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Number 382 March | April 2023

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Nitric acid plant emissions monitoring

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ISSUE 382
MARCH-APRIL 2023

BCInsight

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Which way the wind blows

> There are now also major carrots and sticks in place to drive the changeover.

On March 20th this year, just as this issue was going to print, the UN Intergovernmental Panel on Climate Change (IPCC) issued its Synthesis Report, one of its 5-7 yearly comprehensive assessments of how the world's climate is changing and what needs to be done to ameliorate it. In spite of all of the progress that has been made since the 5th Synthesis Report in 2017, the IPCC notes that: "the pace and scale of what has been done so far, and current plans, are insufficient to tackle climate change." While the body believes that keeping warming to 1.5°C above pre-industrial levels is still possible, it is not likely unless work to decarbonise proceeds more rapidly. In particular, the IPCC suggests that CO_2 and equivalent emissions need to fall by 43% by 2030 compared with 2019 values, and 60% by 2035 to achieve this goal.

There is thus an increasing urgency to measures to tackle this, and certainly there was no shortage of presentations and talk of blue and green ammonia at the recent CRU Nitrogen+Syngas conference in Barcelona, as our report in this issue details. In his presentation, CRU's Alex Amin calculated that there is now a total of 160 million t/a of announced blue and green capacity across dozens of projects, though of course economics and financing remain an issue, and at present only around 6 million t/a of this capacity looks likely to be completed before 2030.

Even so, this is a rapid growth rate from a low base, and successful projects are likely to ease the way for future capacity by demonstrating technologies and helping bring down costs. There are now also major carrots and sticks in place to drive the changeover, including the US Inflation Reduction Act, and Europe's carbon pricing regime, and especially its Carbon Border Adjustment Mechanism, which begins a transitional phase this year, and which is due to fully come into force on January 1st 2026. There is also more government money available in the EU, with Germany increasing its spending on renewables by 30% year-on-year, and Spain 60%.

Green capacity requires renewable energy, and one of the ironies of the war in Ukraine is that, as it forces Europe to confront its dependence on Russian gas, so it has also actually accelerated Europe's move towards renewable energy. In October 2022 a report found that use of renewables in EU electricity generation had increased even just since February 2022, by 14% in France, 20% in Italy, and 35% in Spain. The International Energy Agency's Renewables 2022 report estimated that installed solar photovoltaic capacity could surpass natural gas and coal as the largest source of electricity generation by 2027. Renewable power generation is projected to more than double over the next five years, with as much capacity installed in that time as in the previous 20.

With markets for clean ammonia beginning to open up in the power sector, particularly in Japan, and with the longer term prospect of low carbon ammonia and methanol demand from shipping as a clean burning fuel, it is starting to become clear which way the wind is blowing. ■

Richard Hands, Editor

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Price Trends

Market Insight courtesy of Argus Media

NITROGEN

Ammonia prices slumped to 22-month lows in several regions in early March, driven by fresh spot sales in both east and west of Suez in the low-$500s/t c.fr. Global supply continues to heavily outweigh demand because of weak downstream demand and high stock levels across key consumption regions.

On the demand side, the rate of seasonal ammonia demand from the US, Europe and India, which usually drives sentiment at this time of year, remains uncertain. And high stock levels persist, keeping spot demand relatively absent from the market at current price levels. In the Middle East, prices have dropped over $300/t since the beginning of the year, and are not expected to stabilise unless further production is curtailed in competing regions.

Some recent sales have given an idea of market direction. In Turkey, Trafigura has sold 10,000 tonnes to a buyer in Samsum for 1H-April delivery at $520/t c.fr, via trading firm Hexagon. Trammo has sold 2-3 cargoes for prompt delivery to Turkish buyers over the last few weeks. Prices are reported to be in the low $500s/t c.fr. A trader has also reported a sale of 5,000-7,000 tonnes into Taiwan at around $550/t c.fr, dropping prices $90/t on the previous week. In China, producers say a number of turnarounds at domestic ammonia plants in March have led to some supply shortages and a rise in domestic prices. A purchase was reported into Zhanjiang at $680/t c.fr, but traders do not expect import demand to pick up in earnest until late-2Q 2023.

Prices also fell in most urea markets in early March as suppliers continued to chase limited demand. India's purchase tender has yet to formally conclude but it appears IPL will book 1.15 million tonnes of urea at $330-334.8/t c.fr, with supply dominated by traders sourcing from Russian and Middle Eastern producers. Prices in the Americas fell following the India tender to around $320-325/t c.fr in both the US and Brazil. European prices stabilised on steady demand at retail level for spring applications, supporting Egypt and Black Sea prices around $390-403/t f.o.b. But these relatively high price levels in Europe have again pulled supply in from outside the region, particularly from the Middle East and Nigeria.

Sentiment at the Argus Asia conference in Dubai, on March 7th-9th was generally bearish regarding the outlook for nitrogen prices into the second half of the year, largely on the basis of the structural oversupply evident in the urea market. Importers in several markets are still buying last-minute and smaller than usual tonnages, driving a premium for prompt tonnes in Europe but overall softening markets. While supply in Europe has increased, tracking falling natural gas prices, fertilizer prices are again approaching levels of marginal profitability. ■

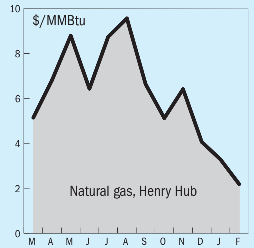
Table 1: **Price indications**

Cash equivalent	mid-Feb	mid-Dec	mid-Oct	mid-Aug
Ammonia ($/t)				
f.o.b. Black Sea	n.m.	n.m.	n.m.	n.m.
f.o.b. Caribbean	550-590	975-1,025	1,100-1,200	1,050-1,095
f.o.b. Arab Gulf	570-600	820-900	890-990	915-1,030
c.fr N.W. Europe	620-660	975-1,020	1,140-1,240	1,165-1,250
Urea ($/t)				
f.o.b. bulk Black Sea	320-380	420-530	n.m.	n.m.
f.o.b. bulk Arab Gulf*	300-355	420-485	546-631	570-680
f.o.b. NOLA barge (metric tonnes)	310-335	495-520	550-585	465-585
f.o.b. bagged China	355-410	440-485	580-620	475-530
DAP ($/t)				
f.o.b. bulk US Gulf	646-678	660-710	756-808	803-836
UAN (€/tonne)				
f.o.t. ex-tank Rouen, 30%N	392-403	575-600	683-693	605-609

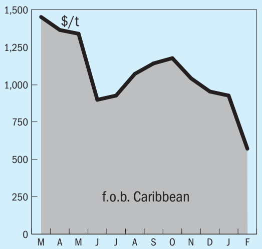
*Notes: n.a. price not available at time of going to press. n.m. no market. * high-end granular.*

END OF MONTH SPOT PRICES

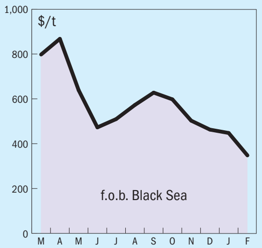
natural gas



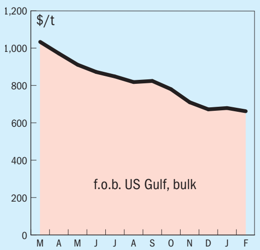
ammonia



urea

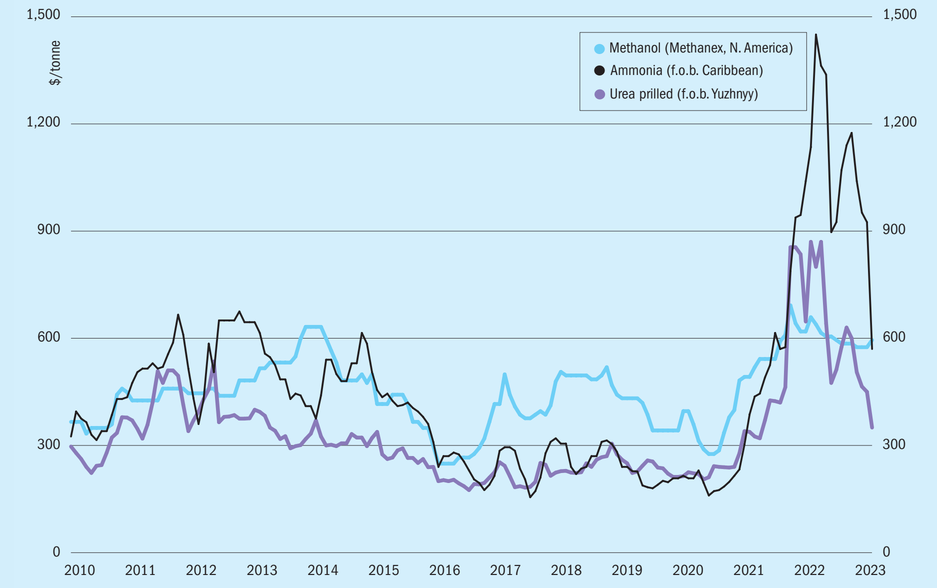


diammonium phosphate



Market Outlook

Historical price trends $/tonne



Source: BCInsight

AMMONIA

- The EU benchmark TTF natural gas price had fallen to $16.89/MMBtu on average for February, down 19% on January's average and 36% lower than the figure for February 2022. By the end of the month it had fallen to $14.83/MMBtu, its lowest level since the outbreak of war in Ukraine. EU gas storage was assessed as 61% full on 28 February, compared to a five-year seasonal average of 40%, due to strong LNG imports and mild weather over the winter. Over one third of European ammonia capacity has returned to production as gas prices fall.
- Ammonia demand is expected to pick up for the spring planting season in the northern hemisphere, but remains subdued at present.
- Market fundamentals suggest that some further price deterioration is possible as buyers continue to stay out of the market on expectations of further price cuts by producers.

UREA

- A large overhang of ammonia stocks weighed heavily on all nitrogen markets, including urea. Buyers have been thin on the ground, with the US Gulf taking some excess capacity.
- There are also expectations of more supply from China in the coming months as export restrictions are lifted. Chinese urea exports halved to 2.6 million t/a in 2022 from 5.3 million t/a in 2021 because of export quotas and other restrictions.
- New plant start-ups added a reported additional 8 million t/a of capacity in 2022, which is also beginning to make itself felt in excess supply.
- Overall, a correction downward in prices to rebalance the market by forcing some production curtailments seems likely given muted levels of demand and high availability.

METHANOL

- Falling coal prices in China as temperatures begin to rise have supported better margins for domestic Chinese methanol producers, but returns remain poor and many plants have elected to take early turnarounds. Low olefins prices have kept MTO operating rates low. Relatively high Chinese coal prices continue to set a floor under global methanol prices.
- The US became a net methanol exporter in 2022 according to recently released figures, with a net outflow of 1.8 million t/a, up from the 2021 figure, which showed imports and exports evenly balanced. Relatively cheap natural gas and Europe's interruption of supply from Russia allowed US producers to ramp up production for export to Europe. Methanex is looking at Q4 2023 for a start-up of its new Geismar 3 plant.
- Equinor said it would restart its 900,000 t/a Tjelbergodden methanol plant at the start of April following a maintenance shutdown.
- Methanol prices have been fairly stable, with a pickup in demand likely in Q1 2023 compared to Q4 2022. ■

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Nitrogen Industry News

JAPAN

Blue ammonia project to use BASF technology

BASF says that its high-pressure regenerative CO_2 capture technology HiPACT®, co-developed by BASF and engineering partner JGC Corporation will be used by INPEX, one of Japan's largest exploration and production companies, in its Kashiwazaki Clean Hydrogen/Ammonia Project. This is Japan's first demonstration project for the production of blue hydrogen/ammonia from domestically produced natural gas, the consistent implementation of carbon capture, utilisation and storage (CCUS) in domestic depleted gas fields and the use of hydrogen for power generation and ammonia production. The project is funded by the Japanese governmental organization New Energy and Industrial Technology Development Organization (NEDO).

HiPACT will capture and recover CO_2 in the process gas from a hydrogen production facility using domestic natural gas as feedstock in the Hirai area of Kashiwazaki City, Niigata Prefecture. The facility will be constructed by JGC and is expected to start up in 2025. The recovered CO_2 will be injected into the reservoirs of the depleted gas fields for enhanced gas recovery (EGR). By releasing the CO_2 off gas above atmospheric pressure, HiPACT is expected to reduce CO_2 capture and compression costs by up to 35% compared with conventional technologies.

UNITED STATES

CF Industries looks to supply blue ammonia to Korea

CF Industries has signed a memorandum of understanding with South Korea's LOTTE Chemical Corp. to potentially co-develop a blue ammonia project in Louisiana's Ascension Parish for shipment to South Korea. CF Industries has already signed a deal with Mitsui to develop the $2 billion "Blue Point" facility and has begun a front-end engineering and design study, and expects to make a final investment decision on the project in the second half of 2023 with a roughly four-year construction timeline, according to filings with the Securities and Exchange Commission. The two companies argue that there are considerable advantages for building the ammonia facility in the United States, including low-cost natural gas, suitable geology for carbon sequestration, and a friendly regulatory and legal framework for project approvals.

"In order to bolster the domestic hydrogen economy, it is important to secure a stable supply of clean hydrogen and ammonia, especially in overseas regions with abundant energy and low geopolitical risks," Jin-koo Hwang, head of hydrogen energy business at LOTTE, said. "Through strategic collaboration with CF Industries, which has a long history and business experience, we will secure a production base in the USA and lead the global distribution channel."

"We look forward to helping LOTTE and South Korea meet their clean ammonia requirements as we continue to accelerate the world's transition to clean energy," said Tony Will, president and CEO of CF Industries.

BP recently signed a deal to sell 2.2 bcf of certified natural gas this year to CF Industries, which CF says "is an important step in CF Industries' decarbonisation journey and reinforces our commitment to be at the forefront of low-carbon ammonia production." Certified gas is produced by companies whose operations are independently verified by a third-party auditor who provide a factual assessment of methane emissions intensity, which is the ratio of methane emissions to natural gas produced.

Topsoe technology chosen for blue ammonia project

Copenhagen Infrastructure Partners (CIP) and the Sustainable Fuels Group (SFG) are aiming to produce blue ammonia from a facility on the US Gulf Coast, expected to be operational in 2027. Front-end engineering work has begun on the project, and will consist of two trains, each with a capacity of 4,000 t/d of ammonia production. It will use Topsoe's *SynCOR*™ steam reforming technology to create hydrogen from high-temperature steam and natural gas for ammonia production, with downstream capture and sequestration of the CO_2 from the production, resulting in 90% well-to-gate emissions reductions compared to traditional ammonia production, abating 5.0 million t/a of CO_2 emissions.

Søren Toftgaard, Partner in Copenhagen Infrastructure Partners, said: "We are developing a global portfolio of clean hydrogen and hydrogen-related products, such as clean ammonia. Blue ammonia is considered an important part of a successful energy transition, which can potentially help fill the ammonia shortage in Europe as well as being a steppingstone to the successful implementation of green projects, and we are excited to bring this project to the Gulf Coast region."

Linde to build blue hydrogen facility in Texas coast

Linde has announced plans to build a $1.8 billion blue hydrogen facility on the Texas Gulf Coast designed to supply ammonia production. The plant, in Beaumont, Texas, is slated to begin production in 2025. The primary off-taker will be fertilizer manufacturer OCI, which is currently building a blue ammonia facility in Beaumont expected to produce 1.1 million t/a of ammonia. Linde's facility will produce blue hydrogen using autothermal reforming with downstream carbon capture. The company says the facility will sequester over 1.7 million t/a of CO_2. It will be integrated within the company's existing Gulf Coat pipeline network, allowing Linde to market the plant's blue hydrogen to other downstream customers in the region wanting to decarbonise their operations.

"Our strategy is to support decarbonization by working with off-takers, like OCI, to safely and reliably supply low-carbon industrial gases at scale," Linde CEO Sanjiv Lamba said. "With Linde's track record in successfully executing complex projects, its extensive pipeline network, and support from the US Inflation Reduction Act, the company is well positioned to secure many more clean energy projects."

BRAZIL

Agreement for green ammonia supply to Europe

Brazilian a renewable energy company Casa dos Ventos, together with energy efficiency Comerc Eficiência, has signed a partnership agreement with the TransHydrogen Alliance (THA) to enable the export to Europe of green ammonia produced in the industrial and port complex of Pecém (CIPP), in Ceará, Brazil. The plant will be built on a 60-hectare site with a capacity of up to 2.4 GW of electrolysis, producing 960 t/d of hydrogen, and. once all project phases have been implemented, will enable the production of 2.2 million t/a of ammonia and its export via the port of Rotterdam beginning in 2026.

"We want to use the abundant renewable resources in Ceará and neighbouring states to expand our low carbon energy solutions abroad", says Lucas Araripe, CEO at Casa dos Ventos. The company and Comerc have already signed a pre-contract with the CIPP. "We are joining forces with a group of companies that will be able to contribute to the technological development of the project and with a portfolio of international clients", explains Araripe.

The TransHydrogen Alliance is a consortium formed in early 2021 by Proton Ventures, Global Energy Storage (GES), Trammo DMCC and Varo Energy. Global Energy Storage (GES) is a specialist in the development, construction and operation of terminals worldwide, and is developing a new clean ammonia import terminal in Rotterdam, which will integrate with the supply chain of Pecém. Trammo DMCC is the largest independent international ammonia trader.

GERMANY

Hapag-Lloyd sign to evaluate ammonia as bunker fuel

Hapag-Lloyd AG has signed a memorandum of understanding with Mabanaft GmbH & Co. KG to evaluate options for the supply of ammonia as bunker fuel to Hapag-Lloyd in and around the port of Hamburg, and also Houston, Texas. The joint study will assess the viability of and the options for the safe handling of clean ammonia as a bunker fuel. Mabanaft is in the process of developing infrastructure in Hamburg for import and supply of clean ammonia, along with partner Air Products, as well as a larger infrastructure investment program to create a platform for low carbon fuel alternatives. The Hamburg import terminal is aiming for completion in 2026. With a fleet of 252 container ships and a total transport capacity of 1.8 million TEU, Hapag-Lloyd is one of the world's leading shipping companies.

"We play an active role in shaping the energy transition and offer our customers innovative fuel solutions to reduce greenhouse gas emissions," explains Volker Ebeling, Senior Vice President of New Energy, Chemicals & Gas at Mabanaft. "In shipping, we intend to support that transition for example through investments in ammonia production and the development of related supply infrastructure".

BASF closes ammonia plant in Germany

BASF has announced the closure of one ammonia production train at its headquarters in Ludwigshafen due to high energy costs. The site was impacted the most by additional energy costs of €3.2 billion which were recorded by BASF globally last year, with higher natural gas costs accounting for 69% of the overall increase. BASF aims to save costs of more than €500 million by the end of 2024, and lower fixed costs by over €200 million annually by the end of 2026 in Ludwigshafen. Around 700 positions in production are likely to be impacted at the headquarters. BASF, however, is "confident" it will be able to offer most of the affected employees employment at other plants. One measure to lower costs at the site is to close its caprolactam plant, one of the two ammonia plants and associated fertiliser facilities. Chair of the board of executive directors, Dr. Martin Brudermuller said: "Europe's competitiveness is increasingly suffering from over-regulation, slow and bureaucratic permitting processes, and in particular, high costs for most production input factors. All this has already hampered market growth in Europe in comparison with other regions. High energy prices are now putting an additional burden on profitability and competitiveness in Europe." BASF aims to secure greater supplies of renewable energy for the plant. "We want to develop Ludwigshafen into the leading low-emission chemical production site in Europe," Brudermuller said.

Heraeus given supplier reliability award by Nouryon

Heraeus Precious Metals has been awarded the "Supplier Reliability Award" for its supply reliability, collaboration, and close partnership with Nouryon, a global leader in specialty chemicals. Heraeus' Catalytic Gauzes product line was recognized for its support of Nouryon during the Covid-19 outbreak in Shanghai, China. In order to maintain supply chains and production, employees from Heraeus temporarily moved to the Shanghai factory premises and were able to avoid production downtime. The company was able to successfully process all orders during this time and ensure on-time delivery to Nouryon.

MIDDLE EAST

KBR technology selected for low-carbon ammonia plant

KBR says that its ammonia technology has been selected for a large-scale 900,000 t/a low-carbon ammonia facility at an undisclosed location in the Middle East region. Under the terms of the contract, KBR will provide the technology licence, basic engineering design, proprietary equipment and catalyst for the plant. The company says that the project reinforces the region's focus to emerge as a leader in low-carbon fuels by capitalising on ammonia as a vector for clean hydrogen.

"We are honoured that our leading low-carbon ammonia technology has been selected for this world-scale energy transition project," said Doug Kelly, KBR president, Technology. "This project will be among the first large energy transition projects to come onstream in the world and we are excited to be part of this journey with several global industry leaders."

UNITED ARAB EMIRATES

Brooge and Siemens to develop green ammonia plant in Abu Dhabi

Brooge Energy Ltd, a Cayman Islands-based infrastructure provider, has announced a partnership with Siemens Energy to build a photovoltaic solar farm to supply a green hydrogen and ammonia project in Abu Dhabi, UAE. Brooge will work with Siemens Energy to build an eventual 650 MW solar PV plant to supply BRE's planned Phase 1 of the green ammonia project with renewable energy. Siemens Energy will serve as technical partner to Brooge, providing engineering, design, procurement, and construction services, including grid connection and operation and maintenance services. The two companies will partner to obtain the necessary project approvals from governmental agencies as a first step of the project.

SAUDI ARABIA

NEOM Green Hydrogen signs $8.5 billion finance deal

NEOM Green Hydrogen Co. has signed finance agreements with several financial institutions totalling to $8.5 billion in order to finance its clean energy facility. The project includes the development, financing, design, engineering, procurement, manu-

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facturing, and factory testing of a world scale green hydrogen/ ammonia plant. Under a 30-year green ammonia offtake contract with Air Products, the project will also comprise transportation, construction, erection, installation, completion, testing, commissioning, insurance, ownership, operation and maintenance of the facility. NEOM Green Hydrogen is a joint venture between Air Products, NEOM Co, and ACWA Power – which holds a 33.3% equity stake.

The total investment cost will be funded by a combination of long-term debt and equity, comprising $5.85 billion of senior debt and $475 million mezzanine debt facilities, arranged on a non-recourse project finance basis. It also includes $1.5 billion from the Saudi National Development Fund on behalf of the National Infrastructure Fund. The consortium of financiers includes First Abu Dhabi Bank, HSBC, Standard Chartered Bank, Mitsubishi UFJ Financial Group, BNP Paribas, Abu Dhabi Commercial Bank, and several others.

Gas allocation for new AN plant

The Saudi Chemical Holding Company says that its subsidiary Saudi Chemical Company, in partnership with another Saudi company, has received a gas allocation letter from the Ministry of Energy to set up a nitrate plant. The facility will produce 440,000 t/a of nitric acid and 300,000 t/a of ammonium nitrate, and will provide raw materials for several downstream industries in Saudi Arabia, including civil and defence explosives, missile, and rocket propellants, and smelting salts used in producing solar panels and pharmaceutical industries.INDIA

Offtake agreement for green ammonia plant

Uniper and Greenko ZeroC Private Ltd has signed a memorandum of understanding with Uniper to enter into exclusive negotiations for the offtake of green ammonia from Phase 1 of Greenko's new green ammonia facility in Kakinada. Under the MoU, Greenko and Uniper intend to negotiate a pricing, supply and tenure structure for a supply and purchase agreement for 250,000 t/a of green ammonia.

Greenko's Kakinada project is a multi-phase green ammonia production and export facility which is eventually aimed to reach 1.0 million t/a of green ammonia capacity by 2027. The first phase will be powered by 2.5 GW of renewable assets in India and reinforced by Greenko's Pinnapuram Integrated Renewable Energy Storage Plant (IRESP).

The CSBP Wesfarmers site at Kwinana.

AUSTRALIA

CSBP looking to expand ammonia production

Australian fertilizer producer CSBP has proposed to build and operate a new 300,000 t/a ammonia plant within its industrial complex at Kwinana, Western Australia, to the state's Environmental Protection Authority (EPA). The expansion aims to cater to growing demand for ammonia in Australia and is expected to be completed by the end of 2027, subject to EPA's approval timeline, according to the company. It will be integrated with existing CSBP facilities at the site and will use natural gas from the Dampier-Bunbury natural gas pipeline as feedstock. CSBP has a current capacity of 255,000 t/a at the site, mainly used as raw material for downstream chemical and fertilizer products, as well as for supply to the domestic market.

CHINA

Green ammonia project claims to be world's largest

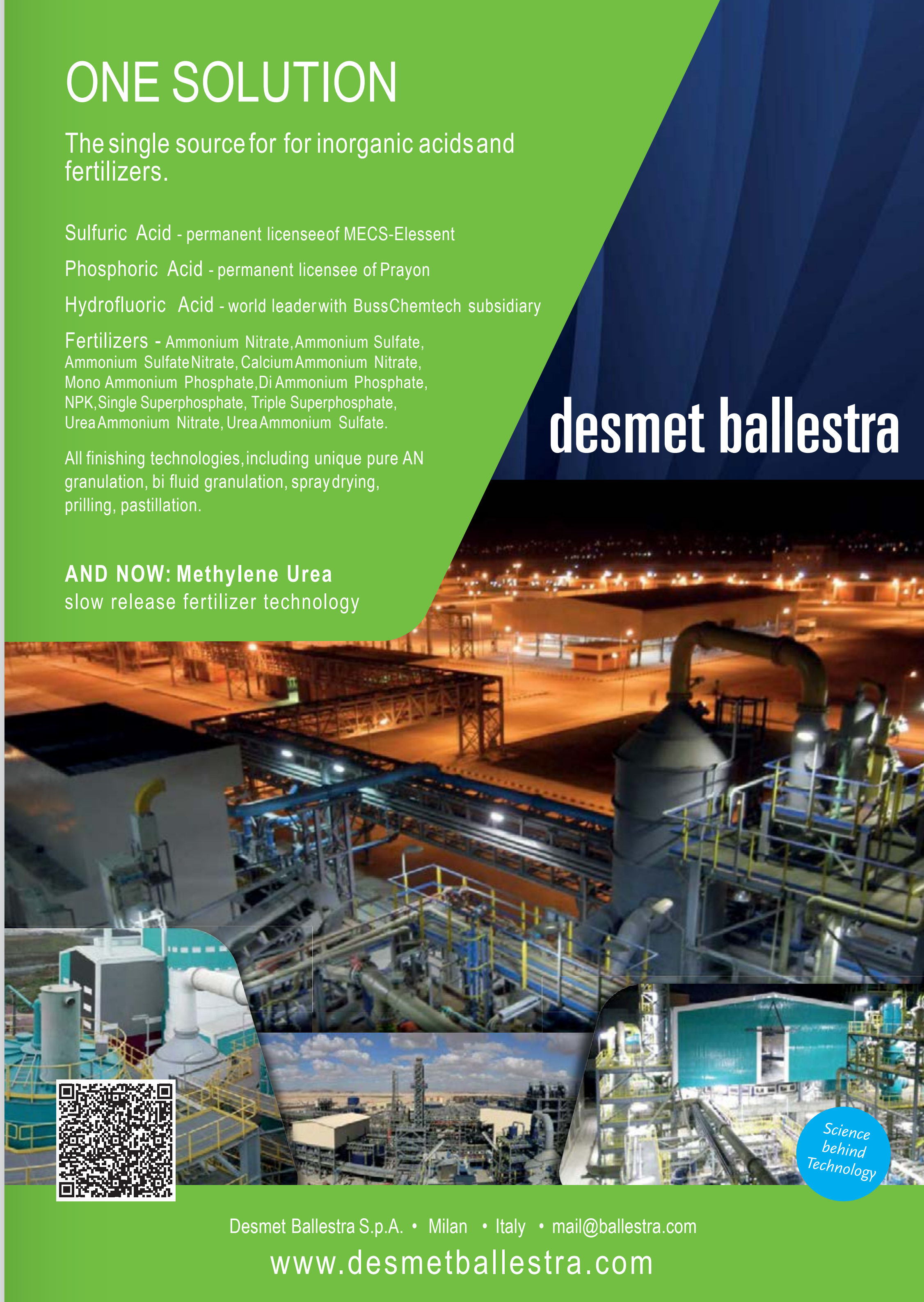
Sinpoec has begun construction on a green hydrogen project at Ordos, Inner Mongolia. The project will use 390 MW of electrolysers to produce 30,000 t/a of green hydrogen as a feed to existing coal-based ammonia capacity at a cost of $830 million. Power will come from 450 MW of wind powered generation and 270 MW of solar power. The project includes 288,000 m^3 of hydrogen storage, as well as a pipeline network to deliver hydrogen to the nearby Zhongtian Hechuang Ordos Coal Deep Processing plant. Sinopec has ambitions to be producing 2 million t/a of green hydrogen by 2025. It is also building its 20,000 t/a Kuqa plant in Xinijang which will supply hydrogen to Sinopec's Tahe refinery.

PARAGUAY

Power agreement signed for green ammonia

NeoGreen Hydrogen Corp. has signed a long term 75MW baseload power purchase agreement with ANDE, the national electricity company of Paraguay. The power, from the Itaipú hydroelectric dam, will supply a green nitrogen project in Tres Fronteras, an area where Brazil, Paraguay and Argentina converge, close to the Iguazu and Parana rivers. The initial design concept is for 10,000 t/a of green hydrogen that will be converted into ammonium nitrate for use as part of NPK fertiliser blends, at an estimated investment cost of $400 million. A final investment decision for the project is expected by Q4 2023, and green hydrogen and ammonia production is targeted for mid-2026.

NeoGreen has worked with its consortium partners and engineering, management, and development consultancy Mott MacDonald to finalise a number of studies, and is now looking to move the Tres Fronteras project towards the front end engineering and design stage. ■



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Syngas News

UNITED STATES

ExxonMobil awards contracts for blue hydrogen plant

ExxonMobil has awarded the contract for front-end engineering and design (FEED) of what it describes as the world's largest low-carbon hydrogen production facility. A final investment decision for the project is expected by 2024, subject to stakeholder support, regulatory permitting, and market conditions. Technip Energies will conduct the FEED for the Baytown integrated complex, which will produce up to 1 bcf/d of low carbon hydrogen, while capturing more than 98% of associated CO_2 emissions, totalling around 7 million tCO_2e/year. Offtake agreements are reportedly under discussion with third party customers. Start-up is planned for 2027-2028. The carbon capture and storage network being developed for the project will also be made available for use by third-party CO_2 emitters in the area in support of their decarbonisation efforts.

Topsoe has agreed to license its SynCOR reforming technology for the project, with Honeywell UOP supplying carbon capture technology.

"This project allows us to offer significant volumes of low-carbon hydrogen and ammonia to third party customers in support of their decarbonisation efforts," said Dan Ammann, president of ExxonMobil Low Carbon Solutions. "In addition, the project is expected to enable up to a 30% reduction in Scope 1 and 2 emissions from our Baytown integrated complex, by switching from natural gas as a fuel source to low-carbon hydrogen."

Elena Scaltritti, Chief Commercial Officer, Topsoe, said: "We are very excited to support ExxonMobil with our unique technology. Once complete, this ambitious project will result in hydrogen that can be used for low-carbon fuels and chemicals to help meet global net zero targets. We are eager to start working with ExxonMobil and to enable the capturing of massive volumes of CO_2 emissions from the hydrogen production."

KP Engineering acquired by Shaw Group

KP Engineering (KPE), involved in the design and execution of customised EPC solutions for the refining, syngas, hydrogen, and renewable fuels industries, says it has completed its acquisition by The Shaw Group, a leader in global pipe and module fabrication. Going forward the company's new legal name will be KP Shaw, LLC.

Shaw says that this strategic acquisition will further enable Shaw to deliver complete engineering, procurement, and fabrication (EPF) project solutions to a variety of industries around the world. William E. Preston, who will continue as the President and CEO of KP Shaw, LLC, added: "This acquisition serves to fulfil an urgent requirement for bankable EPF service capacity in the growing North American market. KPE enhances the services in Shaw's already strong portfolio of offerings, which includes pipe, module, and structural steel fabrication, induction bending and specialty coating services. The integration of Shaw's high-quality services will enable us to better meet the needs of our well-established customer base and will also provide us with fresh opportunities to engage with new customers on a global scale."

UNITED KINGDOM

Metso Outotec faces litigation over waste-to-energy plants

Metso Outotec says that it is in legal proceedings with MW High Tech Projects UK Ltd in connection with three waste-to-energy plants in the United Kingdom. Prior to the Metso Outotec merger, Outotec supplied its gasification technology to these projects, which date back to 2015. MW has made various claims against Metso Outotec and Metso Outotec has significant counterclaims in the litigation, which commenced in 2019. In December 2022, Metso Outotec won the first judgment in the claim regarding a project in Hull and applied to the court for an interim payment of £6 million from MW. MW is now attempting to bring separate additional claims against Metso Outotec and, on February 9th, served an official claim with similar demands regarding a project in Surrey. In addition, Metso Outotec and MW are in an arbitration procedure regarding the third plant in the UK. Metso Outotec continues to reject MW's claims in all three cases. Metso Outotec has reported the Waste-to-energy business as a discontinued operation since the merger and is no longer offering these solutions to its customers.

CHINA

Linde to build syngas plant for BASF

Linde Engineering has signed an agreement with BASF for the engineering, procurement and construction of a synthesis gas plant in Zhanjiang, China, in a consortium together with its Chinese partner East China Engineering Science and Technology Co., Ltd (ECEC). The two companies have previously worked together in the design and construction of several Rectisol® acid gas removal units in China. For the new BASF project Linde will be acting as consortium leader, including the provision of basic engineering and key equipment. ECEC will be responsible for the detailed design and the construction.

"Linde Engineering's one-stop solution for BASF combines state-of-the-art technology with a comprehensive EPC execution package. Our long-standing relationship and understanding of our customers' needs has enabled us to develop a tailor-made package of technology and services which will support their growth in China," said John van der Velden, Senior Vice President Global Sales & Technology at Linde Engineering.

Start-up for new methanol plant

Chinese automaker Geely and resource company Henan Shuncheng Group say that they have started production at a new 110,000 t/a methanol plant at Anyang City in Henan province. Although the plant describes itself as a 'green' methanol plant, it in fact takes hydrogen off-gas from Shuncheng's coke oven and carbon dioxide captured from industrial exhaust gas, with methanol produced using 'emissions-to-liquids' (ETL) technology from Icelandic company Carbon Recycling International (CRI).

DENMARK

Topsoe and Steeper Energy to provide waste to biofuels plants

Topsoe has signed a global licensing agreement with Steeper Energy for Steeper's hydrofaction™ technology, used for converting biomass to renewable biocrude oil, enabling Topsoe to offer a complete waste-to-fuel solution for refineries, project developers, and industries having access to excess waste biomass. The end-products include sustainable aviation fuel (SAF), marine biofuel, and renewable diesel from waste biomass.

Hydrofaction or hydrothermal liquefaction applies supercritical water as a reaction medium for the conversion of biomass directly into a high-energy density renewable biocrude oil. Steeper's process subjects wet biomass to heat and high pressure in process conditions chosen to promote reaction pathways that favour high yields of high-quality renewable oil. It is possible to convert up to 85% of incoming biomass on an energy basis, making it one of the most effective conversion technologies available.

Peter Vang Christensen, Senior Vice President, Clean Fuels & Chemicals – Technology, Topsoe, said:

"We are excited to work with Steeper and to combine our technological capabilities. This will make it easier for refineries and project developers to access the technology they need for advanced biofuels. It will also allow them to access new renewable feedstocks while supporting decarbonisation of the transportation sector, not least aviation and shipping."

Technip to construct green fuels plant

Arcadia eFuels APS of Denmark has awarded a contract to Technip Energies to deliver front-end engineering and design (FEED) services on the operator's proposal to build what it says would be the first-ever plant to produce carbon-neutral 'electrofuels' (eFuels), including a sustainable aviation fuel (SAF) equivalent, using renewable electricity, water, and biogenic carbon dioxide.

Technip Energies will engineer a plant that will produce about 55,000 t/a of renewable kerosine, 25,000 t/a of renewable naphtha, and an unidentified volume of renewable diesel, all of which can respectively be blended up to 50% with conventional jet and road fuels to help the aviation and heavy transportation industries meet voluntary and regulatory carbon-reduction goals in line with the global energy transition, the service provider said. Technip Energies said its scope of delivery also includes engineering of an associated 250 MW electrolyzer for production of green hydrogen at the complex, which will be built at the port of Vordingborg, in the southern part of Zeeland, 100 km south of Copenhagen. The complex is scheduled for start-up in 2026.

Arcadia eFuels also confirmed its January 2022 award of a joint contract to Topsoe AS and Sasol Ltd. for delivery of preliminary engineering on the proposed plant, which will be based on the service providers' integrated G2L eFuels technology. CO_2 will be sourced either from biogenic carbon via carbon capture technology at a designated source, from direct air capture, or a combination of the two. Hydrogen produced from the electrolysis process will then be reacted with captured CO_2 to produce syngas, as a feedstock to the Fischer-Tropsch (F-T) process. Hydrocarbons produced in the F-T process will be converted into eJet fuel, eDiesel, or a combination of both, along with smaller amounts of eNaphtha and eLPG. Topsoe's SynCOR reforming technology will be used for converting methane-rich gas and oxygen to carbon monoxide and hydrogen, with Sasol providing its F-T process. Final hydroprocessing will use Topsoe technology, which breaks down, isomerizes, and saturates the long-chain molecules to produce designated end-products (e.g., jet fuel, diesel, naphtha).

INDIA

Green methanol plant

Danish-based Umwelt Energy says that it will invest $850 million in Tamil Nadu to build a green methanol plant in the state. Although the location has not been disclosed, land purchase has reportedly been completed. According to Saibaba Vutukuri, Managing Director, Umwelt Energy India, the plant will be able to produce 100,000 t/a of green methanol. It will be a fully integrated plant, starting from 500 MW of wind-solar hybrid generating capacity which will power electrolyser to produce green hydrogen. The green hydrogen will be reacted with carbon dioxide to form methanol.

SWEDEN

JM to supply license for blue methanol project

Johnson Matthey (JM) has been selected to provide the methanol license and engineering services for Perstorp Group's Project Air in Stenungsund, Sweden. The plant will produce 200,000 t/a of sustainable methanol, avoiding the emission of 500,000 t/a of carbon dioxide, equivalent to the annual emissions of around 340,000 new cars running on fossil fuel. The initiative – which will substitute all the fossil methanol used by Perstorp in Europe as raw material for chemical products with sustainable methanol – is expected to be fully operational by 2026 and is a cooperation between Perstorp and Uniper.

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The new plant will operate a first-of-a-kind carbon capture and utilisation (CCU) process at an industrial level – converting carbon dioxide emissions from Perstorp's operations, together with biogas and renewable hydrogen to create sustainable methanol. The project has received €97 million funding from the European Union Innovation Fund which supports green technology projects in the EU, and approximately €30 million from the Swedish Energy Agency.

Alberto Giovanzana, Managing Director of Catalyst Technologies at Johnson Matthey said: "The chemical industry has often depended on fossil-based raw materials to produce products. Moving away from fossil feedstock at the beginning of the value chain is crucial to reduce the overall carbon footprint of end products. Project Air demonstrates how JM's Low Carbon Solutions technologies can create more sustainable chemicals on a large-scale, significantly reducing the environmental impact of manufacturing."

Contract awarded for green methanol plant

Carbon Clean says it has been awarded the carbon capture equipment supply contract for Ørsted's FlagshipONE methanol project in Sweden. The technology will capture 70,000 t/a of CO_2 from a biomass-fired combined heat and power plant in Örnsköldsvik, Sweden. FlagshipONE will combine the biogenic carbon dioxide with renewable hydrogen to produce 50,000 t/a of low carbon methanol for use in the shipping industry, which today accounts for around 3% of global carbon emissions.

Aniruddha Sharma, Chair and CEO of Carbon Clean, said: "The FlagshipONE project not only demonstrates the role carbon capture must play in decarbonising hard-to-abate sectors, such as shipping, but also that the technology is ready and there is absolute confidence in our ability to deliver at scale. We speak often about the storage of captured carbon, but this project is a perfect example of utilisation – the 'U' in CCUS – and we are thrilled to be working alongside Ørsted to deliver this project."

The carbon capture plant will be modular and designed for ease of construction and future replication. Following off-site testing, modules will be transported and assembled on site in autumn 2024. FlagshipONE is expected to be operational in 2025. The carbon capture plant will use Carbon Clean's proprietary CDRMax technology which has been used widely in projects globally for many years.

Construction approved for methanol powered icebreakers

Aker's ARC 130 S design for the world's first methanol-ready icebreaker has been finalised in conjunction with the Swedish Maritime Administration (SMA), which is now evaluating shipyards which could construct the vessel. The decision to construct at least two new icebreakers for Sweden was made in December 2022. The first vessel is planned to be delivered in 2026 and the second about a year later. A shipyard to build the ships was expected to be chosen by the end of February 2023, after which requests for tenders will be issued. Dan Broström, project manager at SMA said that they aimed to sign a final agreement in September 2023 and begin construction preparations immediately afterwards. He added: "Currently, the plan is to build the icebreaker initially for fossil-free renewable diesel oil (hydrotreated vegetable oil; HVO) with readiness to adopt methanol fuel as soon as the technology has matured and fuel availability is secured. The harbour generators will use methanol-based MD97 fuel from the start."

SPAIN

Cement off-gas to green methanol project

Mexican building materials company Cemex has signed an agreement with green fuel producer ETFuels to transform carbon emissions from Cemex's Alicante cement plant in Spain into green methanol. Under the agreement, ETFuels will combine up to 450,000 t/a of captured CO_2 with green hydrogen to produce sustainable fuel. Cemex is evaluating several strategies and partners to perform CO_2 capture for this project. The fuel produced through this agreement is intended to be used in the shipping industry, with the goal of further reducing overall carbon emissions in the global supply chain.

"Our goal of reaching net-zero CO_2 emissions is achievable and will be driven by collaboration and innovation," said Fernando A. González, CEO of CEMEX. "Our decarbonisation roadmap includes reducing emissions to the lowest possible level through proven levers such as clinker substitution and alternative fuels. New levers, such as rapidly developing CCUS initiatives, must effectively tackle the remaining CO_2 emissions to hit our ambitious 2050 objectives."

"ETFuels is honored to work with the CEMEX team in our joint ambition for decarbonization of industry. This pioneering fuel production project combined with Carbon Capture and Utilization presents a scalable way to decarbonize supply chains and aligns fully with our vision to deliver energy transition at hyperscale with commercially viable solutions," said Lara Naqushbandi, CEO of ETFuels.GERMANY

Conversion of CO_2 using plasma reactors

Evonik has launched the PlasCO2 project together with three partners. The aim is to use carbon dioxide as a raw material in the production of C4 chemicals. The German Federal Ministry of Education and Research is funding the project with more than €1.8 million. PlasCO2 stands for 'Plasma-induced generation of carbon monoxide from carbon dioxide and its chemical utilisation'. The researchers are working on extracting synthesis gas from carbon dioxide and hydrogen by means of a plasma reactor using a newly developed process. The synthesis gas obtained in this way can then be used for the production of chemical products. The project consortium, which is coordinated by Evonik, also includes the Leibniz Institute for Catalysis (LIKAT), the Leibniz Institute for Plasma Research (INP), and Rafflenbeul Anlagen Bau GmbH.

"If we succeed in generating carbon dioxide as a raw material, we would not only make a significant contribution to reducing our carbon footprint, but we would also open up a completely new world of chemistry," said Professor Dr. Robert Franke, head of hydroformylation research at Evonik Performance Intermediates and coordinator of the PlasCO2 project.

CANADA

Blue methanol plant cancelled

Alberta-based Nauticol Energy Ltd. has confirmed it will not be moving forward with a proposed C$4 billion blue methanol plant near Grande Prairie in northwest Alberta. The plant would have created 3.4 million t/a methanol from natural gas. In 2021, Nauticol announced plans to add carbon-capture technology. Speaking to local media, Nauticol president and CEO Mark Tonner said that the pandemic had created "headwinds" for the project, and costs had doubled from the original C$2 billion estimate. He added that no final decision has been made on the future of the site, and that a scaled-down net-zero methanol plant might still be possible, focusing on domestic supply.

People

BASF has announced some changes to its leadership team. The company has appointed **Dr. Stephan Kothrade**, President, Intermediates, as a member of the board of executive directors from March 1st, 2023. Stephan Kothrade has been with BASF since 1995 and has led BASF's Intermediates division since 2022. Dr. Kurt Bock, Chairman of the Supervisory Board said: "Stephan Kothrade has proven himself in several leadership roles in Germany and abroad. He has worked successfully for many years at our Verbund sites in Europe and Asia and will complement the Board of Executive Directors in an excellent way." Kothrade succeeds **Saori Dubourg,** who left the company as from February 28, 2023, by mutual agreement. The board thanked Dubourg for her successful work and wished her all the best for her future career.

Christian-Matthias Jutzi, previously Senior Vice President, Mobile Emissions Catalysts will assume responsibility for the Corporate Finance Division in Ludwigshafen, Germany, from May 1st, 2023. He succeeds **Dr. Dirk Elvermann**, who was appointed as the new Chief Financial Officer and Chief Digital Officer by the Board in October last year. Finally, **Ralph Schweens** will retire effective March 31st, 2023. He will be succeeded by **Dr. Mary Kurian**, Senior Vice President, Petrochemicals North America, BASF Corporation, Houston, Texas. She will assume responsibility for the Care Chemicals global operating division at Ludwigshafen from April 1st, 2023.

In the United States, the National Corn Growers Association (NCGA) has announced that **Neil Caskey**, a long-time professional in the agricultural arena, will be the organisation's next CEO. Caskey has served as NCGA's vice president of communications and industry relations for over four years and spent over a decade promoting agricultural issues as executive vice president at OBP Agency, an advertising and public relations firm. His professional background also includes work for the American Soybean Association and as a legislative aide for a US member of Congress.

Methanex's new president and CEO Rich Sumner has made some changes to the company's leadership as January 2023. **Dean Richardson**, previously Vice President, Corporate Finance, has been appointed as Senior Vice President, Finance and Chief Financial Officer, from February 1st, 2023. Richardson has worked closely with Ian Cameron, retiring Senior Vice President, Finance and Chief Financial Officer for over a decade, in a variety of progressively senior and strategic finance roles.

Kevin Maloney, Vice President, Corporate Development, has been appointed as Senior Vice President, Corporate Development. Vanessa James will step down from her role as Senior Vice President, Corporate Development and Sustainability and will support the transition through Q1 2023. Maloney was the Geismar 3 project business owner and is well equipped to take over executive leadership of G3, Methanex's new project in Louisiana which is expected to produce methanol in Q4 2023.

Gustavo Parra, Vice President, Manufacturing Strategy and Planning, has been appointed as Senior Vice President, Manufacturing, replacing Kevin Henderson, who retires as Senior Vice President, Manufacturing. **Karine Delbarre**, Vice President, North America Marketing & Logistics, has been appointed as Senior Vice President, Global Marketing & Logistics, filling the vacancy left by Rich Sumner following his appointment as President and CEO.

Jesús Enrique Mora Marín has been appointed as CEO of the Brunei Methanol Company, responsible for the management control and direction of day-to-day activities of the company in accordance with the Board of Director. Mora majored in chemical engineering at the Universidad Central de Venezuela, and served for many years with Metanol de Oriente, SA (Metor) in Venezuela, from which he retired in 2017.

Calendar 2023

APRIL

17-19

Syngas 2023,
BATON ROUGE,
Louisiana, USA
Contact: Betty Helm,
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Baton Rouge, Louisiana, USA
Tel: +1 225 706 8403
Email: betty@syngasassociation.com
Web: www.syngasassociation.com

MAY

22-24

Nitrogen+Syngas USA,
TULSA, Oklahoma, USA
Contact: CRU Events,
Chancery House,
53-64 Chancery Lane,
London WC2A 1QS, UK
Tel: +44 (0)20 7903 2444
Fax: +44 (0)20 7903 2172
Email: conferences@crugroup.com

22-24

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

JUNE

1-2

33rd IMPCA Methanol Mini-Conference,
DUSSELDORF, Germany
Contact: IMPCA, Avenue de Tervueren
270 Tervurenlaan,
1150 Brussels, Belgium
Tel: +32 2 741 86 64
E-mail: info@impca.be

8-9

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

11-14

IMTOF 2023, LONDON, UK
Contact: Polly Murray, Johnson Matthey
Email: polly.murray@matthey.com

AUGUST

20-24

67th AIChE Safety in Ammonia Plants and Related Facilities Symposium,
MUNICH, Germany
Contact: Ilia Kileen, AIChE
Tel: +1 800 242 4363
Web: www.aiche.org/ammonia

SEPTEMBER

10-15

Ammonium Nitrate/Nitric Acid conference,
VARNA, Bulgaria
Contact: Sam Correnti, DynoNobel,
Karl Hohenwarter, Borealis.
Email: sam.correnti@am.dynonobel.com,
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Plant Manager+

Problem No. 66 Urea storage for bagged urea

Storing urea under hot and humid ambient conditions can be a challenge. Several quality parameters of the urea product itself like moisture, temperature and particle size distribution are critical. Fluctuations of these parameters over time are also important and can lead to caking issues and complaints by clients. Off-spec product means big losses in revenue and results in a troublesome stream that has to be handled separately. Learning from each other's experiences is vital to minimise and avoid these problems.

Amir Tafazol from Shiraz Petrochemical Company in Iran kicks off this interesting Round Table discussion: We want to build a storage facility for bagged urea. Are there any standards or conditions that need to be considered? Is it necessary to consider an air conditioning (AC) system? The location of the storage is in a port which has humid weather.

Mark Brouwer of UreaKnowHow.com in the Netherlands asks a question for clarification: Is it for 50 kg bags (more closed) or 1000 kg big bags (more open)?

Amir replies: The storage is for big bags.

Mark asks some further questions: I assume your concern is caking? Caking is determined by the product quality (moisture content, hardness and smoothness of granules, dust-content, etc.) and on the local-specific conditions, such as the ambient conditions (relative humidity and temperature and their fluctuations). Basic philosophies for a urea warehouse is to keep it as airtight as possible (keep doors closed) and apply thermal insulation. This will minimise any relative humidity and temperature fluctuations. I assume the product temperature is already ambient when it reaches the port and that the big bags are properly closed. Does anyone have experience of whether AC is required in hot and humid climatic conditions? Does anyone use special big bags? Are you talking about prills or granules? What is the moisture content?

Amir responds: Yes, my concern is about caking. As you mentioned, we know the basic philosophies for a urea warehouse but I am wondering if it is for bulk storage only and whether it is also essential for bagged product? We have experience of some temporary general warehouses which are not airtight and do not have an AC system, and we had any problems of caking in these warehouses. But now we want to build a standard bagged product warehouse for our company at the port, so it is better to consider the essentials in the design. Furthermore, you assumed right, the product temperature is already ambient when it reaches the port after couple of days and the moisture content is decreased. We produce both prilled and granulated urea. The moisture content of fresh prills is max. 0.3 wt-% and max 0.5 wt-% for fresh granules.

Mark replies again: You state you have seen no caking issues of either product in the available warehouses at the port which are not airtight and have no AC. In that case why would you expect problems in a new airtight warehouse?

Prem Baboo, Ex NFL India and Dangote Fertilizers Nigeria joins the discussion: In hot countries there is no need for air conditioning in a urea storage warehouse, the critical relative humidity (CRH) of urea is high (70 to 75% at 30°C) compared to ammonium nitrate and calcium ammonium nitrate (CAN). In the rainy season all doors of the silo (urea storage) should be closed to withstand the hot and humid conditions in those countries. Only ammonium nitrate requires an air conditioning system.

The relative humidity can be controlled in the prilling system by operating the position of the louvers in the bottom and top of the prilling tower, these can be throttled in the rainy season to control the humidity. The relative humidity can also be controlled by means of a desiccant-type dehumidifier.

Up to 0.3 wt-% moisture content of urea is ideal to avoid physical quality problems like caking. In the summer season, urea must be cooled to below 60°C (even better 45-50°C) because the trapped moisture in the hot urea can condense when it is stored or bagged resulting in caking. Cooling of urea in the summer season can be done by means of SOLEX coolers.

The moisture content can be controlled by process parameters like vacuum pressure, free ammonia content, etc.

Prem refers to the following articles with more background information:

- *2002 Orphanides Urea caking problems, how to avoid them:* To the knowledge of the author there are not enough precise reports explaining the phenomenon of urea caking when stored in bulk (in onshore storage or in hatches of ocean-going vessels). In the literature, many studies and investigations report on the effect of various parameters with regard to caking (CRH, particle size and hardness, abrasion and impact resistance, treatment and conditioning, storage pressure and temperature, urea moisture, moisture absorption, etc.), but only few explain the mechanism of how caking spreads from a relatively limited initial area to the whole pile, often observed in even very good quality urea, stored under more or less correct conditions in bulk. The basic phenomenon governing the spread of caking in a heap of urea in bulk, so-called humidity migration, is where initially a relative thin layer only has absorbed humidity, (due to the hatch cover being left open during a period of high atmospheric relative humidity), or where a relatively small amount of warm urea (above 55°C) with a higher residual moisture content is present in a heap of relatively cold urea with low residual moisture content. If this water pick-up, or this inclusion happened, and urea is subject to temperature cycling, which usually is the case during storage, or loading – shipping – unloading, then caking of the whole holding of the hatch may result. This caking may be severe, resulting in hard to break lumps, or less severe (easy disintegration of lumps), depending on the quality of the urea and the number of cycles.
- *2018 06 Baboo Caking of urea in summer season:* In India the ambient temperature reaches 46-48°C in peak summer. The prill temperature goes even higher i.e., in our plants, the line-1- prill temperature is 70-72°C and has reached 78°C at higher plant load with recovery of urea solution. The prill temperature of line-2- prills is 64-66°C without bulk flow cooling. The caking of urea fertilizer has been investigated in a warehouse of large scale in National Fertilizers plant. In this article the caking tendency of urea was investigated for a silo and urea bags. The main cause of caking is the growth of crystal bonds on the contact point of prills. The caking tendency increases with moisture, the ammonia content causes water to mitigate through the pile, which increases the caking tendency. The effect of plant load, temperature, relative humidity, and storage time on the formation of a bridge between these particles was analysed. The objective was to describe the geometrical changes in the contact region and to measure the strength of the resulting inter particle bridge. Urea particles are used which are known for creating solid bridges under well-defined climatic conditions. The measurements indicate that, unlike isotropic materials, the bridge between two particles has higher shear than tensile strength. Moreover, the strengthening of the bridges with storage time is very inhomogeneous. The effect of load, temperature, relative humidity, and storage are the main objective of the study.
- *2018 04 Baboo NFL urea product quality:* This article includes many studies and investigations reporting on the effect of various parameters on prill quality like crushing strength, size distribution, abrasion and impact resistance, humidity factors urea moisture absorption, vacuum studies etc. The nitrogen, moisture, prill strength and biuret contents and the size distribution of prilled urea are important factors determining urea quality. High temperature of prilled product is common in most urea plants in India. In some plants in India the temperature of prills reaches 80°C on hot summer days at high load. At our plant the prill temperature is also 65-70°C. This result in poor strength, dust formation, and an increase in caking tendency. Granulated urea has a definite advantage over prilled urea but has been more expensive to produce until recently. We have installed a bulk flow cooler for lines 1 and 2. A modification was also carried out on urea line-1 in March 2018 to solve a foaming problem in the waste water section (distillation tower). This modification is now proven and beneficial.

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

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YPFB's urea plant at Bulo Bulo, Bolivia.

Nitrogen in Latin America

Brazil's agricultural industry continues to expand at the same time that most of its nitrogen fertilizer industry has shut down. Meanwhile, Venezuela continues to deal with the consequences of years of underinvestment and mismanagement, and elsewhere, gas discoveries in other parts of the continent have not led to the new plant construction boom that had once been hoped for.

South America and the Caribbean collectively has a population of 670 million people, or about 8.5% of the world's total. Collectively it also has about 1.15 million km² of arable land, just under that of Russia or China, and about 7.5% of the world's total. Yet it is also a key exporting region for a number of key crops, representing 13% of global agricultural production and 17% of food crop exports, including maize and soybeans, as well as being a major exporter of beef and poultry. Brazil is the dominant agricultural nation, representing around half of this production, and Argentina represents another two thirds of what remains.

From the 1960s and 70s, the region underwent the 'green revolution' along with south and east Asia, with increasing quantities of fertilizer and modern production techniques expanding output almost threefold. The region continues to be a key buyer of fertilizers, though in spite of plentiful resources it has struggled to develop a domestic fertilizer industry to supply this, especially on the nitrogen side.

Brazil

Brazil remains the economic powerhouse of the region, with the 8th largest economy in the world at purchasing power parity. Since the mid-2000s, Brazil has accelerated its transformation from an exporter of mainly tropical agricultural products such as coffee, sugar, citrus, and cacao to a major global supplier of commodities, including soybeans, grains, cotton, ethanol, and meats. But after a decade of growth during the 2000s, the 2010s were a difficult time for Brazil, with a major recession and the Operation Car Wash scandal that saw the impeachment of president Dilma Rousseff and the imprisonment of former president Lula da Silva, as well as forcing a massive restructuring on state oil company Petrobras. More recently the country has struggled with covid, high inflation and debt and weak growth.

In terms of fertilizer demand, Brazil's fertilizer use has been growing over the past decade, and accelerated from 2018-2021, with nitrogen use rising for 4.3 million tonnes N to 5.0 million tonnes N. Overall Brazilian nitrogen demand represents about 60% of that for the whole of Latin America, and this is serviced particularly in the form of urea – Brazil's demand for urea reached 7.1 million t/a in 2020, according to IFA figures. But Brazil imports 80% of its fertilizer needs, and it has been almost uniquely vulnerable to the sanctions that followed the Russian invasion of Ukraine. Around 25% of Brazil's fertilizer imports come from Russia, with another 8% from Belarus. Although it has been potash and phosphate that has been most badly affected by the war, and urea has been relatively plentiful, it is nevertheless estimated that nitrogen use fell by 8-10% during 2022 because of high prices; the knock-on effect of the gas supply crisis in Europe. Farmers have delayed fertilizer applications, and a large stock of urea has built up in Brazil.

The reason for Brazil's import dependence has been the decline of the country's domestic fertilizer sector. On the nitrogen side, there were four main producing sites; two urea plants owned by state oil and gas company Petrobras at Camacari and Laranjeiras, with a combined capacity of 1.0 million t/a; a third 660,000 t/a urea plant at Araucaria which was privatised in 1993 as Ultrafertil, and an industrial grade AN plant at Cubatao. Ultrafertil was bought by Bunge, and then mining giant Vale in 2010, but in 2017 Vale divested its fertilizer division to Mosaic, with the exception of the nitrogen unit, which came back under the control of Petrobras.

Petrobras had also been trying to develop three new fertilizer complexes, at Linhares, Uberaba and Tres Lagoas, at a total cost of $6.5 billion, with the strategic goal of reducing or ending Brazil's dependence on nitrogen fertilizer imports. However, the lack of additional natural gas availability, and the severe recession Brazil was facing led to Linhares and Uberaba being cancelled, and work at Tres Lagoas, where a 720,000 t/a ammonia plant and 1.2 million t/a urea were reportedly 80% complete, being halted in 2014.

Petrobras further added to Brazil's nitrogen deficit in March 2018 when it closed down the Camacari and Laranjeiras plants because of poor economics. Since then Petrobras has tried to find a buyer for its urea units, with Russia's Acron interested at one stage. But in 2020, in the wake of the failure of the Acron deal, the Araucaria plant was also idled, taking away Brazil's last domestic urea capacity. Yara were reportedly in negotiations to buy Araucaria last year, but again no final sale was agreed. Attempts to sell the unfinished UFN-III plant at Tres Lagoas have likewise come to nothing.

> "The Brazilian government... aims to reduce the country's dependency on imported fertilizers."

Seeking to remedy this, last year the Brazilian government launched its 2022-2050 National Fertilizer Plan, which aims to reduce the country's dependency on imported fertilizers. Among its goals, the plan aims to promote the domestic production of fertilizers, as well as the research, development, and innovation environments related to the production and distribution of fertilizers, and the development of logistics infrastructure for its supply chain. It is targeting an increase in the market share of domestically-produced fertilizers from the current 15% to 55% by 2050, also assuming a doubling in demand over the period. It also hopes to attract more foreign investment in Brazil's fertilizer sector. The plan has established an inter-ministerial National Council on Fertilizers and Plant Nutrition (CONFERT), designed to set initiatives and specific goals, coordinate with other federal strategic plans, and establish public-private cooperation related to fertilizers and plant nutrition products.

The plan also includes incentives to increase the use of organic fertilizers, financial investments in research and visits to producers across the country by the Brazilian Agricultural Research Company (Embrapa) to promote the increased efficiency in the use of fertilizers and inputs in the field. The government expects this to reduce Brazil's fertilizer demand by 20% over the medium term.

Argentina

Argentina is Latin America's other major agricultural producer, and consumer of fertilizers. Urea consumption was 2.3 million t/a in 2020. Argentina is an important global producer of maize, exporting 37.5 million t/a of maize in 2021/22 which accounted for 18.5% of global maize exports. However, domestic agriculture has been suffering from extremely dry conditions due to three successive La Niña events, in the southern hemisphere summers of 2020/21, 2021/22, and 2022/23. As with Brazil, high nitrogen prices have also priced some farmers out of the market, and fertilizer consumption dropped 7% last year.

Production, following the closure of the Bunge Campana urea/UAN plant in 2017, is from a single 1.3 million t/a urea plant, Profertil at Bahia Blanca, co-owned by Argentinian oil and gas firm YPF and North American fertilizer produce Nutrien, which almost exclusively produces for the domestic market. Even so, Argentina has to import urea to make up for the shortfall in production. Various plans are circulating for additional capacity in Argentina. Profertil has examined the possibility of a second train, a Chinese investor has discussed a plant at Tierra del Fuego using gas from the fields at the southern tip of South America, and Indian producer Iffco launched a feasibility study in 2021 on building a 'nano-urea' plant in Argentina. So far, however, no firm plans have emerged.

Bolivia

Bolivia is not a major consumer of fertilizer but has large gas reserves, discovered in the late 20th century, which have attracted numerous ammonia/urea project ideas. Bolivia supplies natural gas via pipeline to Brazil, and a site on the pipeline at Bulo Bulo, in the centre of the country, was chosen to build an ammonia/urea plant, under the auspices of state oil and gas company YPFB. After a long and difficult development process, the 726,000 t/a urea plant finally became operational in 2017, with around 85% of its output being exported to Brazil and Argentina. However, the plant has had an equally troubled production history, and did not cover its costs. It was shut down in 2019, and became mired in Bolivian internal politics following the disputed re-election of president Morales and the year long temporary government of president Jeanine Anez. The plant was 're-engineered' to replace degraded equipment items, and started up again in September 2021. Since then it has run relatively smoothly, at about 80% capacity. YPFB is now reportedly looking at a second, larger urea train of around 4,000 t/d (1.3 million t/a), at the same site.

Chile

Chile has no nitrogen fertilizer company, but explosives producer Enaex operates 850,000 t/a of ammonium nitrate production at Mejillones for explosives production. The site began operating in 1983, and has grown to four AN trains over the succeeding decades, the most recent capacity increase being in 2010. There is no domestic ammonia production, however – ammonia is bought in to feed downstream nitric acid and ammonium nitrate production. The site's ageing ammonia plant was sold, dismantled and transported to be rebuilt in China in 2013.

However, Enaex has become interested in the possibility of using renewable energy in Chile to generate ammonia. An 18,000 t/a 'green' ammonia demonstrator plant is under development, licensed by KBR, with completion expected in 2025, and up to 1.3 million t/a of solar and wind-powered green ammonia capacity is at the feasibility study stage.

Mexico

Mexico is the third largest consumer of urea in Latin America, at 1.8 million t/a in 2020. State-owned Petroleos Mexicanos (Pemex) operated several 1950s vintage

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ammonia and urea plants at Cosoleacaque, Chihuahua and Salamanca, but high gas prices forced the closure of most of this capacity in the late 1990s. In 1996 Mexico produced 2.5 million t/a of ammonia and 1 million t/a of urea, but by 2000 ammonia production had fallen to 920,000 t/a, and by 2005 just 500,000 t/a. As a result, like Brazil and Argentina, Mexico has ended up importing most (ca 65%) of its nitrogen fertilizer needs. Attempts to refurbish plants and restart production at Cosoleacaque have been stymied by Mexico's gas pipeline network, which does not connect the production sites in southeastern Mexico to the more extensive pipeline network in the north of the country, which is able to import cheaper natural gas from the United States. The solution was to have been to build a new urea plant at Topolobampo, Sinaloa state, on Mexico's west coast, but the 770,000 t/a ammonia and 700,000 t/a urea facility has faced local environmental opposition, and has been mired in legal challenges since 2014.

Last year, the high price of nitrogen fertilizer affected Mexico in much the same way as Brazil, as Mexico also sourced around 25% of its urea from Russia. The government of president López Obrador signed a deal with the US to import ammonium sulphate as a stopgap, but also announced an ambitious $500 million investment plan to reactivate urea production at the southern sites to guarantee the supply of fertilizer to small producers. The government is targeting 2,500 t/d (825,000 t/a) of domestic urea production, but it remains to be seen if this plan will be any more successful than previous attempts to revive production. In the meantime, there are plans for green ammonia/urea production in Mexico, with a company called Tarafert aiming to produce 200,000 t/a of green ammonia and downstream urea in three tranches, with the first 66,000 t/a unit starting production in 2026.

Venezuela

Moving to the Caribbean, Venezuela developed a gas-based urea industry at three complexes on its northern coast in the 1980s and 90s; Nitroven at Zulia in the west, Fertinitro at Jose in the east, and Pequiven's Puerto Moron in between the two. Venezuela's production capacity totalled 2 million t/a of urea and 1.5 million t/a of methanol. Most of the plants were state-owned, but Fertinitro, completed in 2002, was a joint venture between state petrochemical major Pequiven (35%), Koch Nitrogen (35%), Snamprogetti (20%) and Empreseas Polar (10%). Koch became involved after PCS Nitrogen pulled out of the project in the late 1990s.

Table 1: **Urea production and consumption, Latin America, 2020 (million t/a)**

	Production	Consumption
Argentina	1.3	2.3
Brazil	0.0	7.0
Mexico	0.0	1.8
Trinidad	0.7	0.6
Venezuela	1.2	0.2
Others	0.0	3.2
Total	**3.2**	**15.1**

Source: IFA

But Venezuela's descent into political and economic chaos over the past two decades has seen foreign investment chased out of the country, the nationalisation of Fertinitro in 2010, and lack of money for repairs and maintenance of existing facilities. A plan to develop a plant jointly with Iran failed to get off the ground, though Pequivendid complete a second, 2,200 t/d ammonia-urea plant at Moron with financial support from China, which began production in 2014. Production at all of the plants continues to be dogged by interruptions in electricity and gas supply, and the 1.2 million t/a El Tablazo complex at Zulia has been idled since 2012.

Trinidad

Finally, mention must be made of Trinidad. Trinidad established a major ammonia and methanol industry in the 1980s and 90s on the back of cheap natural gas, with the US, which was facing high gas prices, as a natural market. Trinidad rode high through the 2000s, but was not replacing gas reserves and production at the rate that it was using it, because the government was not paying enough o incentivise the exploration and development of new reserves, and by the end of the decade the country was starting to face gas shortages, which became more acute during the 2010s. Production fell from 38.7 bcm in 2011 to 23.7 bcm in 2021, and in order to maintain LNG exports, domestic consumption fell by 25% during that time. LNG exports represent half of all Trinidad's gas use, and ammonia and methanol production each use another 18% of Trinidad's gas output. The gas price shortages have led to lower operating rates and stoppages among Trinidad's nitrogen and methanol producers. At the same time, the rise in US shale gas capacity has led to restarts and production expansions in Trinidad's major market.

There are some encouraging signs, however; Shell began production at the new Colibri field last year, and belatedly the government is changing its tax and incentives structures to encourage more gas drilling. Likewise the shortage of European ammonia and methanol caused by the gas price crisis and Russian sanctions gave Trinidad a ready market across the Atlantic last year and into this, making up for the loss of the US market for ammonia and methanol. Downstream, Trinidad has 4,100 t/d of urea capacity in three plants, though the large AUM plant uses much of its urea to make UAN solutions for the US market.

Untapped potential

In spite of abundant gas reserves around the continent, Latin America has struggled to develop a nitrogen industry capable of servicing its growing fertilizer needs. Only Trinidad is a world-scale producer, and it has faced challenges with gas. Profertil in Argentina has been a lone success story in terms of urea development, and belatedly the restart of the troubled YPFB plant in Bolivia. Venezuela struggles with sanctions and poor maintenance, and Brazil and Mexico still struggle to attract the foreign investment that could turn their nitrogen industries around. In the meantime, it seems likely that the continent will continue to be an increasingly major buyer on world markets. ■

Future methanol supply challenges

Continuing growth in energy uses indicate robust demand for methanol over the coming years, but the current slate of new projects does not look sufficient to meet it. Is methanol approaching a supply crunch?

Above: CRI's new 110,000 t/a carbon capture methanol plant, Anyang, China.

Methanol continues to be a fast growing use for syngas. In the 1970s and 80s, methanol was almost exclusively used for downstream chemical production, mainly formaldehyde for resins, acetic acid, methyl methacrylate, methyl chlorides and other solvents. Because it was easily transported, as a bulk liquid at room temperature and pressure, production migrated to 'stranded' gas locations as a use for gas reserves that could not otherwise find a market, in places such as the Middle East, Trinidad, and at the tip of Chile. There was a brief boom in the 1990s in its use as a precursor for ether additives for gasoline, such as MTBE and TAME, particularly in the United States, but poor environmental husbandry allowed MTBE to leak into aquifers from ageing gasoline storage tanks, and led to a virtual ban in the US. There was some talk of it being a fuel for cars, and California tried to pilot a methanol fuelled vehicle programme, but it suffered from a lack of distribution infrastructure. In New Zealand, several plants converted methanol to gasoline, but the process was too expensive and the plants eventually switched to only making methanol, and suffered from shortages of feedstock gas.

However, there as a major step change in the methanol industry in the 1990s, with the development by Davy Process Technology (now part of Johnson Matthey) and Lurgi (now owned by Air Liquide) of large scale methanol flowsheets. The move to 5,000 t/d and up plants allowed for economies of scale in methanol production which brought the cost down, and allowed it to compete with oil and gas derivatives both as a fuel and as a feedstock for olefins production. The methanol to olefins (MTO) process was developed by Union Carbide in the 1980s and commercialised by UOP in the 1990s, and Lurgi developed its own parallel methanol to propylene (MTP) process at the same time.

The impact of China

These new processes and uses did not catch on immediately around the world, but they were given a massive boost by the decision of the Chinese government to use methanol as a bridge from coal – of which it had an abundance – to fuels and olefins, which China otherwise had to import. Methanol derivative dimethyl ether (DME) became a widely used blendstock in liquefied petroleum gas (LPG), used for domestic heating and cooking in China, and methanol was also blended directly into gasoline at up to 10% to eke out gasoline supplies. In the 2000s, this was followed by methanol to olefins plants, either using domestic coal-based methanol, or even buying methanol on the open market.

China's move to methanol allowed these technologies to mature and develop, in spite of issues such as LPG explosions caused by DME corroding rubber seals, and led to Chinese domestic versions of western MTO processes licensed by Sinopec and others. Chinese methanol production and consumption came to dominate the global methanol market, with China representing almost all incremental growth and coming to represent around 55% of demand and 45% of production by 2015. The gap between those two led to increasing imports of methanol into China, mainly from the Middle East, but Chinese companies also began to look further afield to source methanol, with an attempt to develop large scale methanol projects on the west coast of North America or the Gulf of Mexico for shipping to China.

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Most of these projects ran into permitting problems, however, and did not come to fruition.

But over the past few years things have begun to change significantly in China. Coal prices have risen, and oil prices have fallen, making coal-based MTO plants less competitive. The methanol fuel and DME blending markets have reached saturation and China's refiners have managed to slow the adoption of national fuel methanol standards, meaning only certain provinces permit it. There has been a large scale build of domestic steam crackers to produce ethylene, in competition with olefins from MTO plants, and the Chinese government has begun to crack down domestically on polluting industries at the same time that it tries to pivot away from a dependence on coal in order to achieve carbon emission targets. Finally, the slowdown in the Chinese economy has throttled back the need for ever-increasing volumes of plastics and other olefin derivatives, though demand from traditional chemical uses continues to rise. Nevertheless, all of this has slowed the increase in China's methanol demand and production to a crawl, and it is becoming clear that the bull run in Chinese methanol may be over for now.

America's methanol renaissance

At the same time, the US methanol industry has had a remarkable turn of fortune, thanks to abundant and cheap shale gas. During the 1990s US capacity closed and production shifted to Trinidad and Venezuela where gas was cheap, the methanol being exported back into the US across the Caribbean. The availability of cheap natural gas has turned that around, and US methanol production finally exceeded demand last year for the first time in decades, turning the US into a net exporter for the first time. Recent plant start-ups have included Koch's 1.7 million t/a YCI Methanol One plant in Louisiana, and two 1.0 million t/a plant relocations by Methanex of plants from Chile, where gas supplies have been curtailed. This year, Argus forecasts that the US will produce around 9 million t/a of methanol, against domestic demand of around 7 million t/a, and this will increase with the completion by Methanex of the new 1.8 million t/a Geismar 3 plant at the company's site in Louisiana, due to be up and running by 4Q 2023.

At the same time, Venezuela's descent into economic basket case status and Trinidad's problems with sourcing sufficient natural gas to feed its ammonia and methanol plants have reduced supply from those sources.

Europe and Ukraine

There has been a major impact upon methanol markets due to the war in Ukraine. Europe is a major consumer of methanol – the second highest region after Asia – and also a large importer of methanol, and Russia is a major exporter. Russia exported 2 million t/a of methanol in 2021, and Europe imported most of that. Europe has not completely banned imports of Russian methanol, but only contracts concluded before October 2022 are still valid, and all imports will stop from June 2023. While the high natural gas prices in Europe at the end of 2021 and most of 2022 caused some shutdowns of European methanol capacity, it has not had the same impact as it has upon ammonia, purely because Europe operates from a much lower production base. Fortunately, Europe has been fortunate that, as well as its methanol imports from North Africa and Trinidad, it has had the new US export volumes to be able to draw on.

> "Methanex and OCI NV put methanol demand for shipping in 2027-28 at 3 million t/a."

Elsewhere

The Middle East is the largest exporting region for methanol, with Saudi Arabia and Iran the largest producers. There is also capacity in Oman, Qatar and Bahrain. In all the region has over 20 million t/a of capacity, and with little domestic demand beyond some MTBE production for fuel blending, most of the region's methanol production is exported, to India and especially China. Outside of Iran, however, new plant building has slowed down as gas supplies become more constrained, while Iran has faced sanctions which have slowed its new capacity additions and ability to sell its product overseas.

India, like China, is a coal-rich country, and there have been some investigations into the possibility at trying to emulate China's move to domestic fuel and plastics production based on coal-derived methanol. In 2018, government think tank NITI Aayog launched its Methanol Economy initiative with the aim of increasing domestic consumption of methanol from its present 2 million t/a to 30 million t/a, and production from 250,000 t/a to many millions of tonnes, allowing a reduction in oil imports. However, in spite of some research and pilot programmes, so far nothing has progressed in terms of actual plant building.

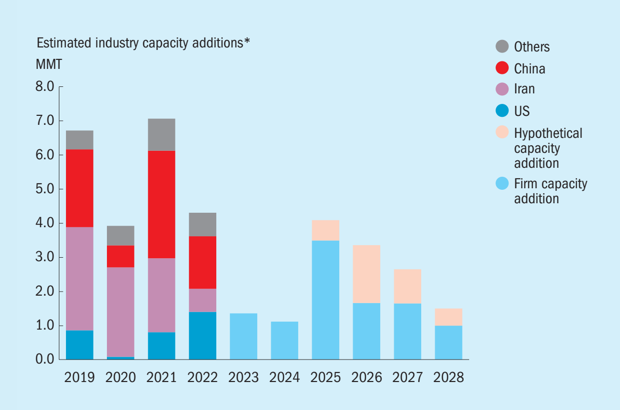
Indonesia likewise is looking at converting its plentiful coal into methanol and dimethyl ether in order to reduce imports of methanol and LPG. Two projects are under development, one in conjunction with a Chinese partner, the other with Air Products, Bakrie Capital Indonesia, and Ithaca Resources, which between them could produce 2.4 million t/a of methanol and some downstream DME

Shipping fuel

In terms of methanol demand, two developments now look like having a major long-term impact. The first is the potential uptake of methanol as a fuel for shipping. Methanex has used methanol as a fuel in its fleet of tankers, operated by subsidiary Waterfront Shipping, for some years, but interest in methanol has been galvanized by plans to decarbonise the maritime industry. The International Maritime Organisation (IMO), the UN body that regulates the shipping industry, has set the target of cutting the sector's carbon emissions by 50% in 2050 compared to 2008 levels. While there are numerous rival fuels, including low carbon ammonia, low carbon methanol has started to gain momentum after shipping giant Maersk began to focus upon it, arguing that: "it is the most mature from the technology perspective; we can get an engine that can burn it."

Stena Line has also been an early adopter, with the Stena Germanica car ferry operating in the Baltic on methanol. In 2022, the Proman Stena bulk joint venture vessels Stena Pro Patria and Stena Pro Marine became the first ships to bunker methanol in South Korea. Two more methanol powered bulk carriers: Stena Promise and Stena Prosperous, were completed in 2022, and two further vessels will be built by Q1 2024. Japanese shipbuilder Tsuneishi Shipbuilding is building a 67,500 dwt Ultramax bulk carrier capable of running on either methanol or conventional marine oil, with delivery planned in

Fig. 1: Methanol capacity additions, 2019-2028



Source: Methanex

2025. Mitsui E&S will provide the dual-fuel engine, expected to reduce emissions of NOx by 80%, sulphur dioxide by 99% and carbon dioxide by 10% compared to existing bunker fuels. Tsuneshi is also building two methanol-fuelled Kamsarmax bulk carriers for US-based trading firm Cargill. Maersk is building eight large container ships that will operate on methanol, with delivery in 2024-25. Each ship requires around 40,000 t/a of methanol, for a total of 500,000 t/a of new demand just from these eight ships alone. The speed of adoption is striking. In 2022 there were 22 methanol powered or duel fuel vessels operational, but Methanex estimates that by the end of 2026, that total will have reached 80 ships, accounting for around 1.7 million t/a of methanol demand. Both Methanex and OCI NV put methanol demand for shipping in 2027-28 at 100-120 vessels and 3 million t/a of potential demand.

Blue and green methanol

Much of the impetus behind the move by Stena, Maersk and others to methanol as a shipping fuel is predicated on using low carbon methanol. A few plants around the world already use low or lower carbon sources, including biofuel-based production in Sweden, waste gasification in Canada and a plant using geothermal energy to electrolyse water to hydrogen in Iceland. But the rapidly falling cost of electrolyser capacity and the push for low carbon hydrogen sources, as well as the opening up of large potential markets like shipping for low carbon methanol, are collectively leading to a rapid proliferation of blue and green methanol projects. There are around 80 projects already announced, according to the Methanol Institute. Some are already up and running, including a 110,000 t/a blue methanol plant in China using carbon capture co-designed by Carbon Recycling International, owners of the Iceland geothermal facility. Others are smaller scale pilot units or use waste or biomass gasification. There is also a proposal for 500,000 t/a of blue methanol capacity on the US Gulf Coast. It is expected that this sector will start to see increasing growth as the market for low carbon methanol expands, especially in the light of increasing carbon taxes in Europe and the huge boost to green/blue hydrogen production represented by the Inflation Reduction Act in the US. However, it may be towards the end of the decade before low carbon capacity begins to make its presence felt on the methanol market in any major way.

A shortage of methanol?

Methanex estimates that global methanol demand increased slightly to approximately 88 million tonnes in 2022. Of this, about half (44 million t/a) was represented by traditional chemical uses for methanol, which continue to see steady growth, perhaps 3-4% year on year, in line with global GDP growth. Another 16 million t/a (18%) came from MTO plants in China. This segment of demand is fairly stable, but MTO is not running at anywhere near capacity in China at present because of the affordability of methanol compared to end product prices. The remainder of demand, 28 million t/a, or about 32%, comes from fuel-related applications, including esters for gasoline additives, dimethyl ether for LPG blending, and methanol as a direct fuel blend in Chinese vehicles and in some ships. It seems to be this segment that has the largest potential for growth over the medium to long term, particularly the estimated 3 million t/a of extra demand for shipping fuel over the next five years. For the time being, Methanex puts 2027 demand at 102 million t/a, up 14 million t/a on present demand and representing an average annual growth rate of 3% – relatively modest compared to the growth methanol has seen over the past three decades.

Even so, there are concerns that the current project slate may not be enough to meet this demand. Plants in China, Iran and Trinidad are all impacted by feedstock restrictions, especially in winter for China and Iran, when gas is diverted to power production, as well as Chinese environmental regulations. New methanol capacity, shown in Figure 1, includes the 1.8 million t/a Geismar 3 plant in Louisiana, a 1.8 million t/a plant in Iran (but Iranian plants are subject to project delays because of sanctions and, as noted, gas restrictions), and a new 1.8 million t/a plant for Petronas at Sarawak in Malaysia which will almost double the company's current capacity when it starts up in 2024. There are incremental capacity additions at Chemanol in Saudi Arabia (200,000 t/a), and a number of low carbon plants based on waste or biomass gasification and the 50,000 t/a FlagshipONE green methanol plant in Sweden which collectively could add another 1.0 million t/a out to 2026-7. The Indonesian coal gasification plants are another 2.4 million t/a. There are some planned capacity additions in China over the short to medium term, but these are likely to be the closure of some small-scale, inefficient and older plants. All of this added together represents only around 9 million t/a, leading to a potential shortfall of 5 million t/a of methanol by 2027-8 unless new plants begin to be developed and built soon. ■

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The cost of ammonia production

Rising costs of fossil fuels in many markets, including coal in China and high gas costs in Europe are pushing up ammonia production costs. Can the falling cost of electrolysis make green ammonia production cost competitive in the near future?

CF Industries' ammonia no. 6 plant at Donaldsonville, Louisiana, a typical modern (2016) ammonia plant.

PHOTO: CF INDUSTRIES

While the ammonia industry is coming around to the idea that future production will need to minimise its carbon emissions, large scale implementation faces the challenge of how much that low carbon ammonia will cost to produce. The modern ammonia industry has geared itself up to producing ammonia efficiently using natural gas or coal. This involves optimisation of not only ammonia conversion, but also recovery of the large quantities of heat that are needed to drive conversion, and of economies of scale using plants that are almost as a minimum 2,000 t/d in size, and often 3,000 or even as high as 4,000 t/d, requiring a large dedicated coal mine or gas pipeline from a nearby gas field.

Ammonia plant efficiency has a theoretical minimum energy consumption per tonne of ammonia of 19 GJ/t ammonia, dictated by the thermodynamics of the process. In the very early days of the Haber-Bosch process, which relied on very high pressures and temperatures to force the conversion, the actual energy consumption was over 200 GJ/t. Successive improvements to the process over the intervening decades have driven the average energy cost of ammonia production to around 41 GJ/t (LHV), with the most modern and efficient plants able to achieve 28-30 GJ/t, which is approaching a practical limit for process efficiency.

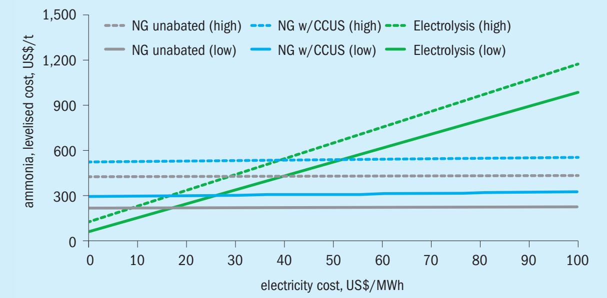
This efficiency very much drives the cost of production, as for traditional 'grey' ammonia production, most of the operating cost is determined by the feedstock being used. For natural gas, 28-30 GJ/t is equivalent to 30-32 MMBtu/t. At a low or subsidised natural gas price of, e.g. $5.00/MMBtu (US Henry Hub prices are below even this at time of writing, and some producers in the Middle East have legacy contracts with even lower gas costs), that would be a feedstock cost of $150-160/t ammonia.

But of course, ammonia prices are not set by those producers at the bottom of the cost curve, with the most advantaged feedstock costs and the most modern, efficient plants. They are set by the marginal producers at the top of the cost curve. At the moment, this is mainly coal-based capacity in China and gas-based capacity in Europe. At current European gas costs of $14/MMBtu, that is a feedstock cost of $420/t or more. Taking staff, rents, write down of capital and other costs into consideration over and above this, it is no coincidence that ammonia prices were around $500-550/t at time of writing.

Blue ammonia costs

The cost of blue ammonia production remains closely tied to feedstock cost, as grey ammonia production costs set a baseline for blue production, with the additional cost of carbon capture and storage added on. Most operational blue ammonia capacity uses captured carbon dioxide for enhanced oil recovery (EOR), because this has a value to the oil producer, and so CO_2 for EOR can be sold at around $20/t, recovering some of the cost of its use. Carbon credits or taxes can also help ameliorate the cost of blue production. According to last year's Innovation Outlook for Ammonia, published by the International Renewable Energy Agency (IRENA) and the Ammonia Energy Association (AEA), The cost of carbon capture and storage/utilisation for ammonia production depends upon the plant type; it is lowest for gas-based autothermal reformers, at an estimated $40-80/t then gas based steam reformers ($100-150/t), with coal gasification the highest cost ($>135/t). Production of ammonia entails the generation of around 2.7 tonnes of CO_2 per tonne ammonia. With European carbon prices currently around €100/tonne CO_2e ($108/t), and assuming 90% carbon capture, this would be a premium of $262/t blue ammonia, and goes a long way to explaining why in terms of current low carbon ammonia projects, proposed blue ammonia tonnage is outnumbering green ammonia tonnage by 4:1. It seems highly likely that blue ammonia will form the bulk of low carbon ammonia projects over the next few years.

Fig. 1: Cost of grey, blue and green ammonia production



Source: IEA

Renewable electricity cost

The point at which green ammonia becomes cost competitive is perhaps the most interesting one, though, and that depends upon two things; the 'feedstock cost' of renewable electricity, and the capital cost of electrolysers. Figure 1 comes from the International Energy Agency's 2019 report The Future of Hydrogen, and seems to assume a value for carbon capture and storage for blue ammonia in the lower bound of around $50/t, but it is illustrative of how the cost of electricity is crucial to the cost competitiveness of green production. The graph puts the lower cost of electrolysis at $450/kWe, and the higher cost at $900/kWe, with electrolyser efficiency in the range 65-75%. The lower bound for natural gas cost is around $3/MMBtu, the higher bound looks to be around $10/MMBtu. Assuming production towards the lower cost bound for electrolysis, the graph nevertheless indicates that green production can be competitive with the least efficient gas-based production at an electricity cost of around $50/MWh. This is not an unreasonable electricity cost. The IRENA report notes that the global weighted average levelised cost of electricity of new utility-scale solar PV projects commissioned in 2021 fell by 13% year-on-year, from $55/MWh to $48/MWh. Most studies project the cost of renewable electricity falling further as more economies of scale are achieved and further development work is undertaken, with $20/MWh deemed achievable by 2050, which as Figure 1 shows, would be competitive even with the cheapest natural gas today.

Furthermore, the US has subsidies for renewable electricity production. New electric power sector solar, wind, geothermal, and closed-loop biomass plants receive a tax credit of $25/MWh of generation, for example, putting current generation costs at an effective figure of $30/MWh.

Needless to say, there is considerable argument about these figures. IRENA argues that today's cost of renewable ammonia, without carbon credits, is $720/t at locations with good solar and wind resources. However, consultancy CRU puts the cost of green ammonia from an integrated 'renewables-hydrogen-ammonia' facility at about $900/t "even where solar and wind resources are plentiful and considered 'low cost'", and puts a "very optimistic" lower bound for production cost at $610/t. Others argue that a future cost of $20/MWh for electricity is over-optimistic and almost brings the cost down to the cost of the raw materials. Even so, we have been through a year where ammonia prices have been above $1,000/t and still are over $500/t. A present day cost of $720/t that could come down with increasing efficiencies does not look wildly over-expensive, and if it could indeed be brought down as some proponents argue to $250-300/t, then the switch from fossil fuel to electrolysis based production would become a stampede.

And of course, this does not take into account the impact of carbon pricing and other such mechanisms. As with blue ammonia, at current EU carbon prices, knocking $260/t off the equivalent cost of green ammonia would put it on a level footing with current ammonia prices. While this only currently impacts European domestic production, from 2026 the imposition of the new Carbon Border Adjustment Mechanism (CBAM) will expose any importer of nitrogen products into the EU to EU carbon prices. This puts Chinese coal-based capacity at the highest production cost, particularly if China introduces, as it aims to, a similar carbon pricing mechanism. Green ammonia was competitive with grey ammonia in Europe when gas prices were high, but less so as they have fallen back. But the CBAM means that users will have to pay for the carbon cost wherever the ammonia is sourced from, which should make EU green ammonia cost competitive.

Fuel

But will there be a market for green ammonia? At present the two most promising areas seem to be in burning ammonia either in fossil fuel power plants to lower the overall carbon cost, as Japan aims to, and for use in ships to generate carbon free motive power. Some of the critics of ammonia as a fuel point out that, while the spin is that ammonia burns to form only nitrogen and water, in practice most combustion methods also produce nitrogen oxides, some of them (like N_2O) considerable greenhouse gases in their own right, and use of ammonia as a fuel would therefore also require the installation of NOx scrubbing technology. However, as the use of selective catalytic reduction systems in modern road vehicles has shown, this need not be prohibitively expensive.

Tipping point

The aim of all of this, of course, is to try and decarbonise fertilizer production, shipping and power, to avoid our climate reaching a 'tipping point' beyond which the effects may be unpredictable and potentially disastrous. There is a persuasive argument that money spent now to prevent this would be an investment that repays itself many times over in terms of avoided extreme weather events and biodiversity loss. That said, banks and ammonia producers are unlikely to invest in new capacity unless they are assured of a return. Government incentives are needed to push the adoption of the technology, but it is beginning to look as though current financial incentives now make blue and even green ammonia production an attractive option, and it is beginning to feel as though the industry has reached its own tipping point, and may soon be changed beyond recognition. ■

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Nitrogen + Syngas 2023

CRU's Nitrogen + Syngas conference convened at the Hyatt Regency Barcelona Tower in Barcelona, from March 5th-8th.

Above: La Sagrada Familia, Barcelona at night.

The Nitrogen+Syngas conference met for its 36th year in Barcelona this March, following a successful return to face to face meetings last year in Berlin. This time, in spite of the situation in Russia, there were 600 attendees, and the meeting very much felt back to 'normal'. Sadly it also marked the swan song of CRU's event director Amanda Whicher, who has successfully organised the meeting for nine years, who is moving on to other duties within the company, and who opened the conference proper on Monday afternoon, following the morning's technical showcases.

Nitrogen markets

The first paper was of course the nitrogen market overview, presented by CRU's Alex Derricott. Ammonia had a very volatile 2022, he said, with prices spiking above $1,000/t. Several factors contributed to this; high gas prices in Europe, peaking at over $93/MMBtu, led to 70% of European ammonia capacity and 78% of urea capacity being idled. Trinidad also had power cuts at the start of the year and gas supply disruptions, and the closure of the ammonia export pipeline to Odessa meant that Russian ammonia exports dropped from 4 million t/a in 2021 to just 800,000 t/a in 2022. More recently, European markets have been assisted by lower gas prices, and only 35% of ammonia capacity, 25% of nitrate capacity and 46% of urea capacity remains idled. There are also forecasts that the Yuzhnyy pipeline may be back onstream in the second half of 2023. Meanwhile, new merchant projects in the US and Middle East will compensate for loss of Russian tons. Alex's forecast was for gas prices to continue to fall, European production to restart, and probably lower than anticipated industrial demand leading to falling prices out to the end of 2023, although now that the EU gas market is increasingly reliant on LNG, it may have a higher floor price.

Looking to the longer term, nitrogen demand is forecast to rise to 204 million t/a by 2027, still dominated by urea, and with some lower carbon ammonia capacity beginning to commission.

On the urea side, prices peaked in Q4 2021. The following year saw a lot of new capacity and more producers globally, and hence less exposure to EU gas prices and lack of Russian supply. Black Sea prices continue to trade at a discount to the market, while Egyptian prices are at a premium as they replace Russian AN shipments. Urea demand has been flat in 2021-22 with increased demand in Europe and India balanced by lower demand in Latin America, Southeast Asia and the US. In China, inland prices have tended to be below port prices, but the gap has closed as demand increases in the interior. The government has restricted exports leading to high stock levels. India continues to see new projects coming on-stream, with production rising to 29 million t/a this year. Overall, urea prices are on a slow decline to the end of 2023 at around $300/t. Longer term, falling gas prices may have an impact, but likely lower than that on ammonia. Capacity growth outpaces demand as far as 2027, but demand will recover from 2024 onwards as affordability increases.

On decarbonisation, there is an increased push from governments and regulation, and growing new markets in power and marine fuels. European carbon prices have increased to $65-70/t CO_2e, and could rise to $128/t by 2027. In that year, the new Carbon Border Adjustment Mechanism (CBAM) will come into force, which will expose any importer of nitrogen products into the EU to EU carbon prices. This puts Chinese coal-based capacity at the highest production cost, particularly if China introduces, as it aims to, a similar carbon pricing mechanism. Green ammonia was competitive with grey ammonia in Europe when gas prices were high, but less so as they have fallen back. But the CBAM means that users will have to pay for the carbon cost wherever the ammonia is sourced from, which should make EU green ammonia cost competitive.

Gas markets

Laura Page of Kpler discussed gas pricing. There was 64 bcm less Russian gas flowing into Europe in 2022 compared to 2021, she said. To balance this shortfall, Europe had imported 30 bcm of LNG from the US and 20 bcm of LNG from other sources, as well as more Norwegian pipeline gas, and had built up gas supplies ahead of winter. But there was also 60 bcm of demand destruction in Europe and Asia which helped LNG markets pivot to supplying Europe. As a result the EU will end the winter with gas storage up 18 bcm, and approximately 50% full. Even so, it needs to restock to 90% by November if it is to get through the next winter, and Russian gas supplies could fall by another 38 bcm this year. China is also expected to return to the LNG market and draw cargoes away from Europe even though the global LNG supply will increase by 19 million t/a in 2023, 45% of that in the US. Asian demand is forecast to be up 5 million t/a this year as the Chinese economy rebounds (Chinese LNG demand fell 15 million t/a last year), balanced by lower LNG demand from Japan and Korea as nuclear power generation increases. Europe may manage to attract 14 million t/a of that extra 19 million t/a (equivalent to 19 bcm). There are new import terminals in Finland and Germany and fewer bottlenecks in internal pipeline networks. But this will only offset half of the gas lost from Russia this year, and this is likely to mean more demand rationing (down another 15%?) to meet the 90% storage target. There is scope for lower consumption from power, but the picture on industrial demand is mixed. Even so, global gas prices are expected to be lower and less volatile than they were last year, with the European TTF averaging $19/MMbtu as compared to $40/MMBtu in 2022. US Henry Hub prices are put at $3.10/MMBtu on average for 2023, down from $6.50/MMBtu in 2022. Longer term, more Russian gas will flow to China, but this is a long term prospect as most of the pipelines currently run to Europe.

Green markets

AFRY is a leading advisor to hydrogen project developers, and Solomos Georgiou and Raimon Marin of that company were on hand to discuss how to optimise green hydrogen production. The main challenge of course is to convert intermittent renewable energy supplies into a steady hydrogen production flow. This can be achieved by hybridising the feed (combining wind and solar), using hydrogen storage (though this can be expensive and there may be space or safety restrictions on-site), using batteries (expensive and with a potential efficiency loss), making demand more flexible, and via a connection to the electricity grid, though at the cost of increased complexity and possibly carbon intensity. Optimisation at the concept stage can identify the best economically competitive systems, and this is often very site specific. Solomos and Raimon showcase AFRY's modelling of these factors with reference to some case studies.

This was followed by Alex Amin of CRU on green ammonia supply. Announced low carbon ammonia capacity now totals more than 160 million t/a, with a roughly 4:1 ratio of blue to green. But there is a funding disconnect, Alex said, and an open question as to how much of this would ever produce ammonia. The average carbon cost of producing ammonia from natural gas is about 2.5 tCO_2e/t ammonia. Blue production aims to reduce this to around 0.8 tCO_2e/t. Most CO_2 will be destined for enhanced oil recovery. This is a mature technology and a medium term solution for many players. Blue ammonia projects are concentrated in North America, Russia and parts of Asia. Green ammonia depends on the availability of renewables and is more spread geographically. In the US, the Inflation Reduction Act offers subsidies of $50/t for carbon capture and storage or $35/t for carbon capture and use respectively, and $3/kg of green hydrogen produced. In the EU, the RED II programme mandates that 50% of the hydrogen used in industry must be renewable by 2030. The EU is looking at 10 million t/a of green hydrogen being produced domestically by that time, and another 10 million t/a imported. Looking to the longer term, the demand potential is greatest for shipping fuels, with up to 120 million t/a of low carbon ammonia demand by 2050. Ammonia as a hydrogen carrier and ammonia co-firing for power might require another 35 million t/a by that time, with some substitution for existing ammonia production also occurring. But in the short term, Alex calculated that there is 6 million t/a of low carbon ammonia capacity at the final investment decision stage, and another 9 million t/a at the front end engineering design stage, and he forecast that there would be 3 million t/a of low carbon ammonia being produced by 2026. As the traded ammonia market is only 18 million t/a, merchant green ammonia could have a significant impact on markets.

Keshni Shri of OCI gave a producer's perspective on low carbon ammonia. OCI has a 1.1 million t/a blue ammonia project in Texas due to come onstream in 2025, and is expecting to make a final investment decision on a 90,000 t/a green ammonia facility in Egypt this year. It also uses waste gasification at BioMCN in the Netherlands. Keshni saw that low carbon ammonia could represent 50% of merchant ammonia by 2030, with power generation an attractive use for the near term market, and shipping fuel as a longer term focus form 2030-35, once engine development and shipowners safety concerns have been addressed. She felt that low carbon methanol would be a better prospect for the 2020s. Existing producers are best positioned to take advantage of these markets because they have an existing sales and distribution infrastructure.

Finally, Andy Franks of Lloyds Register looked at ammonia as a shipping fuel. The IMO has mandated that the shipping industry must reduce its carbon emissions by 50% by 2050, and there are moves afoot – a decision may be taken later this year – to make that 100%. It would require three times the current world market for ammonia to replace fuel for the entire shipping fleet,

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and double the world's current renewable energy production. But shippers have an aversion, he said, to ammonia's toxicity, and some operators have said they will not use ammonia because of the risk. There is also the question of risks to local residents where ammonia is bunkered at ports. Lloyds Maritime Decarbonisation Hub has an ongoing project to evaluate the risks. Ammonia also has a low energy density, which reduces cargo capacity and ship economics.

Ammonia as an energy carrier

If ammonia is to be used as a hydrogen carrier, then a way of breaking it back down to nitrogen and hydrogen at the other end is required. Elena Stylianou of KBR described KBR's new H2ACT process, which is a chemical cracking of ammonia in a furnace similar to a steam reformer, using a nickel or ruthenium catalyst at high temperature and low (20-40 bar) pressure. The flowsheet uses some hydrogen generated by the process to burn to generate the temperatures required, but nevertheless manages a yield of 76% and an efficiency of 85%, which KBR hopes to improve in future. They are confident that they can deliver reactors from 5 t/d up to 1,200 t/d, as every stage of the process uses existing, proven technology. It is designed for flexible offtake rates and has a turndown capability to <50% which can be moved at 25% per hour. A demonstration unit is due to be up and running in 2025.

Lower carbon syngas

The technical papers perhaps unsurprisingly focused on lower carbon ways of generating syngas, beginning with a presentation by Topsoe on their new eREACT electrically heated reformer. The process is described in the article on pages 37-39 this issue. The contribution by thyssenkrupp Industrial Solutions detailed the practicalities of injection of green hydrogen from an electrolyser stream into an existing ammonia plant, something that a number of producers are considering, which of course can be used as part of a revamp to increase capacity and improve efficiency.

Several papers covered the topic of blue hydrogen, ammonia, and other syngas production, using carbon capture and storage or utilisation. To sequester the CO_2, you must of course first separate it, and BASF presented their *OASE®* white amine scrubbing technology for deep CO_2 removal from syngas. Linde likewise presented their *HISORP* adsorptive CO_2 removal process. A paper from thyssenkrupp looked at ways of optimising CO_2 removal, by treating flue gas from the primary reformer or (for an autothermal reformer plant) from the fired heater, to bring carbon recovery up from 70% to 98%. KBR showcased their own blue ammonia process is based on its *PurifierPlus™* technology which incorporates KBR's *Purifier™* and KBR Reforming Exchanger technologies while capturing more than 95% of the units overall CO_2 output.

KT Kinetics Technology detailed a case study of blue hydrogen production for refinery or chemical use, and noted that the imposition of carbon taxes in regions like Europe shifted the balance between capital and operating expenditure when designing a conventional steam reforming based hydrogen plant. Clariant also looked at increasing efficiency in blue syngas production with a concept they called recuperative reforming. A detailed look at this can be found on page 40 of this issue.

For a real world look at blue production, Saipem and Horisont Energi presented the latter's Barents Blue ammonia project in northern Norway, capturing 99% of the CO_2 produced and feeding it back to the offshore natural gas supplier for pumping underground. The remote coastal site has necessitated a high degree of modularisation in the construction.

Urea technology

A number of papers covered urea technology. Toyo has been working on its ACES-21 urea process and developed a lower pressure version, which operates at 136 bar instead of 152 bar, with new steels allowing a reduction in passivation air and lower pressure meaning lower power requirements and more efficient operation. Toyo also covered its post-EPC assistance for improved reliability of urea plants.

Stamicarbon gave two papers on urea, one on using their proprietary Safurex steel, this time as a thin foil for pressure, level and flow measurement devices. The other looked at the very end of the urea plant, and turning the salty by-product from acidic scrubbers either as lean UAN or UAS into valuable products., either by upgrade the acidic scrubber to convert the lean UAN solution into UAN-32 via "*mini-UAN™*" plant" technology, or via recycling lean UAS solution into the urea product to provide traces of sulphur as a micronutrient. Also at the project finishing step, Casale has tied up with Green Granulation and is now able to offer fluidised bed urea granulation as part of its portfolio. A first project has recently been signed.

Real world operating experience was provided by our regular correspondent Mark Brouwer of UreaKnowHow, in this case how to deal with a blocked leak detection system. Iffco Kalol detailed how they had improved the performance of their high pressure synthesis and waste water treatment sections of their urea plant, Engro Fertilizers related optimising a vintage urea plant to enhance capacity and efficiency, Abu Qir fertilizers presented lessons learned from replacing a high pressure stripper and scrubber, and Petrokimia Gresik described problems with carbamate solution carryover during a urea plant startup.

Nitric acid

For the nitric acid strand, Carmen Perez of Stamicarbon presented her company's nitric acid process. Although Stamicarbon licensed many plants in the 1960s-80s, it has not been in the nitric acid business since 1989, returning to the field only in 2017. The company has now licensed its first new nitric acid plant since the 1980s, using monopressure technology and Stamicarbon's own proprietary tertiary NOx abatement system.

NOx abatement always remains a hot topic in nitric acid production, and Umicore, Heraeus and thyssenkrupp Uhde all showcased their own NOx removal systems. Johnson Matthey looked at start-up, often the most difficult phase of nitric acid operations emissions-wise, and how improved start-up can improve gauze performance and ammonia oxidation. Mitsubishi detailed experiences with the commissioning of the Navoiyazot nitric acid plant in Uzbekistan. Measuring emissions from nitric acid plants is a continually moving target, as described by David Inward of Sick AG – an article on this is on page 48 of this issue.

David Kelley of PGM Technologies explained how platinum and other precious metal catalysts are lost from the gauze during plant operation, and methods of recovering it at the end of a campaign, both destructive and non-destructive. Finally, Johan Olsson of KBR talked on nitric acid and ammonium nitrate plant safety, and avoiding pre-ignition in a nitric acid converter cone, or deposition of ammonium nitrate in the neutraliser. ■

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Seeing inside the box

The steam methane reformer is at the heart of most world-scale synthesis gas plants for ammonia, methanol or hydrogen production, and its optimum performance will maximise plant production and efficiency. This article studies the wide variety of parameters that need to be considered if a steam methane reformer is optimised.

Matt J. Cousins, Chris Murkin, Kate McFarlane (Johnson Matthey), David A. Brinkmann (OnPoint Digital Solutions LLC) and Pierre Coddeville (Yara France).

Optimising the primary reformer is key to making ammonia as efficiently as possible, with approximately 30% of the total natural gas demand consumed by driving the reforming reaction.

Johnson Matthey (JM) has proprietary models, such as REFORM™, that take into account many of the parameters that contribute towards this optimisation. However, accessing accurate data has been a barrier to continued optimisation in the field. The use of OnPoint's ZoloSCAN™ TDLAS (Tunable diode laser absorption spectroscopy) technology makes continuous in-situ flue gas analyses achievable. This article details how, when coupled with process data and Reformer Imager data providing insight into the tube wall temperature profiles across the reformer, it has enabled benefits such as lowering fuel demand, excess air, and therefore NOx emissions and CO_2 footprint.

Johnson Matthey's REFORM modelling package has been utilised as part of a future continuous monitoring system (CMS).

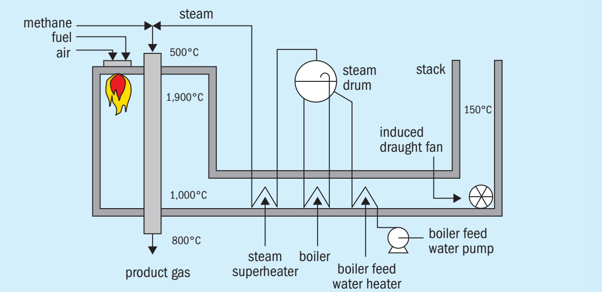
The work has interpreted process data, tube wall temperature data, and thermometric and gas compositional radiant section data. These data streams are used together to develop new insights into what is happening inside a reformer cell. This creates an opportunity for improved reformer optimisation.

The work referred to as REFORM CMS was led by Johnson Matthey in partnership with OnPoint Digital Solutions LLC and delivered to Yara Le Havre, who pioneered the system's use.

The benefits of the REFORM CMS work include:

- Improved plant reliability – enhancement of asset integrity programs.

Fig. 1: **Outline diagram of a steam methane reformer, showing typical process conditions**



Source: Johnson Matthey

- Improved ammonia production efficiency – optimisation of hydrogen production.
- Maximised furnace efficiency – optimisation of excess air.
- Enablement of continuous improvement culture by translating information into knowledge and supporting the implementation of improvement actions.
- Improved plant safety – minimise risk of unwanted tube failure.

Background

Steam methane reforming has been used as an industrial means to realise hydrogen since the 1920s. Over the last hundred years, our understanding of this process has grown enormously, enabling developments that make it possible to reform a wide range of hydrocarbons in various licensed reformer designs. However, many reformers operate without the ability to measure and optimise all the parameters that affect their operation.

The steam reforming process reacts purified hydrocarbon feedstocks with steam to produce hydrogen and carbon oxides. In the reformer, a series of interconnecting reactions take place over the catalyst. The two hydrogen forming reactions, steam methane reforming and water-gas shift are detailed below:

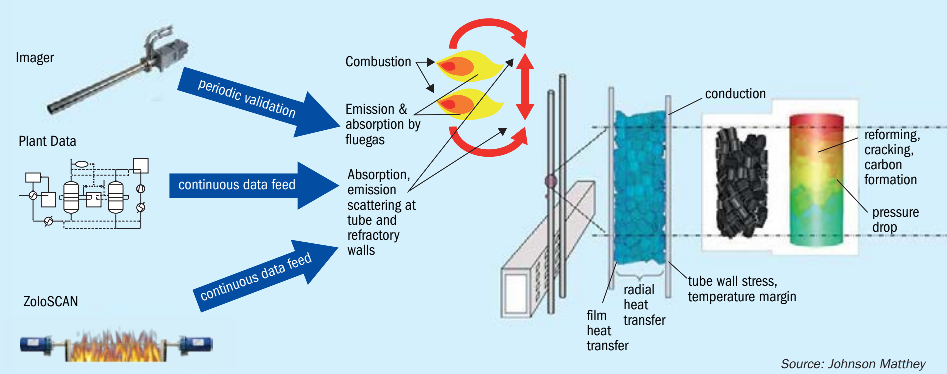
$$CH_4 + H_2O \rightleftharpoons CO + 3H_2 \qquad \Delta H = +206\ \text{kJ.mol}^{-1} \qquad (1)$$

$$CO + H_2O \rightleftharpoons CO_2 + H_2 \qquad \Delta H = -41\ \text{kJ.mol}^{-1} \qquad (2)$$

Following reaction (1), process conditions can be optimised to maximise the conversion of methane, at equilibrium, by higher temperature, lower system pressure and increased steam partial pressure.

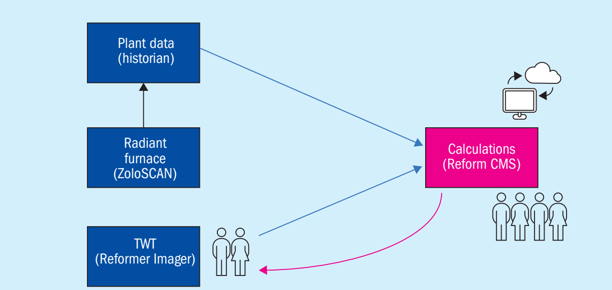
As shown in reaction (1), steam methane reforming is strongly endothermic and large quantities of heat are required to drive the reaction to the hydrogen

Fig. 2: **Outline of REFORM CMS process**



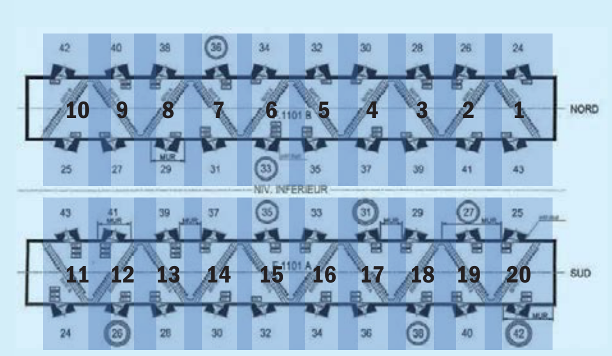
Source: Johnson Matthey

Fig. 3: **Data flow within REFORM CMS**



Source: Johnson Matthey

Fig. 4: **Sketch of the reformer at Yara Le Havre, showing sub-cells as considered within REFORM CMS**



Source: Johnson Matthey

product. To provide the process heat to overcome the heat of reaction, a reformer is designed to hold the catalyst within tubes in a furnace.

This combination of catalytically driven reaction and furnace operation results in one of the most complex process units on the ammonia plant. Much technical know-how and insight is required to ensure safe and efficient operation across the reformer. Reference 1 describes in detail some of the issues that can arise from the sub-optimal operation of a reformer, including:

- Inefficient operation: Poor conversion of hydrocarbon feedstock, poor use of fuel.
- Tube rupture: During normal operation, the tubes are within the creep region and have a limited lifetime. Operation at higher temperatures significantly reduces tubes' lifetime; if this is exceeded, the tubes can rupture within the reformer, with the potential for a serious incident[2].
- Carbon formation: High temperatures or catalyst poisoning can result in formation of solid carbon on the catalyst and within the tubes. This will reduce catalyst activity and increase pressure drop up to blocking tubes[3].

The carbon forming reactions and much more are included in REFORM, Johnson Matthey's proprietary software for modelling the operation of steam reformers. It was initially developed by ICI in the 1960s to support their steam reformer operation, and since then has been continually improved and updated with more detailed models and to reflect changing reformer

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design[4]. REFORM is a powerful tool to design the catalyst loading, evaluate current operating performance and assess optimised operating conditions.

Previously, when optimising a steam reformer, the process was limited by the amount of data available and the one-time nature of the data-collection process. Tube wall temperature (TWT) data would be collected manually and operation optimisation would be carried out based on this data. However, over time – perhaps a few days or weeks – plant operating parameters would change, and plant operation would become sub-optimal.

The REFORM CMS work addresses this issue by considering a wide range of continuous data, covering many aspects of steam reformer operation. If the plant operation is required to change, updated TWT data can be gathered and analysed quickly. This allows timely re-optimisation and maximises the time spent at peak operation[5].

REFORM CMS work considers three differentiated data feeds, each targeted to supply a data input that drives the REFORM model: TWT, process and radiant box data, as depicted in Fig. 2.

This allows the operator to understand:

- where there is an opportunity cost;
- which process parameters to target to optimise the operation.

The following sections describe how REFORM CMS was deployed, looking at the components, installation and inter-operation of the first data.

Components of REFORM CMS

The data fed to the REFORM CMS work comprises three separate streams: plant data (pressures, temperatures, gas compositions, etc.), Reformer Imager data of TWT for the tubes and ZoloSCAN TDLAS data for the radiant box.

In Fig. 3, the data collection activities at the client site are shown in dark blue. They provide data input for analysis and reporting, shown in pink.

In comparison to a typical plant data set, REFORM CMS work considers:

- more of the parameters affecting the reforming operation;
- more granularity within the data, as it is not a global average. Data can be used to define different conditions across the reformer cell.

In the case of the Yara Le Havre reformer, the tubes are arranged in diagonal rows laid out in an unusual sawtooth pattern in each of two reformer cells (north/south), as shown in Fig. 4.

For modelling purposes, each cell was split into 10 'mini reformers' or sub-cells[4]. This required:

- plant data to provide process temperatures for the outlet header of each tube row;
- Reformer Imager TWT data for each tube;
- ZoloSCAN TDLAS temperature data for the radiant cell in the vicinity of each tube row.

Plant data

Plant data is already utilised regularly by the operations team in the safe running of the unit. It is also commonly used every few months to provide a snapshot that is utilised in data evaluations to assess the effectiveness of the process in the context of the reformer operation.

Secure file transfer protocol (SFTP) captures and transmits a comprehensive set of process data from the Yara Le Havre historian to JM.

This provides the required detailed process data:

- inlet gas composition;
- inlet process gas pressure;
- inlet process gas temperature;
- inlet gas flow;
- temperatures of each collector header;
- exit process gas pressure;
- exit gas composition.

This provides a platform for regular data transfer and the daily data processing using the optimisation tools developed for the REFORM CMS work. Using high-quality, consistent data allows the analysis to look beyond a global average.

Tube wall temperature data

A standard visual inspection of the furnace is invaluable but gathering quantitative data on the TWT spread across the furnace is essential. There are three commonly employed pieces of equipment to measure TWTs; each option has its merits. Table 1 gives a summary of how these different reformer measurement devices function.

Based on these properties, the Reformer Imager has been selected to gather TWT data.

The Reformer Imager supplied by LAND Instruments International Ltd. and developed as a portable reformer survey tool by JM provides more insight into the TWTs than any other available method.

The Reformer Imager can measure temperatures in the range of 600-1,100°C, and the measurement wavelength of 1 mm maximises visibility through the hot combustion gases. The Reformer Imager provides a wide viewing angle, so often almost all of a tube row can be seen in one video image, which is more than can be seen visually. The videos are recorded directly to a laptop and can be used for further analysis. For more information on the technical specifications and capabilities of the Reformer Imager, see Reference 6.

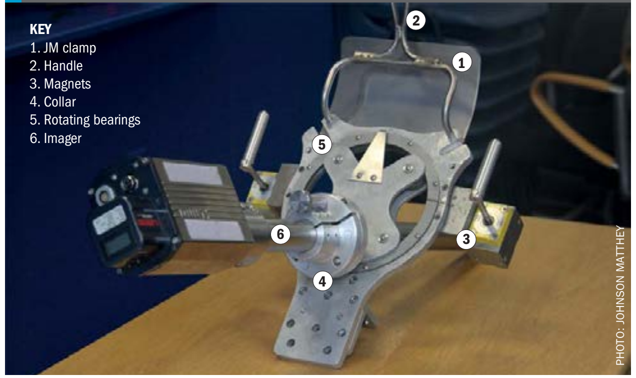
During a standard Johnson Matthey reformer survey using the Reformer Imager, data is gathered by manually moving it through different planes to capture as much of the reformer as possible. However, the natural variation resulting from this type of movement means that each video must be interpreted manually. This can be very resource-intensive, and the interpretation of videos can often take several days of effort. As Reformer Imager surveys are not often carried out, this time is appropriate.

Table 1: **Comparison of different TWT measurement techniques**

Tool	Optical pyrometer	Gold cup contact thermocouple	Reformer Imager
TWT Measurement	Yes – point	Yes – point	Yes – universal
Background correction required	Yes	No	Yes
Time for survey	Medium	Slow	Fast
Video images	No	No	Yes
No. of data points	Single	Single	Multiple

Source: Johnson Matthey

Fig. 5: **Complete set-up for the use of Reformer Imager as part of REFORM CMS**



However, for the REFORM CMS work to be truly continuous, there was a need to enable more regular TWT data collections and interpretation with a quick turnaround. This need led JM to further develop the use of the Reformer Imager as a portable reformer survey tool and to include automation to speed up data extraction. To improve repeatability, a clamp was developed to hold and manipulate the Reformer Imager, rotating it in the same manner in every peephole while the thermometric video data was captured. The benefits of this are:

- consistent positioning is achieved in each peephole;
- consistent movement takes place at every peephole;
- improved automation of data extraction.

The picture in Fig. 5 shows the Reformer Imager positioned in the JM clamp. The clamp provides a collar located within a rotating set of bearings, enabling the Reformer Imager to be rotated through 360°. The clamp is lifted using the handle. The feet rest on the bottom of the peephole, and magnets aid in stability during use by providing easily reversible adhesion to the outer wall of the furnace[7].

A wireless bridge is used to avoid the need for a wired data transfer connection between the Reformer Imager and the laptop. A single battery powers both the Reformer Imager and the bridge. This wireless enablement of the Reformer Imager brings multiple benefits:

- removes tripping hazard of the data transfer cable;
- improved connection reliability;
- decreases the time to complete a TWT survey.

TWT data extraction

The streamlining of the data extraction process was enabled by the consistency gained from the use of the JM clamp. The video captured as the Reformer Imager is rotated in the clamp is first stitched to form a single, complete image, and then

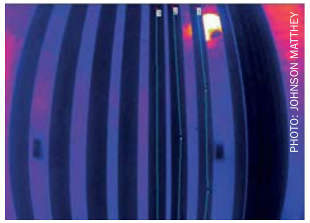


Fig. 6: Still image from video recorded by Reformer Imager, showing sections of reformer tubes.

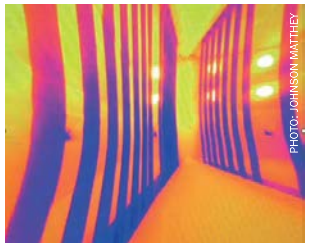


Fig. 7: Composite image generated from complete Reformer Imager video, showing all visible tubes.

TWT data is extracted from this image.

Fig. 6 shows a still image from a video recorded by the reformer imager, displaying a partial view of the tubes within the furnace.

Stitching the individual images that make up the video into a single composite image provides the greatest possible field of view from the peephole without having to view and select multiple frames from video manually. This can be seen in the composite image in Fig. 7, which shows many more of the tubes than the image in Fig. 6.

The single composite still image can now be processed to extract the thermometric data. This extraction has been semi-automated, with the potential to fully automate this process.

The requirement for background radiation correction was tailored for the reformer at Yara Le Havre and managed as part of the data interpretation.

Multiplexed ZoloSCAN TDLAS system

The third data stream was provided by OnPoint's multiplexed ZoloSCAN TDLAS system. This system monitors and describes the gas composition and temperature within the radiant box.

TDLAS measurements are based on molecules, each having a unique signature absorbance profile. An industry standard diode laser is tuned in wavelength across a tiny portion of the optical spectrum. A given combustion component absorbs light at the chosen wavelength, and the relative amount of absorption is proportional to the concentration of that component.

OnPoint's multiplexed ZoloSCAN TDLAS technology transmits multiple laser wavelengths simultaneously along a single path and measures an average across each path for each component simultaneously. This provides real-time, in-situ measurement of temperature, O_2 and CO directly in the reformer combustion zone. The path layout also provides spatial representation profiles of temperature, O_2, and CO. The path layout was defined as it provided a path average data source into REFORM for each sub-cell.

The ZoloSCAN system for Yara Le Havre was designed to provide 22 laser paths across the reformer cells, with transmitting heads termed "pitch" and receiver heads termed "catch" mounted on the outer walls

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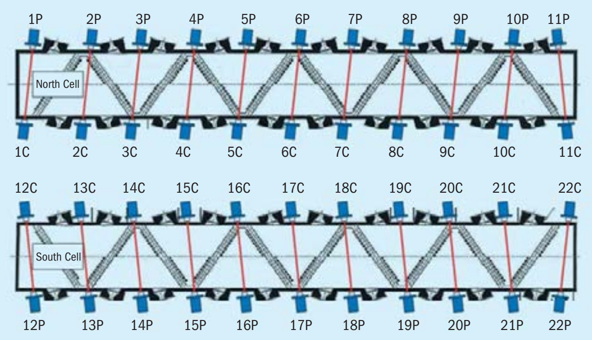
Fig 8: **Overhead view of Yara Le Havre reformer, showing ZoloSCAN TDLAS laser paths "pitch" and "catch" heads**



Source: Johnson Matthey

Fig. 9: Photo of Reformer Imager clamp in use on reformer peephole at Yara Le Havre.

of the furnace as shown in Fig. 8.

Each pitch head periodically emits the combined laser light sources to the catch head maintaining alignment automatically and continuously. The light source transits across the reformer cell, following a path not impeded by the reformer tubes. Further focusing is enabled during operation using a steerable optic assembly within heads to maximise the signal strength. The path design places laser paths between the herringbone arrangement of tube rows, so data is gathered associated to each row of tubes.

Installation of tools needed for the REFORM CMS work

Project implementation was hindered by the Covid-19 pandemic, which delayed the installation of the ZoloSCAN system, a key component, for many months. It took nearly 18 months to achieve project implementation, although the active working time was approximately three months.

Plant data

This was the easiest part of the installation. Clearly, the plant data already existed and was recorded by the historian. Yara and JM agreed on which instrument data were needed to model the reforming operation and prepared a list of associated instrument tag numbers. JM provided a SFTP connection, and data transmittal started.

Reformer Imager

The work required the development of the Reformer Imager clamp and wireless enablement of the Reformer Imager to avoid the communications cable becoming tangled.

Achieving consistency: The clamp

The clamp was developed over several iterations, offering a bespoke design to integrate with the reformer peephole design employed at Yara Le Havre (Fig. 9).

Multiplexed ZoloSCAN TDLAS

The heads were mounted on sight tubes that had previously been fitted to the reformer during planned maintenance (Fig. 10). These provided alignment between the pitch and catch heads. The sensor heads were then able to be fitted while the reformer was in operation, minimising the required downtime.

The output from the ZoloSCAN TDLAS can be read directly from the historian, as shown in Fig. 11, or through the REFORM CMS dashboard.

Training

JM provided training to Yara Le Havre covering the functions of the REFORM CMS work, practical use of the Reformer Imager and use of the thermometric analysis method for the captured videos (Fig. 12). OnPoint provided full training in the use of the ZoloSCAN TDLAS system.

Fig. 10: Photo of installed ZoloSCAN sensor heads on the reformer at Yara Le Havre.

Use of REFORM CMS

Primary actions

Integration with the existing Yara Le Harve asset integrity program is of paramount importance. The TWT data is mapped (see Fig. 13), showing tubes that are too hot or too cold. To protect the tubes, the first action is to reduce the temperature of the hottest tubes based upon this data.

Secondary actions

REFORM CMS runs are based on each day's process and TDLAS data for each sub-section of the reformer cell. It produces key performance indicators (KPIs) for each sub-cell, such as measured and optimised values for the:

- tube exit temperatures;
- approach to equilibrium (ATE) for the reforming reaction;
- hydrogen make;
- excess oxygen in the flue gas.

The dashboard visualises the opportunity value for hydrogen make and excess oxygen. The opportunities are presented as a global value and broken out to show which zones present the best opportunity for improvement and which section of the furnace should be the focus. The basis of the optimisation is to:

- reduce TWT variation and move the average toward the optimal value, thereby producing most hydrogen.
- move excess oxygen toward a decreasing and agreed value. The effect of this is to move the unit away from the fan limit in the duct and directionally lower the NOx in the flue gas.

Benefits of REFORM CMS

Benefits can be measured in several ways, including:

- TWT reduction of hottest tubes, providing an extension of tube life;
- increased product make from the same feed natural gas flow.

These benefits are easily monitored by following the trends provided in the REFORM CMS dashboard, along with the excess oxygen. Other less quantitative, but still crucial benefits include:

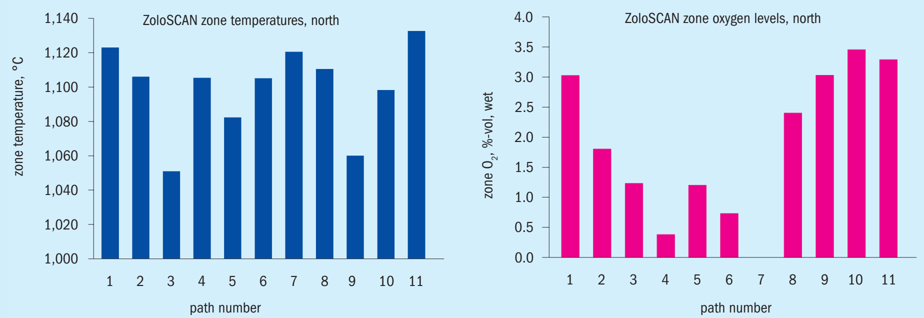
- increased number of focused discussions on reformer optimisation, with data to back these up;
- increased number of adjustments and interventions to optimise performance.

Future for REFORM CMS

Several short-term innovations have further improved the technology and thus could for allow wider implementation of REFORM CMS:

- the new ZoloSCAN2 system will help reduce the cost of an installation as the SensAlign™ heads can be affixed to existing peephole doors. This avoids the need of a reformer outage for installation of the system;

Fig. 11: **ZoloSCAN TDLAS raw data output, showing temperature (blue) and oxygen content (pink) for each sub-cell**



Source: Johnson Matthey

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- continued improvements in Reformer Imager technologies and data collection methods. This would reduce the operator time for data collection and speed up data processing;
- addition of online gas analysis to allow real-time reformer ATE calculation.

Conclusions

The REFORM CMS work shows the potential opportunity from daily analysis of reformer performance and associated optimisation. The system has been constructed to respond quickly to changes in rate, feed composition, etc., to re-optimise performance. Reformer Imager data affords assurance from an asset integrity perspective before and after a change is made. This project has shown the interconnectivity between the process data, the TWT and the combustion cell conditions. Only when all three of these are considered can the operator truly "see inside the box."

Acknowledgements

The authors wish to thank the staff at Yara Le Havre for their support and contributions. Mike Davies, Kate McFarlane and Carl Hamlett at Johnson Matthey have provided essential expertise and insight for this project.

Fig. 12: Training of Yara Le Havre staff in the use of Reformer Imager for TWT monitoring.

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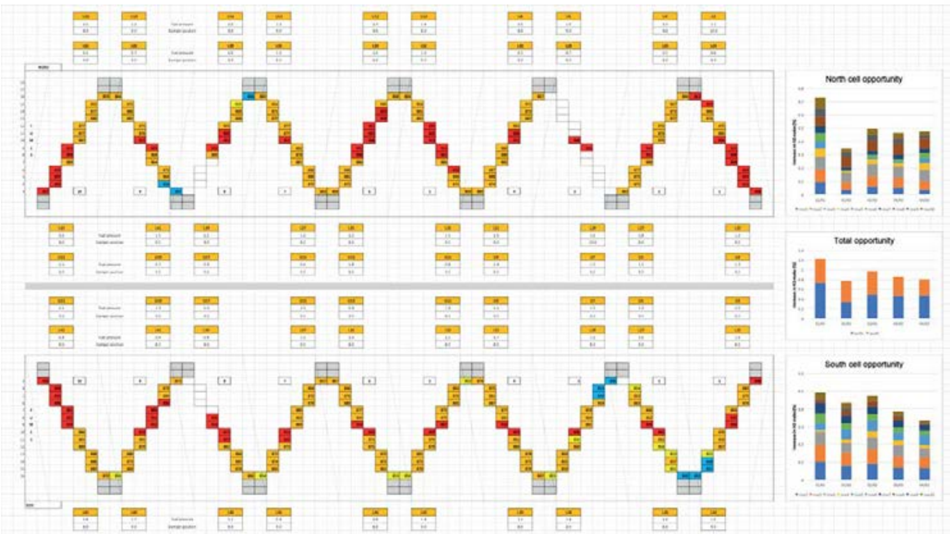


Source: Johnson Matthey

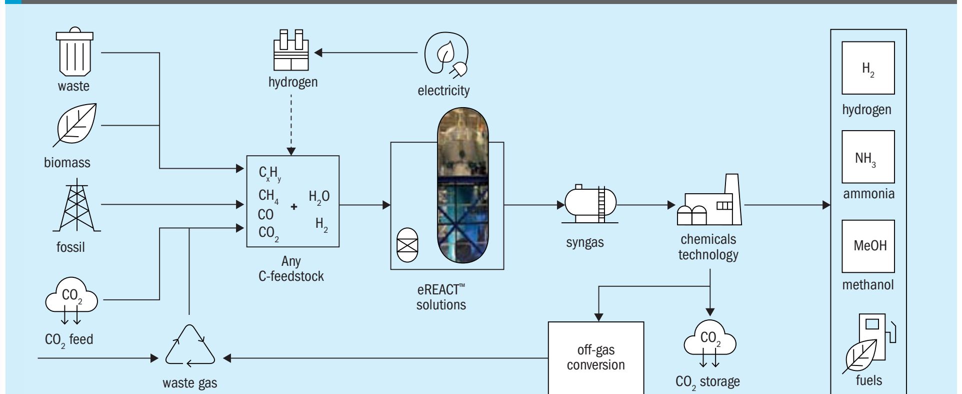
Fig. 13: Tube wall temperature map generated from Reformer Imager data by REFORM CMS.

Emissions-free syngas manufacturing

The world's most common syngas production method remains steam methane reforming, a process which has a substantial CO_2 footprint as the necessary reaction heat is supplied by combustion of hydrocarbons. Topsoe's eREACT™ technology allows for the first-of-its-kind electrification of the traditional SMR process. The reaction heat for eREACT™ is instead generated directly by (renewable) electricity, thereby eliminating the flue gas altogether. Having gone through scale-up from bench scale to industrially relevant pilot scale the technology is now ready for industrial application.

Peter Mølgaard Mortensen, Marené Rautenbach, Martin Østberg, Steffen Christensen, Sudip De Sarkar (Topsoe).

Fig. 1: Options for chemicals production utilising the eREACT™ technology



Source: Topsoe

As the world moves to decarbonise, chemical technology is required to evolve. Topsoe's eREACT™ is the electrified evolution of the world's most common syngas production method, steam methane reforming (SMR). Bridging existing syngas manufacturing with renewable electricity allows for an emission-free chemical plant, built on the existing principles of the syngas platform, allowing leverage of existing hydrocarbon infrastructure or integration with other carbon feedstocks such as biogenic carbon or captured CO_2, effectively allowing chemicals production on existing principles. Options for chemicals production utilising the eREACT™ technology is shown in Fig. 1, demonstrating the versatile range of products and feedstocks linked by eREACT™. While traditional SMR typically generates needed heat through combustion of natural gas, which results in CO_2 emissions, eREACT™ facilitates the same reaction without the associated environmental impact. The reaction heat for eREACT™ is generated directly by (renewable) electricity, thereby eliminating the flue gas altogether[1]. With the cost of renewable electricity decreasing rapidly, this groundbreaking technology empowers even existing industrial complexes to electrify syngas production in a cost-effective manner.

Technology scale-up

The eREACT™ technology is the output of many years of development from Topsoe in transforming existing knowledge from SMR technology to an emission-free electrified counterpart. Having gone through in-house scale-up, the technology is now ready and is currently being demonstrated on an industrially relevant scale using an actual biogas feedstock (methane-rich gas produced by anaerobic digestion of biomass

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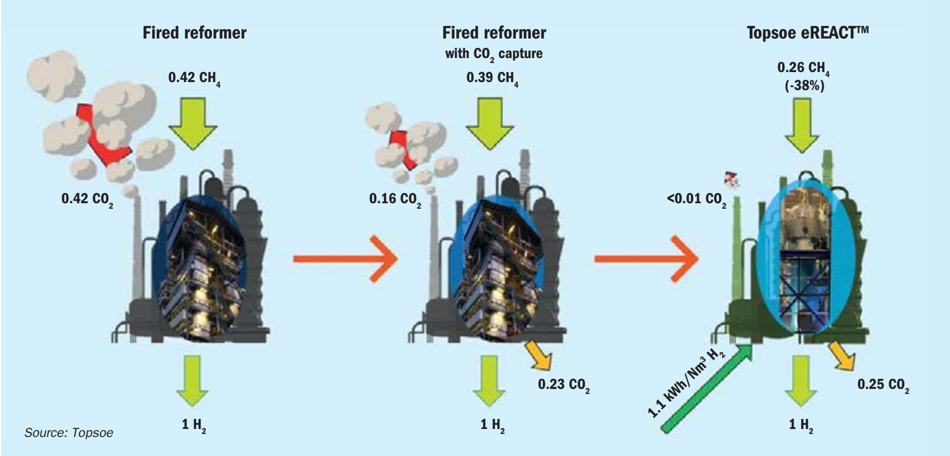
Fig. 2: **Reducing CO_2 emissions with electrified steam methane reforming**



Source: Topsoe

waste) for production of synthesis gas for green methanol. Based on several thousands of hours of operation, the eREACT™ technology has demonstrated conversion of biogas to syngas as an embodiment for syngas manufacturing. Key results and conclusions include:

- Demonstration of the reactor technology: All elements of the electrical reactor were demonstrated in the pilot plant operation.
- Operation at various conditions including feed gas composition, pressure, and temperature (up to 1,050°C): The reactor performs as predicted and expected according to thermodynamics.
- Test of upset situations including trips: Trips occurred both intentionally and caused by malfunction of the peripheral system not related to the electrical reactor. After all trips, the electrical reactor performance was easily brought back to the status before the trip.
- Test of transients: The power load was reduced from 100% to 50% and increased from 50% to 100% very rapidly. This demonstrates the excellent load following potential of the eREACT™ reactor technology. Rapid start-up was also demonstrated.

The technology enables high carbon utilisation, high energy efficiencies, and high stability. Still based on the thermodynamic principles known from fired steam methane reformers, eREACT™ technology demonstrates a larger operating window than conventional SMR technology, allowing for process intensification such as higher temperatures combined with flexible and direct control of the reactor for precise and faster operation response.

Process design

Syngas manufacturing by eREACT™ builds on all previous experience of syngas manufacturing. Consequently, when designing a process around the electrified solution, most of the processes resemble known practices from existing steam reforming plants. The front-end of the process is basically the same as traditional SMR type plants, where feedstock cleaning (sulphur removal) is needed as a first step followed by steam addition and pre-reforming. Downstream of eREACT™, the process steps can be chosen freely according to the desired end product, similar to producing synthesis gas by SMR.

The eREACT™ technology offers a simplified solution for syngas manufacturing compared to conventional steam methane reforming, where the fired reformer is operated by balancing two chemical reactors against each other; on the one side, the combustion reactor, and on the other side, the catalytic reactor. In contrast, eREACT™ is an integrated system where heating takes place by direct electricity transfer into the catalyst. This translates into eREACT™ being very agile in operation, allowing fast start-up, fast capacity change, and precise temperature control, all because the plant control is reduced to a direct feedback control loop between syngas temperature and the power supply (PSU) power levels; where a PSU can change power levels on a millisecond scale.

The reduced complexity of eREACT™ translates into an equivalent reduction in the plot plan of the chemical site. Firstly, eREACT™ is a process-intensified reactor compared to SMR, markedly reducing the volume of the unit. Secondly, the utility site is also reduced in complexity.

Minimum requirements for an SMR layout are:

- fuel gas feed section
- a combustion air feed section (including blowers and preheaters)
- combustion chamber
- catalytic reactor(s)
- waste heat boiler
- flue gas waste heat section,
- and a flue gas stack.

In contrast, the eREACT™ solution only requires:

- catalytic reactor
- waste heat boiler
- power supply unit.

In greenfield opportunities, eREACT™ enables efficient feedstock utilisation where practically all carbon feedstock can be converted to an end product. Process layouts can be made completely emission-free, as no firing is needed. This gives an excellent match with carbon capture in, e.g., hydrogen production sites, where excess CO_2 production can be captured from pressurised syngas, utilising existing efficient proven technologies for CO_2 removal. For comparison, state-of-the-art hydrogen production by SMR has a carbon intensity of approximately 9.2 kg CO_2/kg H_2 (kg CO_2 emitted per kg H_2 produced) without CO_2 capture and approximately 3.6 kg CO_2/kg H_2 with process CO_2 capture. eREACT™ enables the carbon intensity to be reduced to approximately 5.7 kg CO_2/kg H_2 without CO_2 capture (corresponding to process stoichiometry) and <0.1 kg CO_2/kg H_2 with process CO_2 capture; an excellent solution for blue hydrogen production from natural gas. In other words, natural gas use is reduced by 30-40% and CO_2 emissions can be reduced by 99%+ for eREACT™ compared to SMR (Fig. 2). Electricity input is obviously needed, which is approximately 1.1 kWh/Nm³ of hydrogen produced. Similar results are achieved when evaluating the production of methanol, ammonia, synthetic fuels, among others, with the eREACT™ technology. In addition, eREACT™ offers the opportunity to retrofit existing syngas installations by integration with existing reforming units for increased syngas manufacturing, but where the added capacity does not have an associated CO_2 emission.

eREACT™ is the next evolution step of syngas manufacturing. It offers an agile solution for best-in-class performance for chemicals and fuels production with minimal to no carbon intensity, but also allows a platform for sustainable chemicals production when the sustainable carbon is used as feedstock. In a world where energy is a valuable resource not to be wasted, eREACT™ provides operators with the possibility to run their plants while nearly eliminating energy waste.

Conclusion

eREACT™ is a novel technology for syngas manufacturing. It is the world's first electrified reforming technology. As it is constructed to have the hottest part centrally in the reactor, it allows for high temperature operation around 1,000°C or above, allowing for high methane conversion and potentially operating pressures exceeding 50 bar for novel process integrations. Experimental experience demonstrated that continuous operation can be done at >90% methane conversion (according to thermodynamics). This translates into increased feedstock utilisation compared with SMR. Better utilisation of feedstocks is indirectly an essential means towards more sustainable chemicals productions, and in the end, it translates into chemicals plants based around the eREACT™ technology that can come very close to operating at stoichiometric conditions. Ultimately, eREACT™ will allow classical steam-reforming-based process plants to be turned into blue or green chemicals plants with minimal to no carbon intensity. In addition, the technology allows for integration with (biogenic) CO_2 and biogenic hydrocarbons for production of (green) sustainable chemicals. ■

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Recuperative reforming for reducing carbon footprint

Previously, recuperative reforming has been mostly applied for capacity increase revamps, but nowadays it is a key enabler for efficient low carbon hydrogen and syngas production. **Jan-Jaap Riegman** of Technip Energies, **Francesco Baratto** of Casale and **Stefan Gebert** of Clariant discuss the benefits of recuperative reforming for reducing the carbon footprint of existing assets.

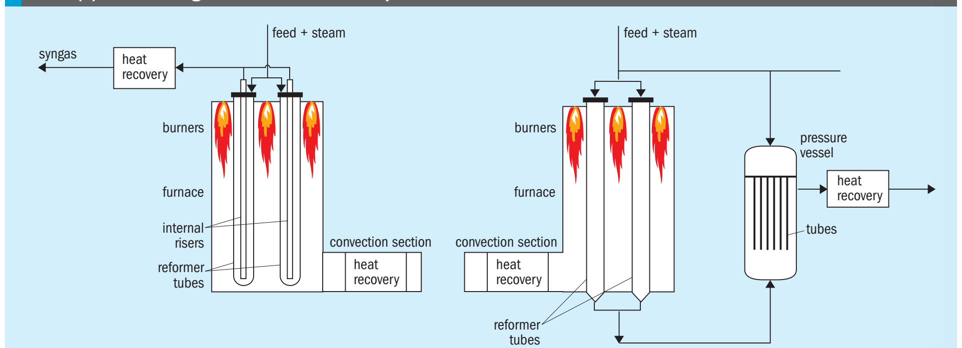
With global warming coming closer to 1.5°C above pre-industrial levels, countries and industries are setting more and more ambitious pledges and targets for their CO_2 emission reduction. As hydrogen is a carbon-free molecule it is an important energy carrier as well as a building block (either as hydrogen or syngas) for the production of other chemicals, for example ammonia.

Among commercially available hydrogen and syngas production technologies, steam reforming (SMR) and/or autothermal reforming (ATR) of natural gas are usually the most cost-effective means to ensure profitable hydrogen, syngas and ammonia production on an industrial scale. Traditionally about 60-70% of the CO_2 emissions from such plants comes from the reforming reaction and, together with the firing in a heater, represents a significant emission source of CO_2. Therefore, there is a large drive to reduce the carbon footprint of this industry.

Partly, this can be achieved with so-called green hydrogen (hydrogen produced from water electrolysis). On the other hand, blue H_2/syngas technology (production of H_2/syngas via a reforming route with the addition of carbon capture and subsequent storage or utilisation (CCUS)) is already available and affordable at a large scale and will therefore play a significant role in the energy transition. A blue syngas/H_2 concept can effectively be applied in grassroot as well as revamp applications.

The excess high-grade energy available in both SMR and ATR reforming schemes is applied to generate steam, which is only partially utilised internally and widely exported or used for steam-driven machinery. Over the last two decades reforming technology licensors have shifted the efficiency and heat integration paradigm and deployed advanced technologies capable of re-utilising the heat contained in the hot process gas exiting the reformer as a heat source to drive the reforming reaction itself. Such technologies are commonly called "recuperative reforming" and lower the energy input required for the reforming process and thus play a crucial role in effectively producing blue syngas and hydrogen.

Fig. 1: **(a) U-shaped reformer tubes having an internal riser allowing for internal counter current heat exchange; (b) heat-exchanger reformer connected in parallel to the conventional reformer.**



Source: Technip Energies Figure 1a Figure 1b

Recuperative reforming

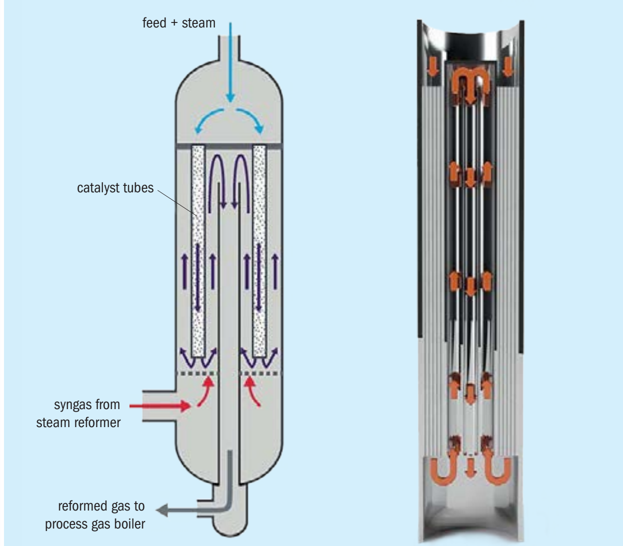
While in past years recuperative reforming was mostly applied for capacity increase revamps, nowadays it is a key enabler for efficient low carbon hydrogen and syngas production. By utilising the high-grade heat from the reformer effluent for heating the reforming reaction instead of generating steam, the load in the primary and or secondary reformer and thus the overall energy input is reduced. This results in lower energy consumption as well as a lower carbon footprint.

Two main concepts for recuperative reforming can be differentiated and are depicted schematically in Fig. 1 in combination with a steam reformer.

Fig. 1a shows a recuperative reforming technology, whereby a tube is inserted in a U-shaped reformer reactor, creating an annular counterflow arrangement to enable high-grade heat recovery within the tube itself. In this layout, the highest temperature is obtained at the end of the catalyst bed located at the U end of the tube, while the syngas exiting at the (top) outlet of the tube is partially cooled by counter-current heat transfer, thereby significantly reducing the firing demand and thus increasing the furnace efficiency. The downside of this concept is that it can only be applied for grassroot applications. Technip Energies (T.EN) developed its EARTH® technology as a similar concept with three passes entering at the top and exiting at the bottom. EARTH® is schematically depicted in Fig. 2b and its first commercial application has been in operation since January 2019.

Fig. 1b shows an alternative design whereby the heat recuperation is carried out in a separate, external heat exchanger recuperative tubular reactor, placed in parallel to the fired steam reformer. In this configuration, syngas exiting the fired reformer is routed to the parallel reactor as the heat source, while additional fresh feed + steam is converted on the tube side (cold side) of the reactor against the provision of this heat. Fig. 2b, schematically depicts the T.EN Parallel Reformer (TPR), which can be applied in parallel to either the steam reformer and/or autothermal reformer and is well referenced.

Fig. 2: **(a) Schematic representation of TPR; (b) Schematic representation of EARTH®**



Source: Technip Energies Fig. 2a Fig. 2b

For EARTH® technology, Clariant and T.EN combined their collective expertise to drastically improve the efficiency and throughput per catalyst tube in the reformer. It is patented by T.EN and contains two concentric heat exchanger tubes with a highly active structured catalyst co-developed with Clariant. The combination of both allows for simultaneously improving the catalyst activity and additional heat recovery.

As the inlet is at the top and the outlet at the bottom it can be applied in both grassroot and revamp applications. The tailor-made proprietary catalyst structure is extremely robust and promotes low pressure drop, optimised heat transfer properties and highest activity. The highly active and mechanically stable catalyst coating on a metal structure has been developed based on Clariant's extensive and longlasting experience with structured catalysts for fuel cell applications.

The first application has been online since January 2019 in a syngas production unit and has been in continuous operation for more than four years at the design capacity. The catalyst performance remains close to the equilibrium to date and potentially opens pathways to significantly longer catalyst lifetimes. EARTH® reduced the total hydrocarbon consumption by 10% resulting in CO_2 emission savings of 20%. In 2022, EARTH® was installed as a revamp in a large-scale reformer in Europe to accommodate a capacity increase of more than 20%, while simultaneously having 5% lower CO_2 emissions per hydrogen produced. The EARTH® inserts were delivered at the site preloaded with catalyst. The complete EARTH® assembly was inserted into the catalyst tube as a drop-in solution. This minimised the site work and eliminated most of the catalyst handling at site. The installation was successfully completed within the shutdown period and showed that the EARTH® installation can be completed within a similar timeframe as conventional catalyst loading. The catalyst structures are very stable and ensure that the catalyst pressure drop is the same in every tube eliminating the need for correcting and reloading. The plant was successfully started-up and has been in stable operation since.

Next to the EARTH® catalyst, Clariant also offers the very active, stable and robust ReforMax®-series catalysts for TPR and ATR. There are numerous references of these high-performance catalysts on the market.

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Recuperative concepts for blue hydrogen

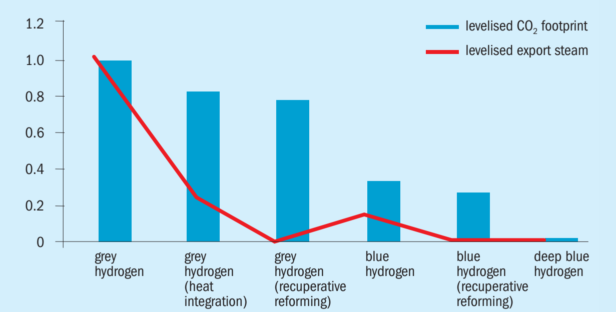
As traditional hydrogen production is a significant source of CO_2 emissions formed during the production as well as in combustion, CO_2 curtailment and carbon capture are widely considered for hydrogen production. This is valid for both grassroot applications as well as for revamping existing assets. Grassroot blue hydrogen plants are typically designed to achieve hydrogen production with a carbon capture rate of 95% or higher. For revamping of existing assets, the target can be lower or staged. In low-carbon fuel production there is an interest in minimising the carbon emission associated with the conversion of natural gas (NG) to the final product. In particular, in the blue hydrogen market there is an interest in reaching a carbon intensity of around 0.1 kg of CO_2 per kg of hydrogen. This value includes the direct emissions from the plant (scope 1), the emission related to the utilities required by the plant i.e. electricity (scope 2) and the emission associated with the final use of the product (scope 3).

Both TPR and EARTH® technology typically reduce the carbon footprint of the syngas production plant intrinsically by up to 10%. When combined with CCUS and possibly further synergistic design changes it allows for up to 99% reduction of the carbon footprint. At the same time the excess steam production can be reduced to zero. Fig. 3 indicates the typical levelised CO_2 footprint as well as levelised export steam flowrate for a typical hydrogen plant. The figure is based on an SMR-based plant, but the trend is also valid for ATR-based hydrogen plants.

An ATR-based blue hydrogen plant fed with pure oxygen can be combined with a parallel heat exchanger reformer (TPR) in series/parallel to ATR. The use of TPR as well as the heating of feed gas with the ATR effluent allows the furnace duty and steam production to be greatly reduced, with relevant improvements to the unit efficiency and capex savings, for example, in parallel to an ATR as part of Casale's technology portfolio, which has proven references since 2002.

In specific applications both recuperative technologies (in-tube and external heat exchanger reformer) can be applied together and combine and exceed the benefits of both technologies applied separately. This is particularly beneficial in case of a combination of a primary and secondary reformer, where EARTH® is applied to the primary reformer and the outlet reformer effluent is fed to the secondary reformer, and where the TPR is installed in parallel to the primary plus secondary reformer. As the concept amplifies the positive effects of both separate technologies a combined intrinsic CO_2 emission reduction of up to 30% is achievable. As a large part of the high-level duty available from the secondary reformer is utilised for the reforming reaction instead of steam production, the total steam production is reduced. The emissions can be further reduced by synergistic design changes.

Fig. 3: **Levelised CO_2 footprint and export steam flow for a typical hydrogen plant**



Source: Technip Energies

Recuperative concepts for low carbon ammonia revamp

To achieve significant decarbonisation by revamping ammonia plants, careful evaluation of necessary modifications for each plant section is crucial. Though there is no single most important section for an ammonia plant, the reforming section is often a main focus in decarbonisation for simple reasons:

- it is the main source of CO_2 emissions to the atmosphere;
- the performance of this section also impacts the performance of other sections;
- the hydrogen required by the ammonia synthesis is generated here.

In the process scheme of a single recuperative concept, the reforming section is revamped by adding a TPR. The pre-heated mixed feed consisting of natural gas and process steam flows in parallel to the primary reformer radiant box and secondary reformer (about 70-85% of the gas) and to the TPR (about 15-30% of the gas).

The main advantages provided by the TPR are:

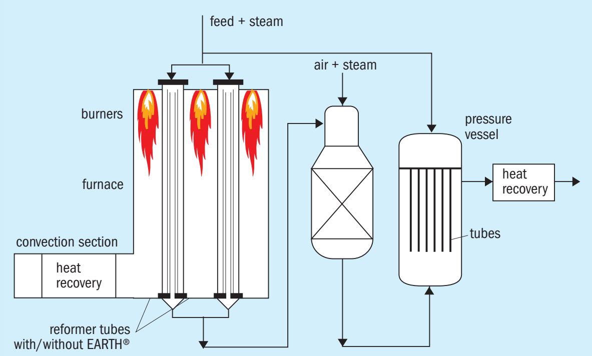
- adds up to 30% additional hydrogen in capacity revamps of existing plants without additional firing demand or major modifications to the existing reformer;
- minimises export steam;
- lowers CO_2 footprint per unit of hydrogen up to 15% compared to a standalone steam reformer of equal capacity.

In addition to the TPR in parallel to the primary and secondary reformer, EARTH® can also be applied in the primary reformer in a so-called double recuperative concept (Fig. 4). The concept allows for an additional significant reduction of carbon footprint per syngas produced and for effective low carbon ammonia production.

In this process scheme, EARTH® is applied directly in the primary reformer as the inlet gas is from the top and the outlet remains at the bottom of the firebox. The heat recovery allows intensification of the primary reformer while maintaining an equal or lower inlet temperature of the secondary reformer and can be optimised to have the minimum overall impact in the syngas generation section.

The TPR is installed in parallel to the primary and secondary reformer and produces additional syngas with the available high-grade heat from the secondary reformer. The syngas to the downstream ammonia synthesis loop is not impacted and direct decarbonisation of the syngas production section thus results in a carbon footprint reduction of the ammonia production unit.

Fig. 4: **Simplified flow diagram for the double recuperative concept with the TPR in parallel to the primary and secondary reformer as well as EARTH® in the primary reformer. Alternatively, the TPR can be applied in parallel to the primary and secondary reformer without EARTH® in the primary reformer**



Source: Technip Energies

The combination of these two recuperative concepts as described can reduce CO_2 emissions from the syngas generation section by up to 30%, while maintaining the same methane slip and nitrogen to hydrogen ratio to the synthesis loop. The combination boosts the positive effects of the separate recuperative technologies while eliminating most of the drawbacks. As the high-grade heat is utilised for the reforming reaction, this reduces the overall steam production, and the steam balance of the ammonia plant needs to cope with this reduced steam production. Casale technologies and combined process schemes for energy saving perfectly fit this scenario, increasing plant efficiency by reducing steam demand. Finally, onsite electrification efforts to apply electric motors to drive compressors instead of steam turbines is also a possibility.

Table 1 compares a typical ammonia production unit comprising a primary reformer, an air blown secondary reformer, with a similar scheme with the addition of a TPR and the double recuperative flow scheme as indicated above. The addition of a TPR allows for a slightly lower hydrocarbon consumption and results in up to 15% reduction of the CO_2 emissions. At the same time, steam production is reduced by up to 25%.

The double recuperative concept enables a step change in further reduction of the hydrocarbon input by up to 10%. This also relates to a CO_2 emission reduction of up to 30% without impacting the downstream synthesis loop. On the downside, the steam production is reduced by up to 40% and therefore would typically be combined with electrification efforts for the downstream compressors.

> **Recuperative reforming technologies are essential to decarbonise hydrogen and syngas generation of existing assets as it enables an intrinsic reduction of CO_2 emissions.**

Conclusion

Recuperative reforming technologies are essential to decarbonise hydrogen and syngas generation of existing assets as it enables an intrinsic reduction of CO_2 emissions. It also enables more effective application of carbon capture and utilisation, for both SMR and ATR based plants and allows up to more than 99% carbon capture rate.

Technip Energies recuperative technologies are commercially proven. Its TPR technology is applied in parallel to SMR and/or ATR. EARTH® technology (with a structured catalyst jointly designed with Clariant) is applied inside the SMR catalyst tubes. Both TPR and EARTH® technology can be applied separately and result in a CO_2 emission reduction of typically up to 10-15%. In the case of a hybrid reforming scheme with a primary and secondary reformer both EARTH® and TPR technology can be applied together in a double recuperative reforming concept. This combines the benefits of both recuperative technologies and enables a CO_2 footprint reduction of up to 30% and is especially attractive for decarbonising existing ammonia assets.

Both EARTH® and TPR can be effectively applied together with Casale's technologies and experience and Clariant's catalyst technologies to revamp both ammonia and methanol production units. This allows the plant's energy consumption and CO_2 footprint to be reduced, while coping with reduced steam generation in the syngas generation section. ■

Table 1: **Decarbonisation of syngas production for ammonia production unit by application of recuperative reforming**

	Existing asset	Revamp with TPR	Double recuperative revamp
Ammonia capacity	100%	100%	100%
Hydrocarbon consumption (feed+fuel)	Base	2-5% reduction	5-10% reduction
Direct CO_2 emission (syngas section)	Base	0-15% reduction	15-30% reduction
Steam production	Base	15-25% reduction	25-40% reduction

Source: Technip Energies

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Customised revamping of steam methane reformers

When revamping the steam methane reformer, a detailed analysis of the whole reformer by an experienced technology licensor with deep plant knowledge is required to achieve the best solutions. Casale presents two case studies which provide examples of what can be achieved when following this approach.

Nowadays, revamping of the steam methane reformer (SMR) is the simplest way to increase plant throughput or reduce plant energy consumption, which in turn contributes to CO_2 footprint reduction.

In Casale's experience, SMR revamping is an activity often required by its clients many times and with ever increasing frequency.

Statistically, it is not uncommon to find a furnace that has been pushed beyond its upper throughput limit. Many critical components of the steam reformer unit, such as the catalyst tubes, pigtails, intermediate tube sheets and shield coils are inevitably forced to operate very close to their material design limits.

In addition, many other limitations can be experienced over the years due to aging of the reformer components, misoperation, the original design, or new environmental emission requirements.

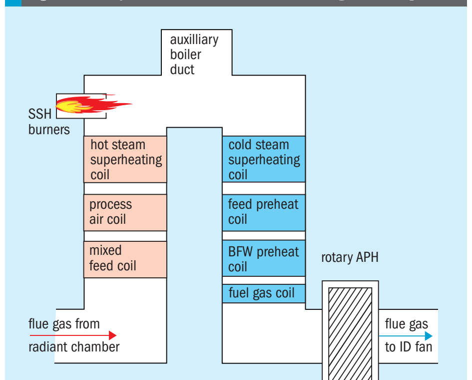
In many cases, conditions that were already critical can be exacerbated when improvement modifications or revamping activities are carried out, particularly when the plant owner does not request a licensor assessment, which is fundamental to minimise risks and avoid any subsequent surprises on plant consumption figures.

There is a timeframe before a point of no return when symptoms or warning signs can be identified in time and with good reliability, avoiding unplanned outages and potential risk to plant personnel. This is the starting point or the first step toward the revamping stage.

Based on Casale experience, it is essential to identify where abnormal conditions, design limitations or upset operating parameters are located. It is crucial that this investigation shall be conducted through a whole reformer detailed data analysis to be carried out by a technology licensor with a deep plant knowledge background.

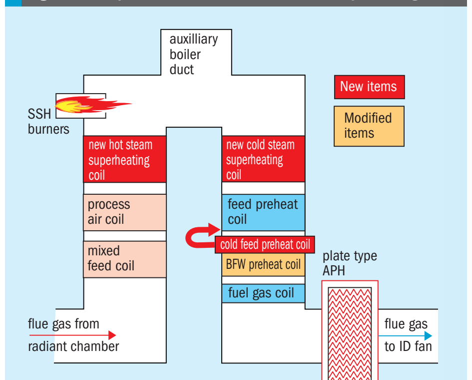
The following two project cases demonstrate the importance of carrying out a detailed data analysis of the whole reformer as well as Casale's capability to customise the revamping scheme and technological solution to the existing steam reformer design, targeting the required objectives.

Fig. 1: **Primary reformer convection section original arrangement**



Source: Casale

Fig. 2: **Primary reformer convection section revamped arrangement**



Source: Casale

Fig. 3: **New steam super heating coils (hot and cold) supplied by Casale**

PHOTOS: CASALE

Fig. 4: **Upper hood of the convection section**

PHOTOS: CASALE

Case 1

Casale was awarded an EP project for an ammonia plant revamp to reduce energy consumption.

Many limitations were found in the primary reformer convection section in addition to the biggest one related to the air preheater (APH) which was an old rotary type. The reformer was an induced-draft, top-fired type with an omega convection section configuration and an integrated auxiliary boiler (see Fig. 1).

During the past, the client had had a lot of issues related to the rotary type APH, mainly related to corrosion issues. Many maintenance activities had been performed on the APH in order to mitigate the overall underperformance of the steam reformer prior to making the decision to approach Casale.

Analysis

After a campaign of data collection, an overall detailed analysis of the primary reformer was performed, and the original reformer design was verified.

It was found that, besides the rotary APH, there were some other issues that needed to be addressed that the client was not aware of.

For example, it was discovered that both the steam superheating coils (hot and cold) were underperforming and were unable to achieve the desired process steam outlet temperature despite the flue gas temperature being higher than the required temperature.

Based on Casale's experience, this primary reformer section was in a very critical condition and subject to mechanical degradation, accelerated by operating conditions, which normally lead to minor or major underperformance of the coils. This phenomenon was made worse by the practice to compensate for the temperature drop by increasing the combustion heat release of the steam superheating burners.

Some other issues were found with regard to the residual life of some components of the reformer, like the high-grade nickel intermediate tube sheets.

Solution

Many modifications to the reformer were required, such as the installation of new hot steam superheating coils as complete modules (Fig. 3), the replacement of the rotary APH with a new more efficient plate type APH with relevant duct modifications, and finally, rebalancing of the heat recovery into the convection section cold leg in a more efficient way, thereby reducing the overall steam consumption required by the reforming reaction.

It was also possible to reduce the required duty of the BFW preheater coil, whose surface was partly replaced by a new coil, with the purpose to "cold" preheat the feed to the HDS section, shifting the heat from the steam system to the more valuable feed preheating system.

Of course, this modification required a more detailed assessment of the steam reformer radiant chamber to prevent any mechanical issues due to the new operating conditions.

Another challenge was from a mechanical viewpoint, due to the one-month timeframe imposed by the client to install the new items withing the turnaround.

All items were prefabricated as much as possible, and all interventions were studied and engineered targeting the required constraints such as the stiffening of the upper hood of the convection section, which was removed in a single piece (Fig. 4).

Thanks to the solutions found, the overall installation was performed according to the requested one month schedule.

All of the issues concerning the steam reformer were successfully addressed and solved, resulting in an energy saving of 9,000 t of the fuel consumption per year, which in turns equates to a carbon footprint reduction of 24,000 t of CO_2 per year.

Case 2

Casale was awarded an EP project for an ammonia plant revamp to increase capacity from 1,800 t/d to 2,000 t/d.

A detailed assessment of the plant revealed some limitation in the primary reformer convection section and the radiant chamber.

The reformer was an induced-draft, top-fired type with an omega convection section configuration and an integrated auxiliary boiler (Fig. 5).

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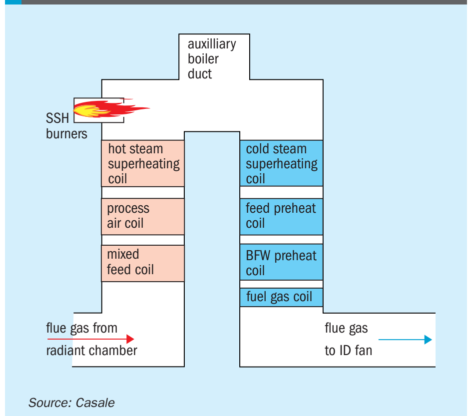
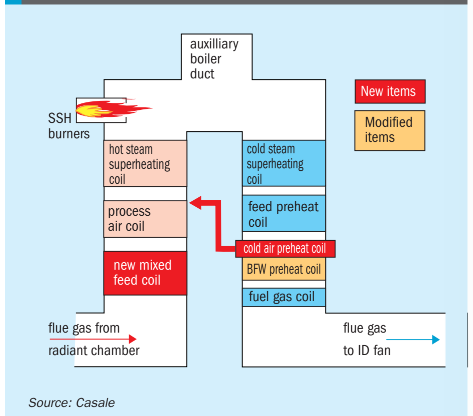
Fig. 5: **Primary reformer convection section original arrangement**



Source: Casale

Fig. 6: **Primary reformer convection section revamped arrangement**



Source: Casale

Analysis

A detailed analysis of the primary reformer was performed, and the original reformer design was verified against the current operation. It was found that both the mixed feed coils and the process air coil, were significantly underperforming and the radiant chamber and the combustion system was verified to be unsuitable for the future increased plant capacity.

Solution

During the engineering phase many parameters around the reformer were analysed in order to minimise the intervention. Thanks to an overall plant assessment and optimisation, the modifications required to target the project scope were limited to a new design of the catalytic tubes and radiant chamber outlet system as well as a new design for a new mixed feed coil and a new "cold" process air coil (Fig. 6).

The new design, together with the newly achieved process parameters, resulted in no modifications being required for the combustion system and burners. In addition, the new design provided a safety margin for the existing design, especially for the reformer inlet system, for any conditions, including higher capacity.

The overall steam consumption required for the reforming reaction and internal plant use was decreased and optimised. In this way, it was possible to reduce the required duty of the BFW preheater coil, whose surface was partly replaced by a new coil, with the purpose to "cold" preheat the process air so that the surface of the existing "hot" process air coil could be used to provide the extra duty required by the increased plant capacity. This more cost-effective solution permitted the performance of the existing process air coil to be restored without impacting its design.

Another challenge was represented by the geometrical constraints of the mixed feed coil which required more surface to be installed within the same layout. In addition, the client requested a solution to minimise the intervention within a timeframe of only two weeks.

A dedicated design was developed, the so-called Casale "pre-assembled" design which permits the complete coil bundle installation (tubesheets, hairpins, manifolds, etc.) with a once-through solution (Fig. 7). This solution preserves the existing system, minimising the required site modifications such as cutting of the reformer wall casing (when there is no splice), refractory dismantling and reinstallation, etc.

Thanks to the solutions found, the overall installation was performed according to the requested two week schedule. All of the issues concerning the steam reformer were successfully addressed and solved resulting in an energy saving of 1,700 t of the fuel consumption per year, which in turns equates to a carbon footprint reduction of 4,400 t of CO_2 per year. ■

Fig. 7: **Mixed feed coil supplied by Casale**

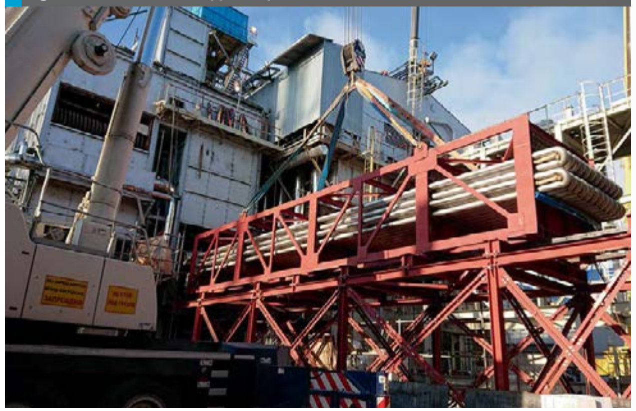


PHOTO: CASALE

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Emission monitoring from nitric acid production

Highly efficient N_2O abatement technologies, coupled with the continually rising CO_2e price/tonne are the driving forces behind nitric acid plant operators looking for increasingly sensitive and precise measurements of the N_2O mass emission. **David Inward** of Sick AG discusses new state-of-the-art emission monitoring technology which provides the measurements required.

The current intense focus on global warming and the need to transition to decarbonised production processes and carbon-free energy streams as a means to reduce the quantities of greenhouse gases being emitted to atmosphere can already point to a tangible success story from the fertilizer sector.

Nitrous oxide, (N_2O), laughing gas, is a notable greenhouse gas with a global warming potential approximately three hundred times greater than carbon dioxide.

The main source of N_2O release to the atmosphere relates to its generation as an unwanted by-product in the manufacture of nitric acid. The vast majority of nitric acid production is used by the fertilizer industry, where it is reacted with ammonia to produce nitrogenous fertilizers, such as ammonium nitrate (AN) and calcium ammonium nitrate (CAN).

In contrast to carbon dioxide (CO_2), N_2O is a more reactive molecule.

Significant progress has been achieved in reducing N_2O resulting from nitric acid production, such that emitted concentrations of N_2O below 10 parts per million (ppm) are now achievable. Measuring such low N_2O concentrations, coupled with the need to report an N_2O mass emission with a pre-defined measurement uncertainty < +/-5% is bringing new challenges to the continuous emission monitoring system used as the basis to report greenhouse gas (GHG) emissions.

These improvements are a result of optimisation of the fundamental nitric acid production technology to reduce the generation of this unwanted by-product as well as the employment of downstream abatement technologies located after the final nitric acid production step which are designed to convert any remaining N_2O in the tail gas stream into nitrogen and oxygen.

Table 1: **European regulation For NOx and NH_3 emissions from nitric acid production (LVIC BREF August 2007)**

	NOx emission level as NO_2 (ppmv)
New plants	5 - 75
Existing plants	5 - 90*
NH_3 slip from SCR	<5

Up to 150 ppmv, where safety aspects due to deposits of AN restrict the effect of SCR or with addition of H_2O_2 instead of applying SCR

Implementation of commercial market drivers, such as the carbon trading scheme and Carbon Border Adjustment Mechanism in the European Union are the fiscal drivers, which will maintain a strong focus on minimising N_2O mass emissions from nitric acid production.

Emission monitoring regulations – Emission limit values

Historically, the main focus in terms of monitoring and reporting emissions from the production of nitric acid was related to ensuring that emissions of "NOx", comprising the sum of the concentrations of nitric oxide (NO) and nitrogen dioxide (NO_2) was below a defined emission limit value.

Since the method to reduce NOx emissions is typically based on a selective catalytic reactor (SCR) or DeNOx unit, which doses ammonia to react the residual NOx to produce nitrogen and water, an ammonia "slip" emission limit value also applies.

In Europe, the Industrial Emission Directive (IED 2010/75) includes a series of industry-specific Best Available Technique Reference (BREF) documents, such as that for large volume inorganic chemicals, which comprises separate chapters that cover specific fertilizer production processes, such as nitric acid.

Table 1 shows NOx emission levels associated with the application of BAT for the production of nitric acid.

Published in the same year, the World Bank guidelines for nitric acid plants also sets guideline values for NOx (NO+NO_2) and NH_3 emissions (see Table 2).

Important to note is that emission limit values for NO/NO_2 and NH_3 are typically based on normalised conditions. This means that that the pollutant concentration value must be referenced to standardised conditions, with reference values set for temperature, pressure, water vapour and oxygen concentrations. This implies a need to also measure oxygen and either measure dry basis (after removing water vapour) or include a water vapour measurement if the sample is measured in a wet condition.

Table 2: **World Bank emission limit guidelines for nitric acid plants**

Air emissions levels for nitrogenous fertilizer manufacturing plants	
Pollutant	**Guideline value**
Ammonia plants*	
NH_3, mg/Nm³	50
NOx, mg/Nm³	
300	
PM, mg/Nm³	50
Nitric acid plants	
NOx, mg/Nm³	200
N_2O, mg/Nm³	800
NH_3, mg/Nm³	10
PM, mg/Nm³	50
Urea/UAN plants	
Urea (prilling/granulation), mg/Nm³	50
NH_3 (prilling/granulation), mg/Nm³	50
PM, mg/Nm³	50
AN/CAN plants	
PM, mg/Nm³	50
NH_3 , mg/Nm³	50
PM, mg/Nm³	50

Notes:
*NOx in flue gas from the primary reformer. The other emissions are from the process, prilling towers etc.
*NOx in all types of plants: temperature 273K (0°C), pressure 101.3 kPa (1 atm), oxygen content 3% dry for flue gas.

Source: World Bank emission limit guidelines (April 2007)

Emission monitoring regulations

In contrast, as described in EN 2066/2018, the reporting of greenhouse gases such as N_2O is done as mass emission, by combining a concentration measurement with a volumetric flow measurement.

Since flow technology inherently measures in-situ, i.e. measuring the volumetric flow of gas out of the final stack in a "wet basis", logically the gas analyser should also measure "wet basis" so that the N_2O concentration and volumetric flow can be directly combined to report in the required units (kg/hour N_2O).

Table 3 shows the European regulation for N_2O emissions from nitric acid production (LVIC BREF August 2007).

Application challenges

The contrasting reporting regulations for emission limit values and greenhouse gas mass emission place a combination of differing requirements on the measurement technology. Furthermore, since the tail gas composition resulting from nitric acid production possesses some unique properties, it follows that applying a conventional emission monitoring technology may not be the best fit.

Cold extractive infra-red gas analyser

A conventional continuous emission monitoring system is based on a cold extractive analyser design (Fig. 1). The conventional infra-red analyser requires a completely dry and particle-free sample gas. Therefore, the sample system is based around two aspects, namely a gas cooler to chill the sample gas to condense out and remove water, coupled with a series of filter elements, which remove first coarse and then fine dust particles.

Fig. 1: **Conventional cold extractive infra-red gas analyser**

PHOTO: SICK

Conventional infra-red analysers are well suited to measuring NO, but are not sufficiently sensitive to directly measure NO_2. To measure total NOx, (NO + NO_2) in emission monitoring applications containing a small NO_2 portion, a NOx converter is usually applied, which reduces NO_2 to NO directly before the infra-red analyser. However, the tail gas from nitric acid production contains a uniquely high proportion of NO_2, which would rapidly exhaust the NOx converter catalyst charge. An analyser that directly measures both NO and NO_2 therefore better suits the application requirements.

The next point to consider concerns the highly water-soluble nature of nitrogen dioxide (NO_2), a physical property that forms the basis of nitric acid production. Since nitrogen dioxide (NO_2) in the tail gas from nitric acid production makes such a significant contribution to the total NOx emission, cooling the gas to remove water vapour and ensure a dry sample gas brings with it concerns that a significant portion of the NO_2 will be dissolved and lost in the cooler condensate.

Finally, the potential presence of ammonia in the sample gas brings major

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difficulties. Utilising an analyser technology requiring the sample gas to be cooled to dry it, introduces the threat that ammonia present in the sample gas will react with oxides of nitrogen at temperatures below approximately 150°C to form solid ammonia salts (ammonium nitrate, ammonium nitrite) which will cause severe blockages in the sample system. Ammonia slip from the use of SCR DeNOx units dosing ammonia creates a consistent threat of salt formation and blockages once the sample gas is allowed to cool.

Table 3: **N_2O emission levels associated with the application of BAT for the production of nitric acid**

		N_2O emission level*	
		Kg/tonne 100% HNO_3	ppmv
M/M, M/H and H/H	New plants	0.12 - 0.6	20 - 100
	Existing plants	0.12 - 1.85	20 - 300
L/M plants		No conclusion drawn	

*The levels relate to the average emission levels achieved in a campaign of the oxidation catalyst.

Note: There is a split view on the emission levels for existing plants. *Source: LVIC BREF 2007*

Fig. 2: **MCS 200 HW hot extractive analyser**

PHOTO: SICK

Hot extractive infra-red gas analyser

Hot extractive infra-red analysers (Fig. 2) have in recent years been broadly applied to the task of measuring emissions from nitric acid production. The fundamental design differs by maintaining the sample at an elevated temperature (200°C) across the entire sampling chain, i.e., from the sample extraction point to the measuring cuvette.

This design inherently avoids both solubility issues related to a proper and precise NO_2 measurement, as well as any threat of ammonia salt formation. Therefore, the analyser can still measure emissions reliably behind an SCR DeNOx unit dosing ammonia and even during process start-up, when ammonia combustion in the primary furnace may not have reached stable combustion conditions.

Since the analyser measures the hot, raw sample gas, water vapour is not removed, but included as a measured component both to dynamically correct interferences to other target gases, as well as to allow the pollutant gases concentrations to be expressed dry basis.

The hot extractive infra-red analyser offers a powerful multi-component capability, which allows a single analyser to measure all required components, irrespective as to whether SCR or SNCR is applied. This includes direct measurement of both NO and NO_2 as the basis for the NOx measurement.

A zirconium oxygen detector, another technology which perfectly fits a hot measurement design allows pollutant concentrations to be normalised to 3% O_2.

Table 4 shows MCS 200 HW hot extractive analyser certified ranges according to EN 15267.

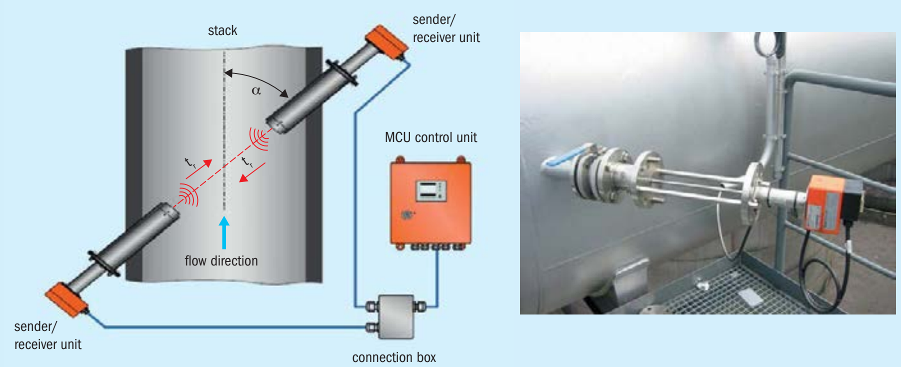
Ultrasonic flowmeter

An ultrasonic flowmeter provides the volumetric flow measurement which when combined with the N_2O concentration gives the desired N_2O mass emission (kg N_2O /hour)

Table 4: **MCS 200 HW hot extractive analyser certified ranges according to EN 15267**

Component	Module name	Certification range	Supplementary range	Unit	Maintenance interval
CO	"CO"	0 - 75	0 - 10,000	mg/m³	6 months
NO	"NO"	0 - 150	0 - 2,500	mg/m³	6 months
NO_2	"NO_2"	0 - 50	0 - 500	mg/m³	6 months
N_2O	"N_2O"	0 - 100	0 - 2,000	mg/m³	6 months
SO_2	"SO_2"	0 - 75	0 - 2,500	mg/m³	6 months
HCl	"HCl"	0 - 15	0 - 3,000	mg/m³	6 months
NH_3	"NH_3"	0 - 10	0 - 500	mg/m³	6 months
CH_4	"CH_4"	0 - 50	0 - 500	mg/m³	6 months
CO_2	"CO_2"	0 - 25	-	vol-%	6 months
H_2O	"H_2O"	0 - 40	-	vol-%	6 months
O2	"O_2"	0 - 25	-	vol-%	6 months
TOC	"TOC"	0 - 15	0 - 50 / 150 / 500	mg/m³	3 months

Fig. 3: **Flowsic 100 ultrasonic flowmeter**



Source: SICK

Table 5: **Tiers for CEMS (maximum permissible uncertainty for each tier)**

	Tier 1	Tier 2	Tier 3	Tier 4
CO_2 emission sources	± 10%	± 7.5%	± 5%	± 2.5%
N_2O emission sources	± 10%	± 7.5%	± 5%	n.a.
CO_2 transfer	± 10%	± 7.5%	± 5%	± 2.5%

Source: European regulation (2018/2066)

To capture the entire flow profile across the stack, the ultrasonic flowmeter is ideally mounted in a cross-duct design (Fig. 3). Ultrasonic signals travel both with and against the flow, the resulting time differential is the basis to precisely calculate the gas flow velocity.

This non-invasive volumetric flow measurement method offers a combination of best-in-class measurement uncertainty with minimal maintenance support.

Current and future requirements – N_2O mass emission

The latest European regulation (2018/2066) sets out the requirements for emission monitoring technology for the purpose of reporting the N_2O mass emission and establishes defined minimum performance requirements for the N_2O mass emission measurement uncertainty, as well as defining how this uncertainty performance is to be defined.

The use of gas analysers and volumetric flowmeters with a valid QAL 1 certificate according to EN 15267 is a prerequisite.

The on-site "QAL 2" calibration procedure performed by a certified (EN 17205) laboratory, compares the emission monitoring system with manual sampling measurements and is the basis to define the measurement uncertainty of the N_2O mass emission.

Table 5 shows the tiers for continuous emission monitoring systems (maximum permissible uncertainty for each tier).

Whilst the current reporting regulation sets out the minimum uncertainty requirement, commercial incentives are having an ever-stronger impact on current performance requirements.

The carbon dioxide equivalent (CO_2e) price per tonne has accelerated rapidly over the last three years, with almost a threefold increase in only the last two years (see Fig. 4). The current 2023 price has just touched €100/tonne and future projections anticipate ongoing increases.

The rising CO_2e price increase acts as a strong incentive for plant operators to reduce their N_2O mass emission, from which significant benefits on the trading of carbon credits can be reached.

State-of-the-art abatement technologies now require emission monitoring technology that can measure very low N_2O concentrations (< 10 ppm). The need to achieve the best possible result on the N_2O mass emission measurement uncertainty is relevant, since the uncertainty performance is included on the N_2O mass emission calculation budget of the plant operator.

Greenhouse gas mass emission – field trial

When looking to optimise N_2O mass emission uncertainty, the two main aspects are optimisation of measurement hardware combined with a calibration procedure that simulates the on-site conditions as precisely as possible. Sick AG already has in-depth experience of a field trial to establish mass emission uncertainty performance for greenhouse gas mass emission reporting. This was based around two complete CO_2 greenhouse gas mass emission monitoring systems to verify uncertainty performance under field conditions.

A CO_2 concentration analyser measuring "wet basis" i.e., without the removal of water vapour, was combined with the volumetric flow measured by an ultra-sonic flow meter.

Extensive experience in the field of fiscal flow metering of natural gas, supported the design considerations, since it is established that multi-path ultrasonic flowmeter designs and precisely simulated calibration procedures allow volumetric measurement uncertainty < +/- 0.1% to

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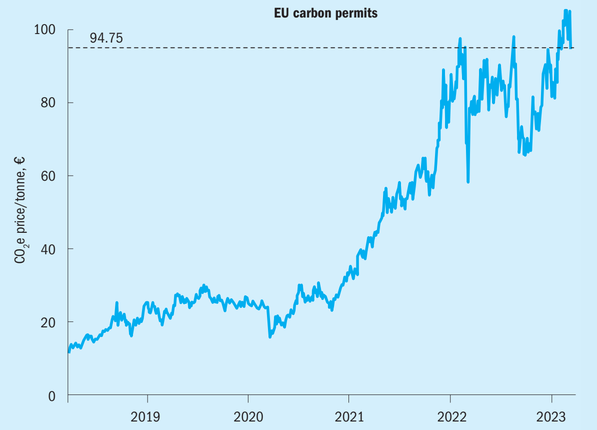
be achieved. Therefore, for the field trial a special dual path ultra-sonic flowmeter design was implemented.

The next focus was that of the site specific calibration. The following site-specific optimisations were targeted to drive down measurement uncertainty performance:

- special calibration of the analyser (optimise linearity at typical measured concentrations);
- establishment of exact flow profile in the stack by means of CFD (computational fluid dynamics);
- very precise flange toflange distance measurements on the stack at site (laser scanner) as the basis of the travel times for the ultra-sonic flowmeter signals (Fig. 5).

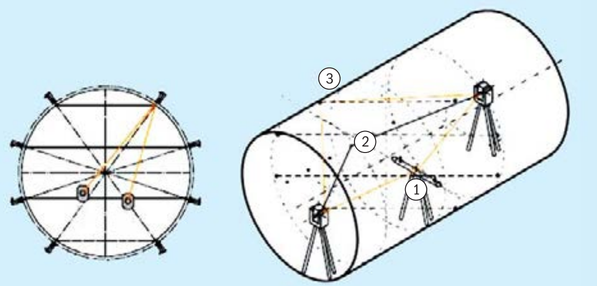
The resulting measurement uncertainty results for the duration of the field trial, expressed against the standard reference methods were comfortably lower than the requirements coming from the European regulations (2066/2018 MRR Annex VIII, Tier 3 +/- 5%).

Fig. 4: CO_2e price / tonne 2018-2023



Source: Tradingeconomics.com

Fig. 5: Laser measurements to establish precise flange to flange distance for ultrasonic flowmeter



Source: SICK

Summary

Highly efficient N_2O abatement technologies, coupled with the continually rising CO_2e price / tonne are the driving forces behind nitric acid plant operators looking for increasingly sensitive and precise measurements of the N_2O mass emission.

The greenhouse gas regulation (2066/2018) in combination with the value in trading carbon credits is bringing a strong fiscal aspect to how the technical requirements for an N_2O mass emission system are defined.

A hot extractive gas analyser is ideally suited to fulfilling the complete measuring task for reporting emissions to air from nitric acid production. This includes the ability to measure N_2O concentrations < 10 ppm.

The combination with an ultra-sonic flow-meter offers a best-in-class complete solution to report N_2O mass emission. The volumetric flow measurement is equally relevant as the N_2O gas analyser in terms of mass emission measurement uncertainty.

The N_2O mass emission measurement uncertainty result for any given plant will be site specific.

The defined N_2O mass uncertainty will be strongly influenced by site specific calibration efforts.

A field trial for CO_2 mass emission as a greenhouse gas indicates that an uncertainty performance exceeding that required by European regulations for N_2O (Tier 3, +/- 5%) is achievable.

A field trial specific to nitrous oxide is planned to establish N_2O mass emission measurement uncertainty according the Greenhouse Gas Regulation (2066/2018) with MRR Guidance Documents 4 & 7.

Sick AG is now looking to initiate a project at a European nitric acid plant to establish N_2O mass emission performance based around applying best-in-class technologies for a complete solution approach. ■

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