted ammonia and purification of the hydrogen product.

The minimum process energy input to convert -33°C liquid ammonia to 25 barg hydrogen can be estimated at ~72kJ/mol$_{NH3}$, dominated by the heat of evaporation and the cracking reaction.

The heat input for the process can be supplied in different ways. The choice of the energy source will depend on factors such the availability, costs, plant scale, emission constraints and product carbon intensity target.

The ammonia cracking process is typically characterised by two metrics: the hydrogen efficiency, and the energy efficiency. The hydrogen efficiency represents the fraction of hydrogen atoms in the raw ammonia that ends up as hydrogen product.

$$\eta_{H_2} = \frac{F_{H_2}^{product}}{1.5 F_{NH_3}^{feed}} \qquad \text{(equation 1)}$$

where $F_{H_2}^{product}$ is the molar flowrate of hydrogen produced and $F_{NH_3}^{feed}$ is the molar flowrate of ammonia in the feed.

The energy efficiency is defined as the ratio of the energy of the product hydrogen to the total energy of the ammonia feed stream and any external fuel plus any power consumption:


*Fig. 2: 2,400 t/d ammonia cracker in Planta Industrial de Agua Pesada (PIAP plant)*

$$\eta_E = \frac{F_{H_2}^{product}\ h_{H_2}}{F_{NH_3}^{feed}\ h_{NH_3} + F_{fuel}^{feed}\ h_{fuel} + E_{el}}$$

(equation 2)

$h_i$ is the specific mole-based energy of compound $i$ referenced to the standard conditions (25°C and 1.01 bar) and $E_{el}$ the input of electric work.

## Ammonia cracking references

Topsoe commissioned its first plant back in 1978. Since then, Topsoe has designed and commissioned several other large-scale ammonia crackers for application in heavy water production by the so-called monothermal ammonia-hydrogen exchange process.

Topsoe's largest ammonia cracker to date was commissioned in 1993 in Arroyito, Argentina. It is referred to as the Planta Industrial de Agua Pesada (PIAP). The PIAP plant has two parallel lines, and each line has an ammonia cracker decomposing 2,400 t/d of ammonia (see Fig. 2). Topsoe's plants are specially designed to withstand the harsh operating conditions and the risk of nitridation. The plants are also supplied with a tailored Topsoe ammonia cracking catalyst with proven performance.

## H2Retake™

In 2022, Topsoe launched an ammonia cracking technology which conservatively updated the industrial ammonia crackers from the heavy water application to a hydrogen process. The 2022 version of the ammonia cracking technology is a fully proven technology albeit not fully optimised.

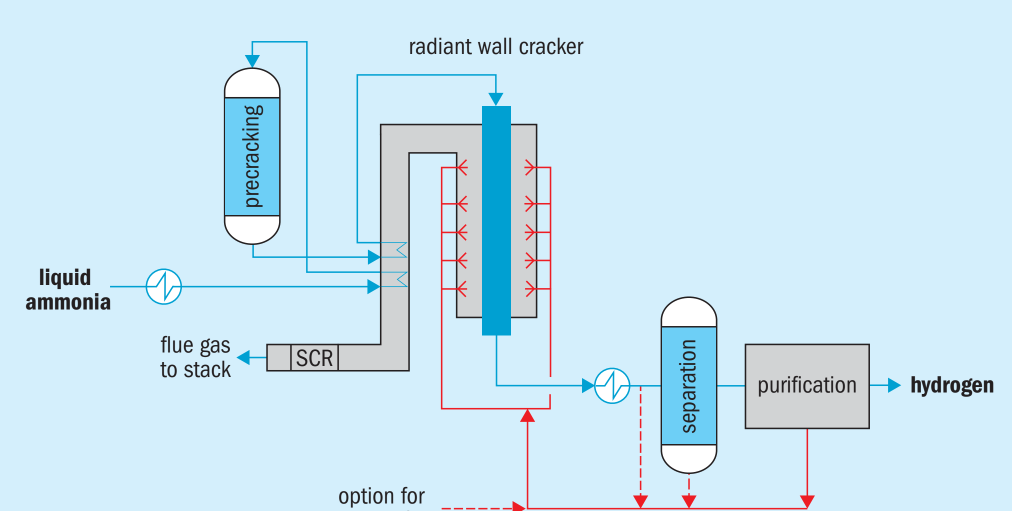
In 2023, Topsoe is launching the H2Retake™ ammonia cracking technology which builds and improves on the proven fired cracking technology and decades of industrial experience to achieve very high energy and hydrogen efficiencies. A simplified diagram of the H2Retake process layout is shown in Fig. 3.

In Topsoe's H2Retake technology, the liquid ammonia feed is pumped to a pressure above that required for $H_2$ delivery (typically 25-45 bar g). The ammonia is vaporised and preheated by transferring heat directly from the hot process and flue gases, which avoids the cost and complexity of having a steam system.

The decomposition of ammonia into hydrogen and nitrogen takes place in an adiabatic pre-converter followed by a fired tubular cracker. Pre-conversion decreases the fuel demand of the fired cracker and makes the best use of the flue gas energy from the firing.

The heart of the ammonia cracking technology is the well-proven fired cracker installed in Topsoe's referenced plants. Multiple parallel tubes filled with catalyst are heated by burners placed on the walls at various elevations to secure a good temperature control. The burner flames are directed backwards against the furnace wall, eliminating any risk of flame impingement of the catalyst tubes. Despite overall similarities in the design with conventional steam methane reformers, very important differences in the choice of materials exist, which must tolerate harsh

Fig. 3: **Simplified diagram of the H2Retake process**




*Source: Topsoe*

nitridation conditions in the ammonia cracker, and in the choice of catalyst.

The process gas leaving the fired cracker contains a small amount of unreacted ammonia due to the reaction equilibrium. This ammonia is removed from the cracked gas before it enters the pressure swing adsorption (PSA) columns, where the final purification of the hydrogen product takes place. The residual ammonia is separated from the gas by a simple water wash. It is then recovered, mixed with the PSA tail gas and sent to the cracker furnace where it is used as fuel. A selective catalytic reduction (SCR) unit located in the exhaust of the fired cracker ensures that the NOx and $N_2O$ emissions remain within project requirements.

A range of supporting technologies for ammonia cracking, such as ammonia storage, ammonia recovery, hydrogen compression, and high hydrogen fuelled burners, have been extensively proven, documented, and successfully utilised in similar applications for decades and can as such be viewed as TRL 9. It is important to note, as mentioned, that these supporting technologies are not the core components in an ammonia cracking plant. The core components encompass the ammonia cracker, the ammonia cracking catalyst, the hydrogen purification system, and the SCR DeNOx system.

Topsoe is in a unique position where all these core components have reached technology readiness level (TRL) 9 as indicated in Table 1 and have been thoroughly proven on an industrial scale.

## Ammonia cracking catalysts

Commercial grade ammonia contains 0.2-0.5 wt-% $H_2O$ to prevent corrosion during transportation and storage. In the energy and cost efficient H2Retake technology, the ammonia carries this humidity through the catalyst beds. This makes catalyst selection non-trivial because water adversely affects the activity of ammonia cracking catalysts by two different mechanisms:

- Water competes with ammonia for the available active sites, thereby inhibiting the cracking reaction. The effect is reversible, meaning that if the water is removed, so is the inhibition. Catalysts operating at low temperatures are particularly susceptible to this mode of deactivation, for example those based on noble metals.
- At higher temperatures, the water will accelerate sintering, and a catalyst may deactivate irreversibly due to the loss of active surface area. Catalysts operating at high temperatures are particularly susceptible to this mode of deactivation, although well-designed catalysts can be very stable.

Due to their lower cost, catalyst formulations using base metals are preferred over catalysts containing noble metals. Nickel catalysts are the most widely used in small-scale ammonia

Table 1: **Ammonia cracking technology readiness levels by Topsoe**

| Component | TRL | Topsoe references | Remarks |
|---|---|---|---|
| Ammonia cracker | 9 | Multiple industrial site references with capacities up to 2,400 t/d ammonia feed. | Only industrial proven ammonia cracking technology available and optimised to perform exceptionally well under ammonia cracking conditions. |
| DNK-2R | 9 | Multiple references with unit capacities up to 2,400 t/d of ammonia feed showcasing excellent performance in real-world industrial conditions throughout multiple years of operation. | Extensive operation history of 100,000 hours to reinforce the proven track record of Topsoe's cobalt-iron based catalyst. |
| Hydrogen purification | 9 | Substantial record of employing pressure swing adsorption (PSA) for hydrogen purification in conventional plants. | Challenges arise when purifying cracked gas from an ammonia cracking unit. Topsoe has proactively investigated these impacts and how best to mitigate them, in collaboration with chosen partners to guarantee a reliable and effective hydrogen purification process. |
| SCR | 9 | Previously been involved in designing and selling DeNOx units for both stationary and mobile applications. | The operational conditions play a crucial role in the design of the SCR system. Leveraging Topsoe's extensive industrial experience, an optimal SCR design can be ensured that allows for both NOx and $N_2O$ abatement. |

*Source: Topsoe*

Table 2: **Comparison of the efficiencies of different process configurations**

| | Option 1 | Option 2 | Option 3 |
|---|---|---|---|
| Fuel | $NH_3$ (cracked) + PSA tail gas | Natural gas + PSA tail gas | Natural gas + PSA tail gas |
| $H_2$ recovery unit | Single-stage PSA | Single-stage PSA | Two-stage PSA |
| Raw ammonia feed, kg/h | 241,573 | 231,333 | 197,600 |
| Additional fuel (NG), Nm³/h | 0 | 4,853 | 20,907 |
| Electricity consumption, kcal/kg$H_2$ | 45 | 45 | 733 |
| Hydrogen efficiency, $H_2$ | 78% | 82% | 96% |
| Energy efficiency, E | 96.6% | 97.2% | 95.8% |
| $CO_2$ footprint kg$CO_2$/kg$H_2$ | 0 | 0.3 | 1.2 |

*Source: Topsoe*

crackers. However, not all nickel catalysts can perform satisfactorily in industrial crackers where energy efficiency is crucial. Most of them exhibit low activity and poor stability in the presence of the water levels usually found in commercial ammonia. This is exemplified in Fig. 4, which compares a conventional Ni-catalyst against Topsoe's stabilised Ni-catalyst DNK-20. The performance is comparable in a water-free atmosphere, but the activity of the conventional Ni-catalyst drops dramatically with exposure to 0.2 vol-% $H_2O$. In contrast, due to a careful selection of structural and electronic promoters, Topsoe's DNK-20 displays high and stable activity even in the presence of water.

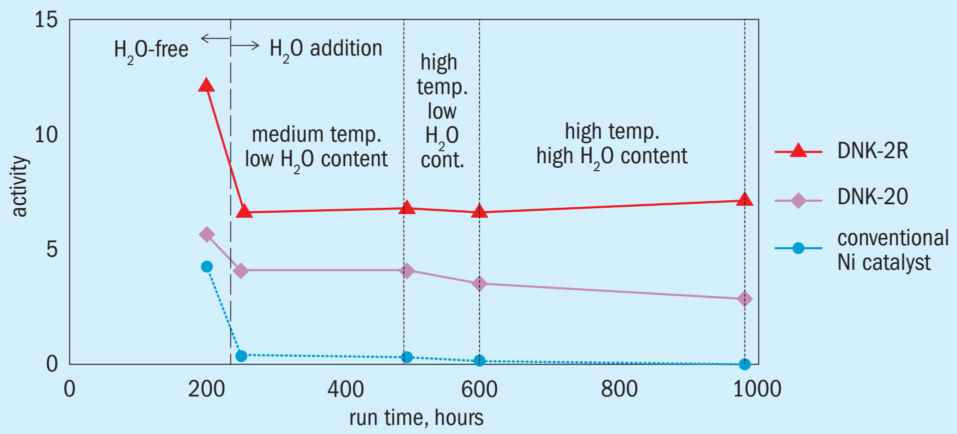
> **Ammonia as the energy carrier and storage medium of the future is becoming a reality, ...**

Topsoe's portfolio also includes the iron-cobalt-based catalyst DNK-2R, a market leading non-noble metal catalyst, fully proven in heavy water plant ammonia crackers. It is almost twice as active as the best nickel catalyst, and it can operate in a water-containing gas down to 400°C. Topsoe's ammonia cracking catalysts are the only ones with references in large-scale crackers.

## Process merits

In H2Retake, the energy input to the fired ammonia cracker is efficiently utilised to drive the decomposition reaction and to evaporate and preheat the raw feed with minimal waste. As a result, an energy efficiency of 96% is achieved and a hydrogen efficiency of up to 96% depending on the fuel choice (see Table 2).

Fig. 4: **Comparison of conventional Ni-catalyst against Topsoe's stabilised Ni-catalyst DNK-20**




*Source: Topsoe*

Key technology features allowing this performance are:

- Very active, non-noble metal catalysts allow operation down to 400°C. Direct heat integration between the process streams eliminates the need for a steam system. Water tolerant ammonia cracking catalyst capable of operating with the water levels present in commercial-grade ammonia, eliminating the need for distillation.
- No usage of cooling water minimises energy losses.

Replacement of the cracked gas in the fuel mixture with an alternative fuel allows larger recovery of hydrogen from the ammonia feed but can result in $CO_2$ emissions. The hydrogen recovery can be further maximised by implementing a two-stage PSA separation. However, this reduces the energy efficiency slightly due to a requirement of an interstage compressor. Table 2 compares the efficiencies of different process configurations for an 800 t/d $H_2$ plant.

## Conclusion

Ammonia as the energy carrier and storage medium of the future is becoming a reality, and the market is currently experiencing a significant interest in large-scale ammonia cracking. Large-scale ammonia cracking technology from Topsoe is fully proven, with several industrial references and high-performance catalysts. Furthermore, with Topsoe's newly released H2Retake technology, improvements are available to realise an energy-efficient process and high hydrogen efficiencies. An energy-efficiency of up to 96% can be achieved, dependent on supplementation of any external fuel for process heat. ■

# A climate silver bullet

The $CO_2$ emissions in a hydrocarbon fed hydrogen plant occur largely during the energy intensive syngas production step. Hydrogen production is therefore a major factor in the $CO_2$ emission balance of an ammonia plant. BASF's OASE® technologies for $CO_2$ capture are capable of achieving cost-effective 99.99% carbon capture at scale. In this article **Elena Petriaeva** and **Bernhard Geis** of BASF investigate different grey and blue hydrogen production technologies.

To meet the emission reduction targets required by 2050 under the EU Green Deal, energy sources will need to shift to being almost entirely carbon-free. An intermediate milestone to support this target to reach carbon neutrality is Europe's plan is to reduce $CO_2$ emissions by 55% from the 1990 level by 2030. This points to a significant role for hydrogen, which can be produced via low-carbon routes from electricity or with carbon capture and storage (CCS). Moving forward, the use of pure hydrogen ($H_2$) can support the energy transition while the high purity captured carbon dioxide ($CO_2$) can be directly sequestered or utilised to manufacture chemical products for commercial scale.

It is widely discussed that blue, or low carbon hydrogen, and green hydrogen should be used to decarbonise the energy sector. However, a clear definition is yet to be developed. Green hydrogen has great potential, but it is not ready to cover market needs. Nearly 96% of all hydrogen is derived from fossil fuels, with natural gas being by far the most frequently used with an estimated 49%, followed by liquid hydrocarbons at 29%, 18% from coal and about 4% from electrolysis and other byproduct sources of hydrogen[3]. Given that there are a lot of existing grey hydrogen plants and with the current affordable cost of fossil fuels in many parts of the world, blue hydrogen is the most economical transition technology to achieve large $CO_2$ emission reductions.

## Technologies for sustainable (blue) hydrogen production

Most of the hydrogen, ammonia, and methanol plants in operation worldwide use conventional steam methane reforming. In the steam reforming process, carbon dioxide is produced as a by-product and emitted from two different sources: as part of the flue gas (FG) and as part of the process gas (PG).

Advanced technologies for synthesis gas production such as the autothermal reactor (ATR), autothermal reactor combined with a gas heated reformer (ATR+GHR) and partial oxidation (POx) are less common and have only one source of $CO_2$ emissions, the process gas. These technologies have already achieved large scale industrial operation and can be used for many different products including ammonia. By having only one source of $CO_2$ emissions, both the highest carbon capture rate (CCR) and lowest opex can be achieved. It is always easier to retrofit existing grey hydrogen plants with CCS to make them blue to achieve a smaller carbon footrprint than building a grassroot green plant.

## Steam methane reforming (SMR)

Conventional hydrogen production based on steam methane reformer (SMR) technology without any $CO_2$ reduction mechanisms leads to emissions of approximately 10 kg $CO_2$ per kg $H_2$ depending on the feedstock and site-specific set-up. Hydrogen produced in this way is called grey hydrogen[6].

An international standard for blue hydrogen is not yet established. Decarbonising flue gas has in most cases a practical target of 90% $CO_2$ capture. The possibility to rearrange process layouts and efficiently remove pure $CO_2$ from synthesis gas, as well as more efficient flue gas capture units has changed the practical/feasible limit to 90-99% capture. Carbon capture is driven by the expectation of a $CO_2$ tax on emissions and the possible income from selling the captured $CO_2$.

## SMR without $CO_2$ capture (grey $H_2$)

Producing hydrogen from hydrocarbon feed inherently results in $CO_2$, which must be removed as part of the process. The hydrocarbon feed is converted to a synthesis gas comprising $H_2$, CO, and $CO_2$. The CO then passes through a water gas shift reactor where it shifts with $H_2O$ to form $H_2$ and $CO_2$, resulting in a synthesis gas comprising mostly $H_2$ and $CO_2$.

$CO_2$ can be recovered from two streams in typical SMR scheme: from the high-pressure syngas stream upstream of the $H_2$ purification step (pre-PSA syngas) and from the reformer furnace flue gas stream. Between 50 and 85% of the total $CO_2$ emissions from a hydrogen plant are contained in the syngas stream. If more extensive $CO_2$ recovery is desired, one can also recover it from the flue gas stream, but due to low stream pressure and low $CO_2$ concentration, this type of recovery is more complex and more costly.

One of the more widely used $CO_2$ removal systems is based on scrubbing with amine solvents. BASF's OASE® white is an industry leading proven amine scrubbing technology for deep $CO_2$ removal from syngas and offers great energy efficiency and robust operation, achieving targeted process gas $CO_2$ capture rate of up to 99.99 mol-%.

For flue gas carbon capture, OASE® blue technology was developed specifically as an optimised post-combustion capture technology with low energy consumption, low solvent losses and an exceptionally flexible operating range. OASE® blue for flue gas $CO_2$ emissions capture and OASE® white for process gas $CO_2$ emissions capture are demonstrating that by combining two effective technologies the target of the lowest overall $CO_2$ footprint is achieved.

## SMR with process gas $CO_2$ capture (blue $H_2$)

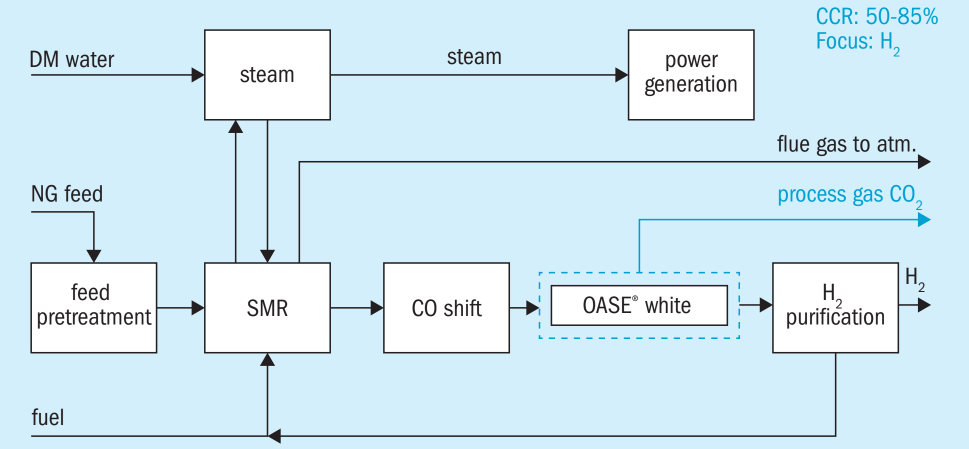
If the carbon dioxide in the syngas (process gas $CO_2$) is captured and stored or sent for further usage roughly 60% can be captured. The consortium CertifHy has defined a threshold of $CO_2$ intensity, below which the hydrogen is labelled "blue" or "low carbon" hydrogen: 36.4 g $CO_2$eq/MJ $H_2$ (LHV). This threshold is under discussion to become more stringent[1,2].

It can be typically achieved with a natural gas (NG) based steam reformer (SMR) without major process adaptions except a $CO_2$ capture unit installed on the syngas, from which about 50 to 85% of the total $CO_2$ emissions can be captured. A block scheme with $CO_2$ capture (BASF's OASE® white) from the process gas is shown in Fig. 1.

The exact process configuration depends on the partial pressure of the acidic components in the feed gas and on the treated gas specification. The choice of process configuration depends on the design philosophy. It can be optimised based on capital expenditures (capex) or on operational expenditures (opex). The local availability and the cost of thermal energy play an important role in the choice of the process configuration.

The specific thermal energy consumption of an OASE® white unit in an SMR configuration is 1.2 GJ/t $CO_2$ for an energy-efficient configuration (minimum opex) and 2.0 GJ/t $CO_2$ for a minimum capex configuration at a carbon capture rate of 99.99%[8].

Fig 1: **Typical SMR scheme with the option of process gas $CO_2$ capture**




*Source: BASF*

## SMR with flue gas $CO_2$ capture (blue $H_2$)

Fig. 2 is a block scheme of a typical system for $CO_2$ removal from steam reformer furnace flue gas. The OASE® blue $CO_2$ capture unit is based on a conventional design comprising an absorber and stripper configuration. The basic principles are the same as for the recovery of $CO_2$ from a high-pressure syngas stream, however $CO_2$ recovery from flue gas has several additional challenges over that of syngas, which makes the unit's design and operation more complex and more expensive.

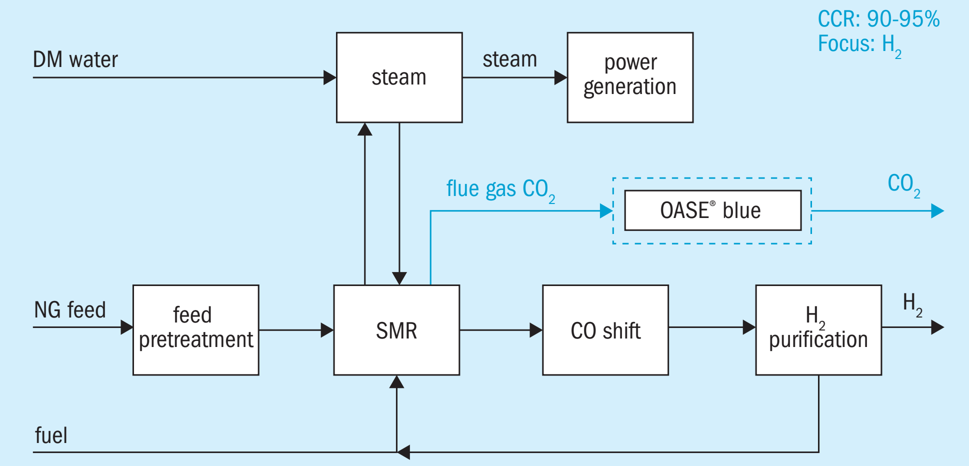
Additional equipment is required for the flue gas capture in comparison to the process gas capture. One main advantage is that the process removes $CO_2$ from flue gas without disturbing the upstream pressure or operation of the SMR process. Before the flue gas enters the absorber, it often has to undergo various pre-treatment stages. These comprise e.g., denitrification (DeNOx), desulphurisation ($SO_2$/$SO_3$), dust removal by a wet electrostatic precipitator or filter bag house, or a direct contact cooler (DCC). Since the gas is at atmospheric pressure, compression is required before further processing. Low pressure leads to larger equipment size. The presence of oxygen and water leads to increased rate of solvent degradation and equipment corrosion, necessitating special solvent formulations and specific metallurgy.

The specific thermal energy consumption of an OASE® blue unit in an SMR configuration is 2.56 GJ/t $CO_2$ at a carbon capture rate of 95%[8].

The process configuration mainly depends on the $CO_2$ concentration in flue gas, the $CO_2$ production rate and economics and customer preferences. The decision on the process configuration selection is a trade-off between capex and opex. BASF offers various advanced integrated schemes which lead to further reduction of specific thermal energy requirements. The availability and cost of thermal energy may play an important role especially in larger plants, while in smaller units sometimes a bare bones design philosophy is optimal.

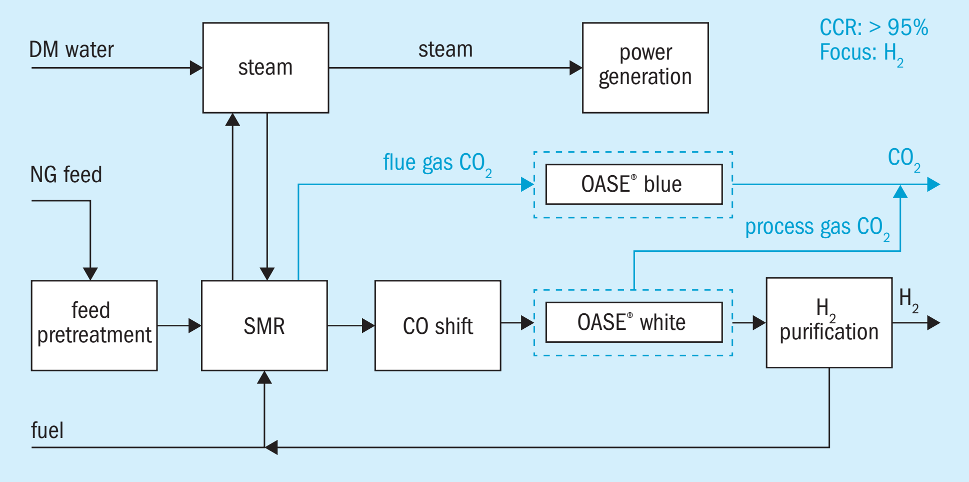
All these factors make low-pressure flue gas $CO_2$ recovery more expensive compared to the high-pressure syngas option. At times, for cost savings or to limit the amount of $CO_2$ recovery (due to market, storage limitation, or other conditions), the amine unit can be installed only on part of the total stream, with the rest of the stream by-passing the $CO_2$ recovery unit[4].

Fig 2: **Typical SMR scheme with the option of flue gas $CO_2$ capture**




*Source: BASF*

Fig 3: **Typical SMR scheme with the option of both process and flue gas $CO_2$ capture**




*Source: BASF*

## SMR with process gas $CO_2$ capture (e-furnace) (blue $H_2$)

One of the most recently developed improvements in steam reforming technology is an electrically heated steam furnace using electricity from renewable sources. This fundamentally new approach has the potential to reduce $CO_2$ emissions by 98%. The demonstration plant construction has been started and the plant is to be fully integrated into one of the existing steam crackers at BASF's Verbund site in Ludwigshafen, Germany.

The specific thermal energy consumption of an OASE® white unit is the same as previously mentioned for the SMR configuration.

## SMR with process/flue $CO_2$ capture (blue $H_2$)

By capturing $CO_2$ from both sources in a typical SMR-based hydrogen production technology, from syngas preparation and from the flue gas emitted from steam reformers and fired heaters, it is possible to achieve a CCR of more than 95% (see Fig. 3).

The specific thermal energy consumption for OASE® white and OASE® blue units along with achieved CCR is the same as previously mentioned.

Although the majority of hydrogen is currently produced by SMR, being the most proven and reliable technology for hydrogen production, the described schematics might fit better for SMR retrofitting and converting grey into blue or low carbon hydrogen/ammonia. For grassroot units, advanced technologies might be the best choice in terms of economics by providing the lowest capex designs at high production capacities, however, this requires installation of energy-intensive air separation units (ASUs) and onsite handling of oxygen which has several safety risks that need to be mitigated. The decision of which hydrogen production technology to select depends on customer preference, experience, and availability of energy resources at site.

## Advanced technologies for hydrogen production

Within the hydrogen industry new plant production capacities are constantly increasing. This exceeds the economic limits of steam reformer technology and therefore advanced hydrogen production technologies have generated interest. Additionally, large-scale single trains bring economy of scale. The synthesis gas generation technologies using autothermal reforming and partial oxidation are operating with a reduced steam-to-carbon ratio below 1.0. This reduces the amount of heat input for the reforming section drastically, and thereby the fuel requirement directly leading to lower $CO_2$ emissions.

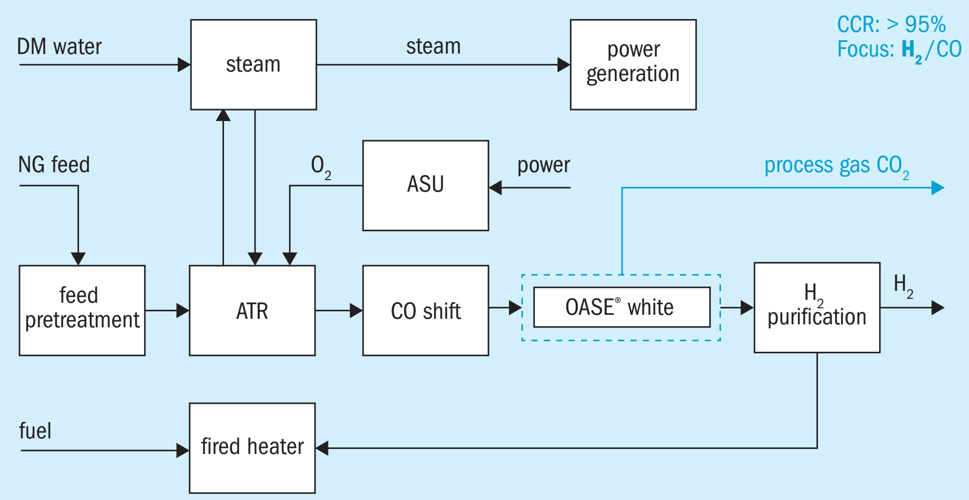
Therefore, when decarbonising, the use of any of the advanced technologies for hydrogen production is beneficial since they either require a smaller or no flue gas capture unit or less hydrogen for fuel, which is a major advantage when compared to steam reformer-based solutions[6].

Technology transition from conventional SMR-based technology to advanced technologies, such as autothermal reforming (ATR), partial oxidation (POx) and an autothermal reformer + gas heated reformer (ATR+GHR) are described below. Selection of technology is defined by the required product: hydrogen, hydrogen with carbon monoxide or carbon monoxide with hydrogen.

## ATR with $CO_2$ capture (blue $H_2$)

Autothermal reforming (ATR) is an advanced technology for hydrogen production where oxygen, carbon dioxide and steam react with methane, producing syngas. ATR combines steam reforming

Fig 4: **Typical ATR scheme with the option of both process gas $CO_2$ capture**




*Source: BASF*

and POx resulting in an overall reaction enthalpy close to zero. The process consists of a POx zone, which supplies the process heat for the subsequent endothermic steam reforming step using catalysts. The total heat balance and the $H_2/CO$ ratio in the product gas are adjusted by varying values of S/C and O/C[5].

ATR has a higher hydrogen yield than POx and provides more flexibility in terms of process conditions, start-up time, and complex feedstock utilisation than the SMR. ATR in principle is used as a secondary reformer in all ammonia production units where high $H_2/CO$ ratios are needed. In the case of ammonia production, compressed air is used instead of oxygen. Autothermal reforming is installed in ~5% of all hydrogen and methanol production units by using oxygen from an air separation unit.

Fig. 4 shows a typical ATR scheme with the option of process gas $CO_2$ capture.

The specific thermal energy consumption of an OASE® white unit in an ATR configuration is 0.8 GJ/t $CO_2$ for a minimum opex configuration with a carbon capture rate of 97%.

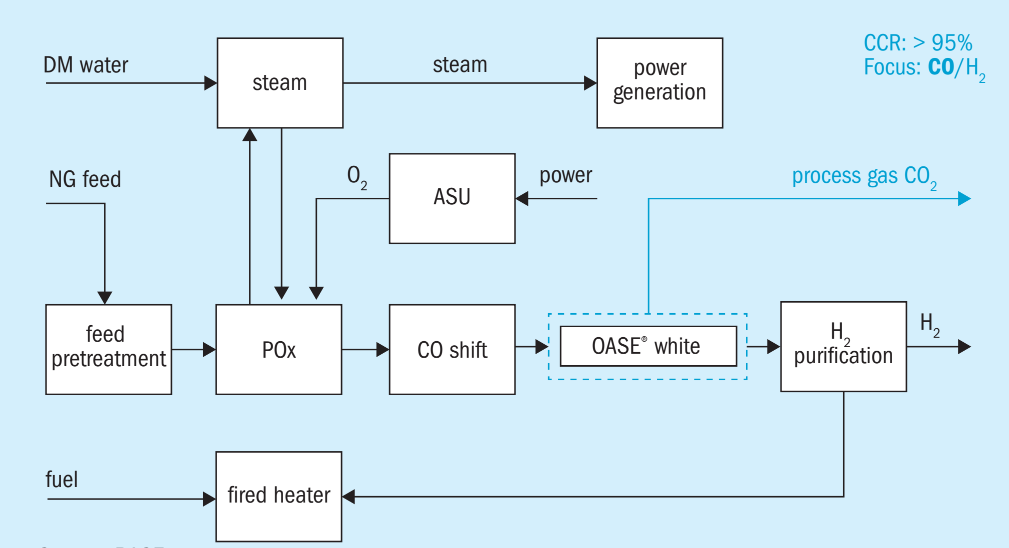
### ATR+GHR with $CO_2$ capture (blue $H_2$)

The autothermal reformer + gas heated reformer (ATR+GHR) configuration has been developed to maximise energy recovery. The main difference between ATR+GHR and SMR is that the energy used to drive the steam reforming reaction is provided by introducing oxygen to the ATR rather than burning natural gas in SMR. In this case oxygen is obtained from an air separation unit (ASU) and by-product nitrogen could be utilised at site[7].

ATRs are already used in the production of syngas and are an integral part of most modern schemes for production of methanol and for synthetic liquid fuels from Fischer-Tropsch processes. These plants are very large and demonstrate that the technology can produce hydrogen at large scale, thereby eliminating scale-up risk. GHRs have operated on a commercial basis for over 100 cumulative plant years and have demonstrated reliability[7].

The specific thermal energy consumption of an OASE® white unit in an ATR+HGR configuration varies between 0.69 and 1.1 GJ/t $CO_2$, depending on configuration along with an achieved carbon capture rate of 99.99%.

Fig 5: **Typical POx scheme with the option of process gas $CO_2$ capture**




*Source: BASF*

### POx with $CO_2$ capture (blue $H_2$)

Partial oxidation (POx) is an oxygen-based, non-catalytic technology which is a mature and cost-efficient process used by ~10% existing hydrogen plants. Being non-catalytic, unlike SMR, ATR and ATR+GHR, POx doesn't require the same extent of gas pretreatment as catalytical processes and can still provide significant feed flexibility. The POx design (Fig 5) has a lower hydrogen yield than ATR.

Fig. 5 shows a typical POx scheme with the option of process gas $CO_2$ capture.

The specific thermal energy consumption of an OASE® white unit in POx configuration is 0.6 GJ/t $CO_2$ along with a carbon capture rate of 99.99%.

By having the highest $CO_2$ partial pressure in the feed gas, this configuration provides the lowest specific energy consumption in comparison to other options.

## Conclusion

The demand for hydrogen is accelerating, driven by stronger national-level government commitments to decarbonise the energy sector and by businesses with net-zero objectives and ambitious sustainability targets. Meeting this demand will require a transformation in how hydrogen is being produced. Just as there is no magic bullet for providing the world's green energy needs, there is no one-size-fits-all approach to clean hydrogen production. Current economics of green hydrogen are challenging when compared to blue hydrogen. Blue hydrogen has a vital role to play in energy transition and is needed in the short and medium term.

BASF's OASE® technologies for $CO_2$ capture have been independently assessed to be the most cost-efficient and are capable of achieving up to 99.99% carbon capture at scale in various hydrogen production flow schemes. BASF being not just a technology provider and licensor, but also a facility owner and operator of its own units with a commitment to reducing its impact on the climate, understands the challenges and concerns of operating companies around the globe. BASF regards blue hydrogen as a timely climate silver bullet, providing a more cost-effective alternative to green and carbon-intensive grey hydrogen. ■

### References

1. Wawrzinek K.: "Decarbonizing ammonia production", Nitrogen + Syngas 2022, pp 31-38.
2. [CertifHy 2019], CertifHy, Hydrogen Criteria, subsidiary document, 2019, www.certifhy.eu
3. Suresh B., Schlag S., Kumamoto T. and Ping Y., CEH Marketing Research Report HYDROGEN, (Jul 2010)
4. Vakil T. and Marquez M.: "The case for blue hydrogen; An analysis of the costs and merits for grey, blue and green hydrogen".
5. Voitic G., Hacker V. et al: "Fuel Cells and Hydrogen" (2018).
6. Kakoti A. and Dahl P.J.: "Decarbonize with blue ammonia". AIChE 2022.
7. Pach J.: "A serious response to a serious threat – Low Carbon Hydrogen (LCH), a step change reduction in the $CO_2$ intensity of Hydrogen production", Nitrogen + Syngas 2020.
8. Xanthoulis E.: "Optimisation consideration for blue hydrogen retrofits", ADIPEC 2021.

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