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

Number 369

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nitrogen+syngas

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Gas pricing and market reform

Sustainable nitrogen use

Plant support during a pandemic

NOx reduction from reformers

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

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

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NUMBER 369
JANUARY | FEBRUARY 2021

Cover: *Nitrogen fertilizer factory, north west Iowa.*
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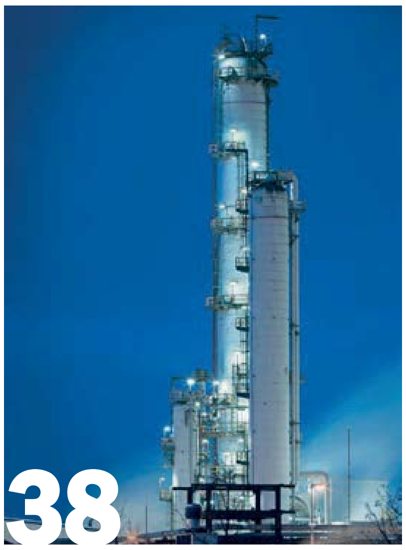
18

Gas markets

The slow spread of gas price liberalisation.



38

Low carbon methanol

Using carbon capture to reduce methanol carbon footprint.

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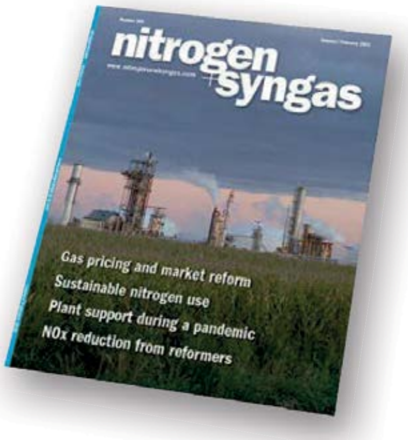
BCInsight

CONTENTS

REGULARS



Shades of green

> "Scale is the issue, and for scale you need money."

It can't have escaped anyone's notice that the question of the carbon intensity of ammonia and downstream nitrogen compound production has been one of the main industry talking points for the past year. Everyone seems to be talking about ammonia of different colours – green ammonia, blue ammonia, and all shades of turquoise in between. If you are confused, it may not be surprising, as these words have come to cover a wide variety of different methods and technologies for producing ammonia, and their green credentials consequently come in a whole range of different shades.

What most people mean when they talk about green ammonia these days seems to be conventional Haber-Bosch production using hydrogen generated from electrolysis powered by renewable electricity. This is certainly the least carbon intensive method, albeit with issues from fluctuation of power source to the cost of hydrogen generation. But what about biomass gasification to generate syngas? Is that 'green'? Or conventional production using methane emitted from the breakdown of organic waste ('biogas')? Both are generating carbon dioxide, though, depending on the source, they may not be emitting any additional CO_2 beyond what the breakdown of the organic matter would have produced anyway.

'Blue' ammonia, on the other hand, tends to mean it has been produced from conventional fossil fuel feedstocks, probably natural gas (though some coal-based ones are also proposed), but that the carbon dioxide generated has been captured and somehow sequestered. However, there are shades of blue as well, according to how much of the total carbon fraction is actually captured – it is by no means always 100%. Sometimes the carbon captured is used for downstream urea production, but the urea will release the CO_2 again in the field when it hydrolyses, so was it ever really captured? And even when all of the CO_2 ends up underground, there are vanishingly few carbon capture installations where the CO_2 has been used for anything other than getting more oil and gas out of an existing well via enhanced oil recovery (EOR). How green (or indeed blue) that really is as a process can be a matter of debate. Saudi Arabia claimed to have shipped the world's first cargo of blue ammonia in September 2020, but again the carbon dioxide from its production had been used for EOR.

And then there is Monolith Materials, who have what they describe as a 'turquoise' methane pyrolysis process which converts natural gas into hydrogen and carbon black. While they claim it produces 'carbon free' ammonia, in fact would generate 530 kg of carbon for every tonne of ammonia, but admittedly not as a carbon oxide. The carbon black market runs to about 15 million t/a, so there is room for more supply, but not on the kind of scale that would make a dent in the current 180 million t/a of global ammonia production.

Scale is of course the issue, and for scale you need money. Lots of money, if you are building an electrolysis-based plant. For this reason, most renewable-based plants that have been built so far have been small scale pilot or demonstrator units. But there are signs that this is now changing. As noted in our news section, Yara is considering moving to fully convert its 800,000 t/a Porsgrunn ammonia plant to electrolysis-based production, and Air Products' NEOM project in Saudi Arabia, which will produce green ammonia from various renewable sources, aims to produce 1.2 million t/a of ammonia, albeit at a capital cost price tag of $5 billion – several times that of a conventional plant, even if the power source is 'free'.

Of course this is still a developing area for ammonia production. Capital costs will come down, as more innovations in electrolysis and economies of scale in production and installation start to be realised, but for the moment large scale government funding is needed to get these projects off the ground. That being the case, it looks as though for the moment, most low carbon ammonia is going to be 'blue'. That was the conclusion of a report by HSBC published just last week, which puts the cost of converting a 1.2 million t/a gas-based ammonia to carbon capture and storage at $500 million – one tenth of that of the comparable sized NEOM project. HSBC believes that hydrogen production is heading towards a 'tipping point', and that the cost of 'pure' green hydrogen production (i.e. renewable/electrolysis-based) will fall below the cost of conventional (gas-based) hydrogen production some time between 2030 and 2050. But for the next decade, most low carbon ammonia will likely be blue. ■

Richard Hands, Editor

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

Price trends

MARKET INSIGHT

Alistair Wallace, Head of Fertilizer Research, Argus Media, assesses price trends and the market outlook for nitrogen.

NITROGEN

The ammonia market started the year on a bullish note, with sharp gains seen in the Middle East and Baltic.

Bad weather impacted ammonia logistics in North Africa and east Asia in late December and early January, adding further pressure and costs to suppliers trying to meet agreed dates with contract partners. The continued rise in European gas costs has resulted in the curtailment of production in the Netherlands and is likely to create additional demand in the first quarter of 2021. Recent market drivers include Middle East price jumps, fresh European demand emerging and further rises in Baltic prices.

Supply tightness is expected to be the main driver of sentiment in 1Q with winter demand and higher feedstocks and logistics costs adding to the bullish price environment. We expect the market to see further price firming in January, with fob prices forecast to rise by $12/t for Pivdenny and $21/t for Middle East. The market will remain generally supply-driven and susceptible to production cutback in certain regions, depending on market conditions and feedstock costs.

The urea market started the year where it left off the last, in bullish mood with attention now focused on markets west of Suez. US Barge prices jumped over $20/st since Christmas, supported by a grain price rally, as it moves to attract spot imports for spring. Last minute seasonal buying in Brazil has seen granular prices climb over $290/t c.fr in early January. Suppliers have benefited from the firm sentiment, with Egypt selling forward for European markets in the $290s/t f.o.b. and other sellers adjusting their price targets higher.

In the east, supply cuts rather than demand have generated rising prices. Indonesia has sold in the range $275.50-278/t f.o.b., a sharp jump on last business, benefitting from the lack of Chinese exports and reduced Malaysian supply. Recent market drivers include grain prices raising US spring hopes, Europe and Turkey facing a price jump and China remaining absent from exports.

Current firm demand west of Suez should bridge into Australian and Thailand buying later in the first quarter. Buying is ramping up for both Europe and US. European buying was low in autumn and buyers are now playing catch up. US prices surged in late December and Nola is now an attractive market for spot urea. An Indian tender, whenever it is called, will add further support. Indian urea sales have fallen below expectations since August and the country is unlikely to tender again before late March/April. Reduced Chinese production and exports along with production issues in some countries have mitigated this loss of demand.

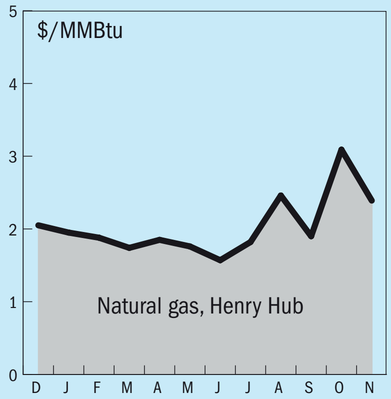
Table 1: **Price indications**

Cash equivalent	**mid-Dec**	**mid-Oct**	**mid-Aug**	**mid-Jun**
Ammonia ($/t)				
f.o.b. Black Sea	204-230	200-210	178-205	180-200
f.o.b. Caribbean	200-230	180-190	160-175	175-190
f.o.b. Arab Gulf	230-260	230-260	230-260	180-200
c.fr N.W. Europe	250-275	225-255	210-250	220-245
Urea ($/t)				
f.o.b. bulk Black Sea	230-250	230-245	230-253	195-215
f.o.b. bulk Arab Gulf*	260-290	249-270	264-285	219-245
f.o.b. NOLA barge (metric tonnes)	242-250	238	230-240	213-218
f.o.b. bagged China	270-300	265-290	275-295	242-263
DAP ($/t)				
f.o.b. bulk US Gulf	419-436	367-395	353-390	293-304
UAN (€/tonne)				
f.o.t. ex-tank Rouen, 30%N	157	157	157	163-165

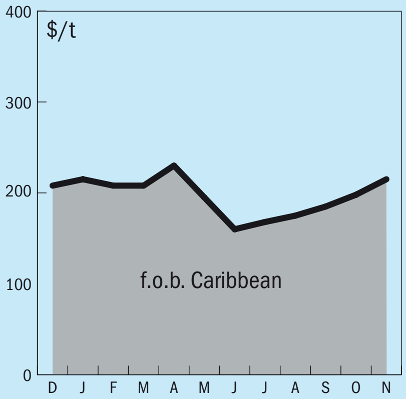
*Notes: n.a. price not available at time of going to press. n.m. no market. * high-end granular.*

END OF MONTH SPOT PRICES

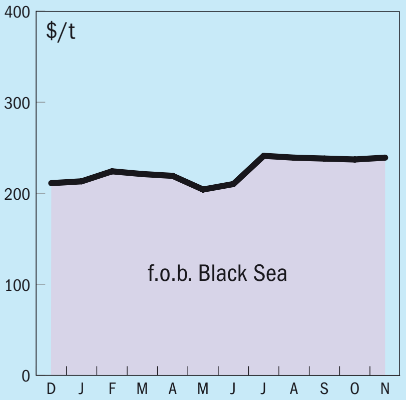
natural gas



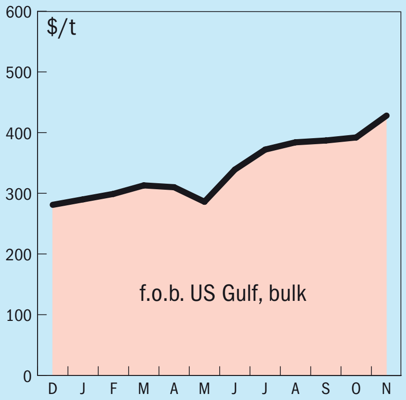
ammonia



urea

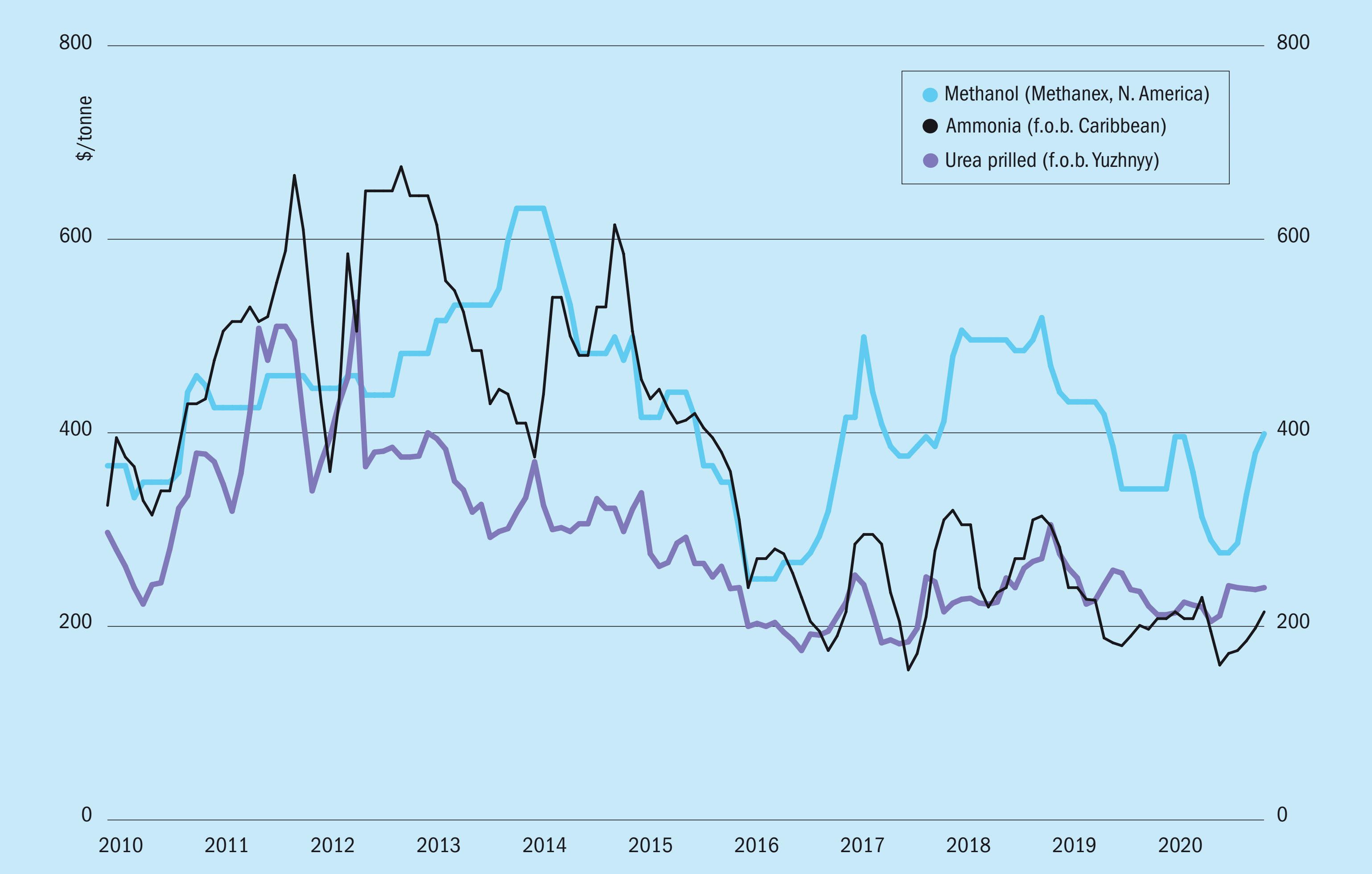


diammonium phosphate



Market Outlook

Historical price trends $/tonne



Source: BCInsight

AMMONIA

- Ammonia supplies have been curtailed by production shutdowns, including Kaltim and PT PAU in Indonesia, SABIC and Ma'aden in Saudi Arabia, Sorfert in Algeria and Chinese gas-based producers. There have also been gas curtailments in Iran and Trinidad.
- Low inventories in the US due to a bumper fall application season are likely to lead to stronger than usual buying in anticipation of the spring application season.
- Yara and Mosaic agreed a price for January of $270/t c.fr Tampa, up $15/t on the $255/t c.fr agreed for December and in line with expectations of a higher settlement.
- Industrial ammonia demand is also recovering after much Covid-related disruption during 2020.
- With supply still constrained in some areas, the prospects are for higher ammonia prices during 2021 in the western hemisphere, although prospects are slightly flatter in the eastern hemisphere.

UREA

- Last year's record Indian demand seems to have abated, and fresh tenders are not expected before March/April.
- A fresh outbreak of Covid-19 and resultant lockdown has affected urea plant operations in China's northeastern Hebei province
- China is also facing urea production cuts due to gas supplies being cut to plants to allow increased power production during the winter. This is leading to high Chinese domestic prices and a lack of product being offered to the export market.
- Lack of availability and good prices for grain have led to New Orleans prices jumping at the start of 2021 to $320/st f.o.b. NOLA ($350/metric tonne), up $65/t in just the first couple of weeks of the new year, to secure cargoes from around the world.
- At the moment the prospect seems to be for higher prices in the short term, especially once Indian buyers return to the market.

METHANOL

- Methanol prices have been rising as supply tightens. Gas curtailments have affected production in Iran and China. Other supply outages have occurred at Tomet in Russia and Equinor in Norway. This has coupled with low storage levels due to previous outages to tighten supply in all major markets.
- Conversely, demand has appeared to be robust in spite of the second wave of coronavirus infections in Europe and North America. Demand was particularly strong in Europe, especially into the formaldehyde sector. In the US, a strong construction sector also helped lift prices for chemical derivatives.
- Methanex posted its January 2021 US reference price at $1.45/gallon ($482/metric tonne), a jump of $0.25/gallon ($83/t), the fifth monthly price rise in a row, and the highest posted price for Methanex since November 2018.
- Continuing supply tightness and strong demand are expected to lead to prices continuing to rise through 1Q 2021. ■

Nitrogen Industry News

NORWAY

Yara hopes to convert Porsgrunn to renewable production

Building on its long experience and leading position within global ammonia production, logistics and trade, Yara says that it aims to capture opportunities in green shipping, agriculture and industrial applications; a market expected to grow by 60% over the next two decades. A major first step includes plans to fully electrify its ammonia plant at Porsgrunn, Norway, with the potential to cut 800,000 t/a of CO_2, equivalent to the emissions from 300,000 passenger cars.

To make its vision of zero-emission ammonia production in Norway a reality, Yara is seeking partners and government support. If the required public co-funding and regulatory framework is in place, the project could be operational in 2026, the company says. The project would eliminate one of Norway's largest static CO_2 sources, and would be a major contributor for Norway to reach its Paris agreement commitments. Yara aims to produce emission-free fuel for shipping, carbon-free fertilizer and ammonia for industrial applications.

"Ammonia is the most promising hydrogen carrier and zero-carbon shipping fuel, and Yara is the global ammonia champion; a leader within production, logistics and trade. I am excited to announce that a full-scale green ammonia project is possible in Norway, where we can fully electrify our Porsgrunn ammonia plant," said Svein Tore Holsether, president and chief executive officer of Yara.

Investment in 'blue' ammonia company

Saga Pure ASA has bought $4 million shares in Horisont Energi AS, taking an 11.7% stake in the company. Horisont Energi, based in Stavanger, is looking to develop a carbon capture based 'blue' ammonia plant in Finnmark in the north of Norway in a partnership together with Equinor, and the company is already in dialogue with several other large international companies for further blue ammonia and CCS projects. The company says that it will use the net proceeds from the private share placement to build its organisation and conduct preparatory work to reach a final investment decision for the project.

"Horisont Energi has developed an attractive value chain solution for production of blue ammonia as well as CO_2 handling, and we see great potential for this company going forward," commented Bjørn Simonsen, CEO of Saga Pure.

NETHERLANDS

Grant for transformation of steel and urea industries.

A consortium led by the Dutch Research Institution TNO has received a grant of €21 million from the European Commission under the Horizon 2020 Framework Program, called the INITIATE (Innovative Industrial Transformation of the steel and chemical industries of Europe) Project, to investigate and develop the potential of symbiotic industrial processes to convert residual steel gas emissions into resources for urea production. Tecnimont subsidiaries Stamicarbon, MET Development and NextChem will all participate in the consortium of steel, chemical and energy transition companies, research institutions, universities and industrial partners active in both the steel and fertilizer industries.

The INITIATE project aims to demonstrate a novel circular process that transforms residual steel gases into resources for urea production. The core of this process is a modular carbon-capture utilisation and storage (CCUS) technology, integrating the flexible conditioning of carbon-rich steel off-gases with the synthesis of ammonia. Steel and urea production are between them responsible for 30% of all industrial carbon emissions. Demonstration/development units will be built at Swerim's facility in Luleå, Sweden, for proof of concept, with the eventual aim of a commercial implantation plant, involving construction of a first of its kind 150 t/d urea plant within the next five years. Stamicarbon will be responsible for this second phase of the project.

Green ammonia project could cut CO_2 by 100,000 t/a

Yara is partnering with leading offshore wind developer Ørsted to launch a medium-scale project to use renewable hydrogen in the production of ammonia. Doing so would eliminate more than 100,000 tonnes of CO_2 per year, equivalent to taking 50,000 conventional cars off the road. The companies say that they are now in the process of securing public co-funding and the appropriate regulatory framework, with an operational target date of 2024/2025. The renewable hydrogen would generate around 75,000 t/a of green ammonia, based on a dedicated renewable energy supply from Ørsted's offshore wind farms. The ammonia would be used in the production of carbon neutral fertilizer products, decarbonising the food value chain, and also has potential as a future climate neutral shipping fuel. A final investment decision to build the new plant is hoped for by late 2021 or early 2022.

"We share a vision of creating a sustainable future for us all," says Terje Knutsen, executive vice president and head of Farming Solutions in Yara. "To support this, Yara and Ørsted have partnered to develop a 100 MW wind-powered electrolyser plant for renewable hydrogen production, aiming to replace fossil-based hydrogen for ammonia production in Yara's plant in the Dutch province of Zeeland."

DENMARK

Topsoe in venture to build commercial scale renewable ammonia plant

Haldor Topsoe says that it will partner Skovgaard Invest, supported by Vestas, a global leader in sustainable energy solutions, to build a 'green' ammonia plant in western Jutland, Denmark by 2022, based on a 10 MW electrolyser to generate hydrogen. The plant will produce more than 5,000 t/a of ammonia from renewable power, using 12 MW of power from existing Vestas wind turbines and 50 MW from a new solar array. To improve the business case and increase the attractiveness of green ammonia as a substitute for fossil fuels, Haldor Topsoe and Vestas say that they are developing a dynamic, scalable and cost-optimised solution. Haldor Topsoe will design the plant's fully dynamic ammonia technology to secure optimal production and adapt to the inherent fluctuations in power output from wind turbines and solar panels. The ammonia plant will interface to a green hydrogen solution developed by Vestas, integrating electrolysis with wind and solar in one smart control system. In addition, the renewable energy generation will be connected directly to the national grid so surplus power can be sold to the grid. When in operation, the project will deliver proof of concept and experience that can pave the way for larger projects in the future. The partnership will jointly invest in the project and has applied for public co-funding.

"This project will proves that we can produce a very clean fuel from renewable power at industrial scale as soon as 2022," said Kim Grøn Knudsen, chief strategy & innovation officer, Haldor Topsoe. "We have available the technologies we need to begin the transition towards renewable fuels and reduce carbon emissions, and with the innovations in this project, we push the limits for how fluctuating renewable energy is used in direct synthesis of clean fuels."

SAUDI ARABIA

SAFCO becomes SABIC Agri-Nutrients

The Saudi Arabian Fertilizer Company (SAFCO) has been renamed SABIC Agri-Nutrients, following after share purchase agreements with SABIC which the company says will provide capital to serve as a growth platform for the business and to support its diversification strategy to achieve sustainable long-term growth. SABIC Agri-Nutrients is aiming to become a global agribusiness leader, hoping to benefit from the SABIC brand. A global brand campaign will soon be launched to promote the new company among key players in the agriculture sector and create awareness of its rebranding strategy.

INDIA

Two killed in IFFCO ammonia leak

Two employees have been killed and at least 16 others, including three contractors, were hospitalised due to ammonia inhalation following an ammonia leak at IFFCO's Phulpur ammonia-urea plant in Uttar Pradesh in December. In a statement, IFFCO said the accident took place during maintenance work as the tie rods of an ammonia plunger pump suddenly broke and became detached, leading to heavy ammonia leakage. The dead were named as deputy manager Abhay Nandan and assistant manager V P Singh.

"Our two officials laid down their lives tackling the accident and saving the lives of their other colleagues. My deepest condolences to their family and friends," said IFFCO managing director and CEO U.S. Awashthi said.

JAPAN

Hydrogen and ammonia to provide 10% of Japan's energy by 2050

Japan's Ministry of Economy, Trade and Industry (METI) has unveiled a proposal for the country's 2050 energy mix as the country gears up to achieve carbon neutrality by 2050, with hydrogen and ammonia accounting for about 10% of the power generation mix in 30 years, from a current baseline of zero. The proposal notes that this would require annual hydrogen procurement volumes of about 5-10 million t/a by 2050. Japan's current hydrogen strategy, agreed in 2017, is targeting 300,000 t/a of hydrogen production at a cost of $0.29/Nm^3$ by 2030, against a current cost of $1.64/Nm^3$.

Ammonia could be co-fired with coal, requiring about 500,000 t/a of ammonia per 1 GW of coal-fired power capacity, according to METI. If ammonia replaced 20% of Japans coal-fired generation capacity, it would require 20 million t/a of ammonia.

Meanwhile, Japanese firms, backed by state-owned energy agency Jogmec, are studying the possibility of producing and shipping 'blue' ammonia produced in Russia far eastern region for coal co-firing. The feasibility study is being conducted by Jogmec, trader Itochu and Toyo Engineering, together with Russian oil producer Irkutsk Oil (IOC). The partners are considering the establishment of an entire value chain for mass-produced 'blue' ammonia using natural gas produced by IOC with CO_2 captured and injected into eastern Siberian oil fields for enhanced oil recovery.

ISRAEL

Haifa awards contract for ammonia plant

Haifa Group has awarded Saipem a $200 million contract to build a long-delayed ammonia plant at Mishor Rotem in the Negev desert, southwest of the Dead Sea. The contract was signed during an online ceremony in the presence of Haifa Group CEO, Motti Levin, Haifa Group board member and project leader, Dr. Eli Abramov, and Saipem's CEO, Stefano Cao, and Saipem's COO Onshore E&C Division, Maurizio Coratella.

Haldor Topsoe technology will be licensed for the plant construction. Capacity is projected to be 100,000 t/a, with construction taking three years. Saipem's scope of work entails engineering, procurement, construction and commissioning for the entire facility.

The plant's offtake will mostly be used for production of potassium nitrate fertilizer, but Haifa says a surplus will be offered to customers in Israel. The plant's construction was necessitated by the closure of the ammonia tank at the coastal city of Haifa, which was used to store ammonia imported by sea.

AUSTRALIA

Feasibility study on urea plant

Australia's Strike Energy and engineering company TechnipFMC have completed a feasibility study for a urea facility in Western Australia. The proposed $1.8 billion Project Haber development at Geraldton Port in Western Australia would include an 800,000 t/a ammonia plant and 1.4 million t/a urea plat, along with 300,000 t/a of on-site urea storage, power, utilities, steam generation and rail sidings. Feed would be via a 120 km natural gas pipeline from the Perth basin. Although this would be a completely conventional gas-based urea facility, Strike says that it is considering additional options for carbon management and abatement, including carbon capture and storage or carbon offsets, which will be evaluated and considered during the front-end engineering and design phase. In the longer term, it also plans to use wind turbines to generate up to 10MW of electricity to electrolyse water to initially produce up to 2% of the plant's hydrogen requirement, with the option of further scale-up of green inputs. It is currently targeting a final investment decision at the end of 2022, with construction anticipated to take 36 months.

Saipem joint venture to build Perdaman urea plant

Perdaman Industries has awarded the $2.4 billion engineering, procurement and construction contract for the Burrup Urea Project to a 50-50 joint venture comprising Saipem SpA and local engineering and construction firm Clough Group. The project will build a 2.1 million t/a urea complex at the Burrup Peninsula Industrial Area,

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47 48 49 50 51 52 53 54 55 56

approximately 20 km northwest of Karratha, on the coastline of Western Australia. The scope of work includes engineering, supply of equipment and materials, construction, pre-commissioning and commissioning, including a water treatment plant, a 100 MW power plant and urea storage, loading and unloading facilities. Saipem will provide Snamprogetti technology for the urea plant, while Haldor Topsoe will license its SynCOR™ technology to build the world's largest single-train ammonia plant.

Stefano Cao, Saipem's CEO, commented: "We congratulate Perdaman Industries for the achievement, and we are grateful for the confidence demonstrated towards our Saipem-Clough JV. This project – one of the largest and environmentally efficient urea plants in the world – will strengthen our leadership role in the gas monetisation market and will contribute to further diversify our geographical footprint."

EGYPT

Abu Qir to begin debottlenecking study

Abu Qir Fertilizers says that it has contracted Stamicarbon to carry out technical studies for the debottlenecking of its number 3 urea plant. The project would raise capacity from 1,940 t/d day to 2,370 t/d.

LIBYA

Yara cashes out of Lifeco

Yara has sold its 50% stake in the Libyan-Norwegian Fertilizers Company (Lifeco) to Libya's state-owned National Oil Corporation (NOC). Lifeco was a joint venture between Yara, NOC and the Libyan Investment Authority (LIA), the latter two of which each held a 25% stake. Lifeco operates a 700,000 t/a ammonia and 900,000 t/a urea complex at Marsa el Brega on the Libyan coast, but the plant has been idle for some time.

UZBEKISTAN

Production begins at Navoiyazot

On December 23rd, urea production began at the new $985 million Navoiyazot ammonia-urea complex, according to the company. The plant has 660,000 t/a of ammonia and 577,500 t/a of urea capacity, as well as nitric acid and ammonium nitrate plants. The output will feed domestic fertilizer requirements in Uzbekistan, as well as neighbouring countries in Central Asia, Turkey, Ukraine, and Georgia. Ammonia technology was provided by Haldor Topsoe, urea by Saipem, and Uhde's urea granulation process. Engineering, procurement and construction was handled by Mitsubishi Heavy Industries and Mitsubishi Corporation.

Jurabek Mirzamakhmudov, chairman of Uzbek state chemical conglomerate Uzkimyosanoat (owners of Navoiazot) said: "I would like to thank our national and international partners who supported the construction of the new ammonia and urea production complex at JSC Navoiyazot. Commissioning of the new complex was completed within 53 days despite Covid and existing restrictions, testament to the hard work of all involved."

UNITED KINGDOM

Consultation on possible urea ban

The UK Department for Food and Rural Affairs (Defra) has launched a consultation with British farmers on a possible ban on the use of solid urea fertilizer. Defra is seeking to reduce emissions of ammonia by 8% compared to 2005 levels by 2020 and 16% by 2030. The department says that the emissions are harmful to natural habitats as well as to human health, with 87% coming from agriculture, of which 18% is attributed to inorganic fertiliser application.

Three policy options are set out in Defra's consultation, including a total ban on solid urea fertilisers, or a requirement to stabilise them with the addition of a urease inhibitor – a chemical that helps slow the conversion of urea to ammonium. Defra is also looking at a requirement to restrict the spreading of solid urea fertilisers so they can only be used from 15 January to 31 March.

Defra Secretary George Eustice says that any changes would need to be made in a way that was 'realistic and achievable' for farmers. "Ammonia emissions are causing harm to sensitive and important habitats by making soils more acidic which damages the growth of some plant species, impacting on biodiversity," he said. "They are also harmful to human health, and we welcome views on how we can address their use in agriculture so that we can all breathe cleaner air. We are committed to working with farmers to help them do this."

UKRAINE

OPZ output back at five year high

The troubled Odessa Port Plant (OPZ) has posted its highest production figures for five years after moving to a tolling arrangement for its gas supplies. The company says that in 2020 it produced 821,200 tonnes of urea, as well as 96,500 tonnes of excess ammonia. OPZ exports 90% of its output. The urea production figure is up 250% on 2019, when the plant was shut down for much of the year, and its highest output since 2015, following ongoing difficulties with gas supply and financing.

BOLIVIA

Pipeline offers hope for urea plant

Bolivian state energy company Yacimientos Petrolifos Fiscales Bolivianos (YPFB), has completed the Carrasco-Yapacaní natural gas pipeline capacity expansion project. The $24 million project will allow gas to flow to the Bulo Bulo ammonia-urea plant, which is now reportedly aiming for a re-start during the first half of 2021. The 700,000 t/a facility has been idled for over a year due to gas availability issues.

GREECE

Startup of new NOx catalyst

Kavala Fertilizers' nitric acid unit in Greece has restarted with a charge of Haldor Topsoe's *TertiNOx*™ catalyst – its first commercial reference. The catalyst removes nitrous oxide (N_2O), a very potent greenhouse gas with an estimated effect on global warming 298 times that of CO_2. At the current performance level, the plant will reduce its greenhouse gas emissions by more than 30,000 t/a of CO_2. The plant has already exceeded its design conversion with N_2O emissions below 10 ppm, low ammonia slip, and practically eliminated NOx emissions.

GERMANY

New ammonia synthesis catalyst

Clariant and Casale have jointly developed a new ammonia catalyst for sustainable CO_2 reduction; *AmoMax*™*-Casale*. The catalyst has up to 30% higher efficiency than previous generations of *AmoMax* due to a larger active surface area. This significantly lowers the energy consumption and hence CO_2 emission of an ammonia plant in two ways; firstly by allowing operation of the ammonia synthesis loop with considerably less pressure, and secondly because of higher conversion, so the plant will consume less energy for the recirculation of the process gas in the reactor loop. There is a much fuller discussion of the catalyst in our article in *Nitrogen+Syngas* 364, Mar/Apr 2020; "Evolution of a new NH_3 synthesis catalyst", pages 44-48. ■


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CHINA

Contract for five methanol plants

Johnson Matthey (JM) has secured a multiple licence for China's Ningxia Baofeng Energy Group's latest project to develop five of the largest single train methanol plants in the world. Located at Baofeng's Ordos City complex in Inner Mongolia, the five plants each have a planned capacity 7,200 t/d. Under the agreement Johnson Matthey will be the licensor of all five plants and supplier of associated engineering, technical review, commissioning assistance, and catalyst. The plants will take synthesis gas as a feed and use JM radial steam raising converters in a patented series loop. Within the design, there is potential for 1-2% more feedstock efficiency over the life of the catalyst. Thanks to JM's methanol loop synthesis technology, the plants will provide enhanced energy savings along with low OPEX, CAPEX and emissions. When complete, the plants will represent JM's 13th operating license in China for a mega-scale plant (>5,500 t/d) and the fourth JM methanol design licensed by Ningxia Baofeng Energy.

"We are deeply proud that Ningxia Baofeng Energy has selected JM yet again as methanol technology provider at their newest and grandest complex", said John Gordon, managing director of Johnson Matthey. "Our continuing collaboration speaks volumes to their confidence in JM's expertise and ability to design and deliver large scale plants. Our plant designs and catalysts are recognized the world over for their efficiency, enabling customers to enhance yields and improve the economic and environmental footprint of their plants. It's an exciting time for both JM and our valued customer so we look forward to this next phase of our partnership". ■

Production boost at MTO plant

Meanwhile, also at Ningxia Baofeng Energy, Clariant is celebrating 18 months of installation of its *MegaMax 800* methanol synthesis catalyst in the methanol section of the Chinese group's coke oven gas to olefin project. The 1.5 million t/a methanol unit was loaded for the first time with the catalyst in June 2018. Since then its high performance has enabled Baofeng Energy to increase the plant load to 117% of design capacity, producing 3.7 million metric t/a of methanol for downstream methanol to olefins (MTO) production. Chaoshan Yi, Chief Engineer of Baofeng Energy Group, said, "We were very pleased with the results of the catalyst's performance, especially the high activity which sets the foundation for the higher yield of the methanol plant."

The Ningxia Baofeng MTO plant.

PHOTO: CHINA DAILY

Linde expands capacity for hydrogen refuelling stations

Linde and the Dalian Bingshan Group have signed an agreement to establish a joint venture company to manufacture hydrogen refuelling stations in Dalian, Liaoning province, to supply fuel cell-powered vehicles, starting in 2021. Linde will triple its production capacity for hydrogen refuelling stations over the next few years.

"The Asian market has long been one of the pioneers in hydrogen-based mobility solutions. Due to our many years of successful cooperation with our joint venture partner, this is the ideal location for us to expand capacity," said Dr. Alexander Unterschuetz, Senior Vice President Components, Linde Engineering.

ITALY

Alliance for waste to chemicals projects

Maire Tecnimont subsidiary NextChem, which focuses on the development of projects and technologies for energy transition, has signed a commercial agreement with JFE Engineering Corporation, part of Japan Group JFE, to cooperate on technologies which use waste as a resource to produce advanced fuels, hydrogen, fertilizers and low carbon chemical products. The companies say that the conversion of waste into syngas and the use of this to produce circular hydrogen, advanced fuels and many other key products can contribute to the decarbonisation of production processes and reduce the carbon footprint in the final use phase of products. The companies will collaborate on feasibility studies, turnkey construction, and training of staff in JFE plants in Japan. Based on JFE's experience NextChem has defined an integrated waste to chemicals technological platform that is ready to be licensed license worldwide.

"The recovery of carbon and hydrogen contained in waste allows us to reduce the use of fossil sources for the production of fuels and basic chemicals," commented Pierroberto Folgiero, CEO of Maire Tecnimont Group and NextChem. "The collaboration between NextChem and JFE Engineering enhances the know-how of both Groups. Our technological waste to chemical platform is solid, referenced, ready and profitable; it is our response to the… path to a low-carbon economy, to the problem of dependence from abroad of many countries for some basic products of the chemical industry and also to the global problem of recovery of waste fractions currently not recyclable"

NORWAY

Haldor Topsoe and Aker Carbon Capture to cooperate on low-carbon hydrogen

Aker Carbon Capture and Haldor Topsoe have signed a memorandum of understanding with the intention to offer a complete solution for low-carbon hydrogen production. The solution combines Haldor Topsoe's proven hydrogen process and Aker Carbon Capture's post combustion carbon capture technology to achieve low-emission and cost-effective production of 'blue' hydrogen – a clean energy carrier with a wide array of applications in industry and as a fuel.

The companies say that decarbonising the existing hydrogen market by adding carbon capture is a key to unlock the emerging hydrogen market in Europe, and the collaboration aims to accelerate this process. The two companies intend to enter into a formal cooperation agreement in early 2021 and approach market opportunities. The European Union foresees investments of €11 billion for retrofitting half of the existing European hydrogen plants with carbon capture and storage before 2030.

"The collaboration with Aker Carbon Capture is an exciting opportunity to support customers in lowering their emissions from hydrogen production. Haldor Topsoe is a world leader in technology to produce hydrogen, and we are determined to lead the transition towards significant reductions in carbon emissions in this field and others," said Amy Hebert, Chief Commercial Officer of Haldor Topsoe.

UNITED STATES

Grön Fuels selects Topsoe technologies for low carbon complex in Louisiana

Grön Fuels, developer of a renewable diesel and jet fuel facility at the port of Greater Baton Rouge, has selected key technologies from Haldor Topsoe, including *HydroFlex*™ hydrotreating and *H2bridge*™ hydrogen technologies, including an option to capture up to 1.0 million t/a of CO_2 for carbon sequestration in suitable deep saline aquifers located below the project site. The facility will produce renewable diesel from non-fossil feedstocks such as soybean and canola oils, distillers corn oil, tallow, used cooking oil, and future feedstocks such as bio-crudes. Following the expected completion of the first phase of the complex in 2024, the plant will produce 60,000 bbl/d of renewable diesel, including a permitted jet fuel option. A final investment decision for the $1.25 billion first phase of the project is expected in 2021. Once completed, it would be the largest renewable fuel site in the world.

The integration of the *H2bridge* and *HydroFlex* processes would enable Grön Fuels to produce renewable bio-hydrogen equivalent to the production of a 1,000 MW hydrolyser plant at a fraction of the cost. The design flexibility to include biocarbon capture and sequestration (CCS) to the project is added to pursue negative carbon intensity renewable fuel production. Bio-hydrogen not used for diesel production will be made available for purchase by third parties for lowering the CO_2 emissions of power production, industrial processes, or transportation.

MoU on green hydrogen plant

Maire Tecnimont subsidiary NextChem has signed a memorandum of understanding with Enel Green Power to support the production of green hydrogen via electrolysis in the United States. Enel will leverage NextChem's hydrogen technology and engineering expertise to grow its green hydrogen business in the US. The project, which is expected to be operational in 2023, will convert renewable energy from one of Enel's solar plants in the US into green hydrogen to be supplied to a bio-refinery. Under the agreement, NextChem will act as technology and engineering partner and full turnkey EPC contractor, providing Enel Green Power with the necessary technical assistance in relation to the development and implementation of the project.

Pierroberto Folgiero, Maire Tecnimont Group and NextChem CEO, commented: "We are really proud to be Enel's partner of choice in this industrial initiative, which enhances our group's expertise in hydrogen chemistry and production of green hydrogen from solar renewables and represents a relevant step in the development of our green hydrogen initiatives." "This new partnership is the latest milestone in the Enel Group's commitment to promoting the development of green hydrogen" said Salvatore Bernabei, CEO of Enel Green Power. "We are actively scouting for opportunities in this segment in several parts of the world, both in Europe and in the Americas, and we look forward to joining forces with partners such as Maire Tecnimont to make the most of the significant potential that green hydrogen represents for the decarbonisation of hard-to-abate sectors."

Federal funding for hydrogen development

The US Department of Energy's Office of Fossil Energy is making $160 million in federal funding available to help move the country's fossil-fuel and power infrastructure towards decarbonised energy and commodity production. The funding, for cost-shared cooperative agreements, is aimed to develop technologies for the production, transport, storage, and utilisation of fossil-based hydrogen, with progress towards net-zero carbon emissions.

Program areas include: net-zero or negative carbon hydrogen production from modular gasification and co-gasification of mixed wastes, biomass, and traditional feedstocks; solid oxide electrolysis cell technology (SOEC) development; carbon capture; advanced turbines; natural gas-based hydrogen production; hydrogen pipeline infrastructure; and subsurface hydrogen storage.

SWEDEN

Perstorp plan to produce sustainable methanol

Speciality chemicals producer Perstorp is developing a plant to produce sustainable methanol from a wide variety of recovered end-of-life streams, combined with hydrogen from electrolysis, and a large scale, carbon capture and utilisation (CCU) unit. The Project AIR methanol plant will be unique in combining CCU and a gasification process where CO_2, residue streams, renewable hydrogen and biomethane will be converted to methanol. Perstorp plans to do this in cooperation with Fortum, Uniper and Nature Energy.

Project AIR aims to substitute all 200,000 t/a of fossil fuel-based methanol that Perstorp currently uses in Europe as a raw material for chemical products. The project would support companies downstream in the value chains in their efforts towards renewable/circular materials, reduced carbon footprints, and in their ability to offer sustainable, affordable products. If completed, it would reduce greenhouse gas emissions by about 500,000 t/a.

If the required funding is granted, the goal is to start producing sustainable methanol in 2025 at Stenungsund. Fortum and Uniper will supply renewable hydrogen from a new electrolysis plant, while one of the world's largest producers of biogas, Nature Energy will seek to supply biogas to Project AIR.

"This innovation would both optimise the use of existing technologies whilst building something completely new, as well as demonstrating carbon capture and utilisation, using captured CO_2 as a raw material. It would be a concrete example of the transition towards a circular economy and of how significant CO_2 emission reductions could be achieved by utilising existing resources and closing loops. This would be an important step for us to achieve our goal of becoming finite material neutral," said Perstorp's president and CEO, Jan Secher.

DENMARK

Methanol fuel cell production begins

Methanol fuel cell developer and manufacturer Blue World Technologies says that it has begun a limited production run of fuel cells as the first step in commercialising their own methanol fuel cell technology. The company, founded only in October 2018, has nevertheless managed to build up an order book that reflects the considerable market demand for methanol fuel cells. The limited production run is intended to be a precursor to a scale up to full production of 2-5,000 units per year, with the aim of reaching full-scale commercial production capacity of 50,000 fuel cell units within three years.

Blue World sees methanol fuel cell technology's potential as being in markets such as maritime, heavy-duty, stationary, and passenger vehicles. The fuel cells run on methanol which is easy to handle, making refuelling convenient as well as making it possible to integrate and reuse existing infrastructure. Blue World uses high temperature PEM-technology combined with methanol reforming. The combination ensures a simple system design with high conversion efficiency and compliance with automotive design requirements.

BELGIUM

CF Industries joins Hydrogen Council

CF Industries Holdings has joined the Hydrogen Council, a global CEO-led initiative that brings together leading companies with a united vision and long-term ambition for hydrogen to foster the clean energy transition. The Company will serve as a steering member of the council. In addition to joining the Hydrogen Council, the company has announced an initial green ammonia project at the company's Donaldsonville Nitrogen Complex to produce approximately 20,000 t/a of green ammonia. CF will install a state-of-the-art electrolysis system to generate carbon-free hydrogen from water that will then be supplied to an existing plant to produce green ammonia. Additionally, CF Industries is developing carbon capture and storage (CCS) and other carbon abatement projects across its production facilities that will enable CF to produce low-carbon ammonia.

"CF Industries shares the Hydrogen Council's vision that hydrogen has an essential role to play in the clean energy transition," said Tony Will, president and chief executive officer, CF Industries Holdings, Inc. "We believe that low-carbon ammonia is a critical enabler for the storage and transport of clean hydrogen to help meet the world's energy needs, which is why we have committed to decarbonise the world's largest ammonia production platform. We look forward to working with Hydrogen Council members to support the acceleration and deployment of hydrogen solutions globally."

TRINIDAD AND TOBAGO

Titan idled "indefinitely"

Methanex says that it expects its 875,000 t/a Titan methanol facility on Trinidad to remain idled indefinitely. As a result, the company has made the decision to restructure its Trinidad operations to support a one-plant operation and reduce its Trinidad workforce by approximately 60 jobs. Methanex says that this is because it has not been able to reach an agreement for an economic long-term natural gas agreement with the government. In a press statement, the company added: "given that the economic recovery path remains uncertain we believe it is prudent to reduce costs while continuing our efforts to secure longer-term gas supply". The neighbouring Atlas methanol facility, in which Methanex has a 63% stake, will continue to operate, as it is has a separate natural gas supply agreement which expires in 2024.

John Floren, president and CEO of Methanex, commented, "We remain committed to doing business in Trinidad and Tobago and we believe that we will be able to secure an economic longer-term natural gas agreement for Titan in the coming years. Our operations in Trinidad are well located to supply global methanol markets and are an important component of our global production network. We are taking the necessary steps to maintain Titan to ensure a safe and efficient restart of the plant when a longer-term gas agreement is reached."

FRANCE

Funding sought for green hydrogen feed

Total and Engie have unveiled plans to build a green hydrogen side feed for Total's biodiesel plant in the south of the country. The project is hoped to be up and running in 2024, provided that the companies secure subsidies to make the project viable. The project partners envisage building a solar farm with a capacity of more than 100 MW and a 40-MW electrolyser at Total's biofuel plant in La Mede. The facility would produce 5 t/d of hydrogen, which would allow Total to avoid 15,000 t/a of CO_2 emissions a year.

UNITED ARAB EMIRTES

Abu Dhabi to become hydrogen exporter

Abu Dhabi has agreed a deal to produce and export hydrogen as fuel, according to the government. State owned Abu Dhabi National Oil Co (ADNOC), state investor Mubadala and state-owned holding company ADQ have signed a memorandum of understanding to establish the Abu Dhabi Hydrogen Alliance, a statement said. The plan is to produce both green hydrogen and 'blue' hydrogen, the latter from natural gas, to export to emerging international markets.

UZBEKISTAN

GTL project slips to July

Uzbekistan has set a new deadline for the commissioning and start-up of its $3.6 billion gas to liquids (GTL) project in the Kashkadarya region after failing to bring it online last year due to the Covid-19 pandemic. According to project operator Uzbekistan GTL, the plant is now set to come into operation in July 2021, with construction said to be 94% complete as of January 11th. Construction efforts at the plant came to standstill in the middle of last year after rising numbers of Covid-19 infections prompted the evacuation of thousands of workers, and a push from authorities to move faster with the project met with resistance from workers who staged a protest in October over prolonged shifts. At full capacity, the GTL plant is set to process about 3.6 bcm of gas, produced at the Shurtan field and purified at a nearby gas chemical facility, operated by Uzbekneftegaz.

CANADA

Shell buys into waste-to-fuels plant

Shell is to take a 40% stake in Enerkem's new waste to fuels plant at Varennes, Quebec. The $700 million plant will use Enerkem's processing technology to convert 200,000 t/a domestic waste and wood waste into 125 million litres of chemicals and fuels. The first phase is scheduled for commissioning in 2023. The plant will also take 11,000 t/a of hydrogen and 88,000 t/a of oxygen from a new 90 MW electrolysis plant which is being built nearby by Hydro-Québec. The waste is sorted, shredded and dried, than passed through a fluidised bed gasifier to generate syngas, which is cleaned and converted to methanol and ethanol. Other partners in the project include methanol and ammonia producer Proman, and oils sands developer Suncor.

The plant is the fourth that Enerkem has under development. It has a 100,000 t/a waste processing facility being commissioned in Edmonton, Canada; a 360,000 t/a facility awaiting a final investment decision for construction in Rotterdam; and a 400,000 ta plant also awaiting investment decision for Tarragona, Spain. ■

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People

Clariant, says that **Conrad Keijzer** become its new chief executive officer as of January 1st, 2021. Interim executive chairman Hariolf Kottmann has thus returned to his position as chairman of the board. Keijzer is a Dutch citizen with a long track record in the chemical industry, including 24 years with leading global paints and coatings manufacturer AkzoNobel, where he was CEO of the Performance Coatings Division and a member of the Executive Committee. Most recently, Conrad Keijzer was CEO of Imerys, a French supplier of mineral-based specialty solutions.

Peter Kirkegaard has been appointed Chief Human Resources Officer of Haldor Topsoe, effective from January 1st, 2021. Since 2016, Peter Kirkegaard has served as executive vice president, chief people & culture officer, with Hempel A/S, which he joined in 2007 as vice president. Before that, he had a 15 year career with Accenture, where he was a partner leading the Human Performance and Finance & Performance Management sections.

"Peter has shown that he can drive large-scale transformation projects with great results and buy-in from the organisation. I am convinced that his strategic mindset, cultural sensitivity and collaborative approach will bring exceptional value to our company, and that Peter will take an important role in securing Haldor Topsoe's success," said Roeland Baan, CEO of Haldor Topsoe.

"I really look forward to be part of the ambitious transformation that Haldor Topsoe has just begun. The vision to become recognized as the global leader in carbon emission reduction technologies by 2024 truly inspires me. Haldor Topsoe – and its employees – has the potential to do a remarkable positive difference on a global scale, and I am proud that I can be part of that," Kirkegaard said.

BASF CEO **Dr. Martin Brudermüller** has been elected the new president of Cefic, at the organisation's recent General Assembly. He succeeds Daniel Ferrari, CEO of Versalis (Eni) who held this post from October 2018. Marco Mensink, Cefic's Director General commented: "I am pleased to welcome Martin Brudermüller as our new President. With more than 30 years' experience in various roles in the chemical industry, he will be able to lead us to deliver on the Green deal objectives.

Brudermüller has been chairman of the board of executive directors of BASF SE and Chief Technology Officer of BASF SE since July 2018. He studied chemistry at the University of Karlsruhe and earned his doctorate in 1987. He has been a member of the BASF board since 2006. He was also a member of the High-Level Group on maximising the impact of EU Research and Innovation Programmes, chaired by Pascal Lamy.

Canadian researcher **Dr. Claudia Wagner-Riddle** has been awarded the 2020 IFA Norman Borlaug Award for her trailblazing multidisciplinary research that has helped improve fertilizer nitrogen use efficiency and reduce nitrous oxide (N_2O) losses by up to 70% without sacrificing crop yields. Dr. Wagner-Riddle was among the first researchers to apply micrometeorological techniques to monitor and better understand year-round N_2O emissions from cropping systems by using a tunable diode laser trace gas analyser. She leads a large collaborative group of scientists at the University of Guelph, where she is currently professor at the School of Environmental Sciences, in a new outdoor soil monitoring laboratory.

Alzbeta Klein has been named as the International Fertilizer Industry Association (IFA)'s new director general, effective from January 11th, 2021. Ms. Klein brings significant finance, sustainability and emerging markets experience, most recently from the International Finance Corporation (IFC)/World Bank Group, and through her numerous board-level positions. She joined the World Bank Group in 1997, after several years at Export Development Canada, and has served on several corporate and advisory boards of leading agribusiness companies such as Hans Merensky Holdings and Grupo Los Grobo, and on advisory sustainability boards of Nespresso and the New York University Stern School of Business. A citizen of Canada and Slovakia, Ms. Klein holds an engineering degree from Prague University, a Masters' degree in Economics from the University of Ottawa, Canada, and is a Chartered Financial Analyst.

"We are delighted to welcome Ms. Klein", said IFA Chairman, Mostafa Terrab. "We are convinced that her breadth of knowledge, as well as her global expertise in finance, sustainability and emerging markets, together with her proven leadership skills, will serve the industry well on its trajectory towards the IFA2030 vision."

Calendar 2021

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

FEBRUARY

16-18

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

27-29

4th International Fertilizers Conference: Eastern Europe, Baltic States & Balkans, BUDAPEST, Hungary
Contact: WFM Chem-Courier agency
Tel: +38 056 370 12 04
Email: conf@wfmeasteurope.com

MARCH

Date T.B.C.

Argus Asia Fertilizer, location T.B.C.
Contact: Argus Media
Tel: +44 (0) 20 7780 4340
Email: conferences@argusmedia.com

1-3

Nitrogen+Syngas 2021, ROME, Italy
Contact: CRU Events
Tel: +44 (0) 20 7903 2444
Fax: +44 (0) 20 7903 2172
Email: conferences@crugroup.com

APRIL

26-28

Syngas 2021, BATON ROUGE, Louisiana, USA
Contact: Betty Helm, Syngas Association, Baton Rouge, Louisiana
Tel: +1 225 706 8403
Web: www.syngasassociation.com

31-MAY 2

IFA 88th Annual Conference, NEW DELHI, India
Contact: IFA Conference Service
Tel: +33 1 53 93 05 00
Email: ifa@fertilizer.org

MAY

18-19

IFS Technical Conference, AMSTERDAM, Netherlands
Contact: International Fertiliser Society
Tel: +44 (0)1206 851 819
Email: secretary@fertiliser-society.org

Plant Manager+

Incident Nos. 4 & 5 Leak detection system failures in urea plants

The following case studies describe serious incidents associated with leak detection system failures. Incident 4 relates to the failure of the active pressurised leak detection system for the loose liner of a urea reactor and Incident 5 relates to a passive leak detection system which failed to work leading to serious corrosion of the carbon steel wall of the HP scrubber.

Incident No. 4

Event description

During a daily routing plant tour the plant operator observed a crystallised white product deposited on the insulation sheeting of the urea reactor which worsened quite quickly over time. Some ammonia vapour was also noticed.

Immediate response action

Initially a leak at the manway cover was assumed, since the active pressurised leak detection system was not indicating any leak. A closer look, however, indicated a possible leak in the liner and so the plant was stopped for inspection.

Causes

The installed active pressurised leak detection system failed to warn operations. The pinhole leak in the liner had created severe corrosion attack of the carbon steel pressure shell and the reactor was taken out of service just in time. The state-of-the-art leak detection had failed to indicate the leak due to a combination of wrong commissioning of the system and failure of some components, as well as insufficient inspection and maintenance of the system.

Primary consequence

There was a near miss of the high pressure vessel rupturing.

Secondary consequence

The incident led to an unplanned shutdown. A temporary repair was carried out initially, with a full repair executed within one year.

Risk level

The likelihood of a major consequence was moderate, but the risk level was high.

Prevention safeguards

Assure proper functioning of the leak detection system. Safe operation of the plant is only possible with a good working leak detection system.

Mitigation safeguards

In case of a leak, confirm and locate the leak, shut down the plant and drain the synthesis section as soon as possible.

Corrective recommendation

The leak detection system was refurbished and made operational before start-up of the plant. In addition, an inspection and maintenance program was implemented to increase the reliability and availability of the existing leak detection system. All plant operators received further training.

Incident No. 5

Event description

In February 2018, a leak was visible in the spherical dome part of a HP scrubber of a 1,750 t/d Stamicarbon CO_2 stripping urea plant. The plant was shut down.

Upon opening of the HP scrubber sphere it became clear that severe corrosion had occurred on the 316L UG liners. The liner was covered with a large amount of corrosion products and many cracks were visible. The cracks had resulted in leaks that had gone unnoticed by the passive leak detection system, likely due to clogging. Therefore, corrosion of the carbon steel pressure part commenced undetected. Many cracks were also found in the carbon steel wall and grooves and holes were partly blocked by corrosion products.

Immediate response action

The plant was stopped to attend the leak.

Causes

In the passive leak detection system it takes too long for the leak to show up at the analyser. The leaks in the liner had already clogged the tubing (the leaks were cracks).

Primary consequence

A rupture of the high pressure vessel was avoided by luck.

Secondary consequence

There was an unplanned shutdown of about two months for extensive work to repair the HP scrubber.

Risk level

The likelihood of a major consequence was moderate, but the risk level was high.

Prevention safeguards

Assure proper functioning of the leak detection system. Safe operation of the plant is only possible with a good working leak detection system, including an accurate and reliable ammonia analyser.

Mitigation safeguards

In case of a leak, confirm and locate the leak, shut down the plant and drain the synthesis section as soon as possible.

Corrective recommendation

The leak detection system was refurbished and made operational before start-up of the plant. In addition, an inspection and maintenance program was implemented to increase the reliability and availability of the existing leak detection system. All plant operators received further training.

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Gas pricing and market reform

PHOTO: EXXONMOBIL

Qatargas' Mozah LNG tanker, the largest LNG carrier in the world.

Natural gas pricing remains the dominant component of ammonia production costs. The fall in global oil and gas prices due to the Covid outbreak and the continued growth in the LNG market is continuing to break the hold of oil indexation on gas pricing. Meanwhile, reform of gas markets continues, in places as diverse as Brazil, China and India.

Syngas-based industries, dominated by ammonia, methanol, and to a lesser extent hydrogen, are highly dependent upon feedstock costs. Since the 1960s, and aside from China's large scale adoption of coal gasification, that feedstock has predominantly been natural gas. While China's coal-based industry has tended to be towards the top of the cost curve, and its large scale production has made it a price setter, global markets for natural gas are key determinants of the profitability of ammonia and methanol production worldwide.

The switch to the use of gas for chemical production happened at a time when most power generation was based upon burning coal, and gas, often a by-product of oil drilling that might otherwise be wastefully flared, was cheap at source but difficult to transport in the absence of expensive long-distance pipelines. This made the economics of gas-based ammonia/urea and methanol production highly persuasive – the urea or methanol was far easier to transport than the gas, and so an export-based industry grew where 'stranded' gas was available, such as in Trinidad, the Middle East, and Central or Southeast Asia.

The gas market has however changed beyond recognition since those times. Global pipeline networks have continued to grow on land, while the spread of liquefied natural gas (LNG) liquefaction and regasification terminals and associated shipping have turned gas into a global rather than regional commodity. Gas market pricing has evolved, via gas trading hubs which now set prices internationally. Elsewhere, old fields have depleted, while the development of horizontal drilling and hydraulic fracturing technologies have opened up new gas deposits in mature markets such as the US which were previously thought to be unrecoverable at any reasonable cost.

Gas pricing mechanisms have sometimes been slow to catch up with these new realities in some regions, where prices remain indexed to the cost of oil production, or where national governments have often continued to control gas pricing. But gas market reform continues to work its way through markets all around the world.

Market turmoil

The past few years have been a turbulent time in global gas markets. Figure 1 shows LNG spot pricing in Japan. Japanese prices had been running high in the wake of the Fukushima nuclear disaster and a major switch from nuclear to gas-based electricity generation. However, LNG prices fell as the Chinese economy slowed, but there was a rebound in 2017-2018 as China made a large scale move away from coal-fired power generation towards natural gas and LNG imports began to increase.

The US and China have been the main drivers of global gas demand growth, accounting for around $^2/_3$ of all incremental demand. Gas' penetration of the US power market has now reached 38%, and use rose 8% in 2019. European consumption increased by 11%. But at the same time, Japan began restarting its nuclear facilities in 2019 and gas demand fell there by 12%. Overall, global gas consumption grew by an estimated 70 bcm in 2019, or 1.8%, which is roughly in line with the average growth rate experienced over the period 2010-17.

At the same time, supply has been increasing rapidly, outpacing demand. US shale gas production was the major culprit. Production growth, at 3% globally, outpaced demand, driven by US shale expansion – US production increases represented 70% of incremental supply in 2019, leading to a large build-up of gas in storage. Russian gas production was boosted by the Yamal LNG project, and China has been increasing production via coalbed methane and shale gas output. Increases in global LNG supply, especially from the United States, where the shale gas boom had led to supply exceeding domestic demand, and also Australia, pushed prices downwards in 2019, as Figure 1 shows. LNG trade increased by 12% in 2019.

Covid

The coronavirus outbreak happened in a market that was already oversupplied, with catastrophic results. Global GDP fell by an estimated 2.8% last year. Industrial consumption of natural gas fell sharply in Europe, while in the US a fall in gas consumption caused by a milder winter was balanced by the cheap prevailing prices and a consequent continuing shift to gas-fired power generation. Overall, however, the gas market has seen a major demand shock, and the International Energy Agency forecasts that the demand contraction in mature markets in Europe, North America, Eurasia and Asia may lead to a 4% year on year decline in global gas demand.

Production has fallen – Russian production contracted by 9% in the first half of 2020 as it was not able to export as much gas by pipeline to Europe. However, LNG supply continued to increase, with added demand in China and India. Meanwhile, LNG demand began to spike at the end of 2020, with a combination of factors responsible, from recovering demand, especially in China, a lack of shipping, delays in the Panama Canal, and production issues in Australia and Malaysia. This drove the run-up in prices at the end of 2020 which can be seen in Figure 1.

LNG

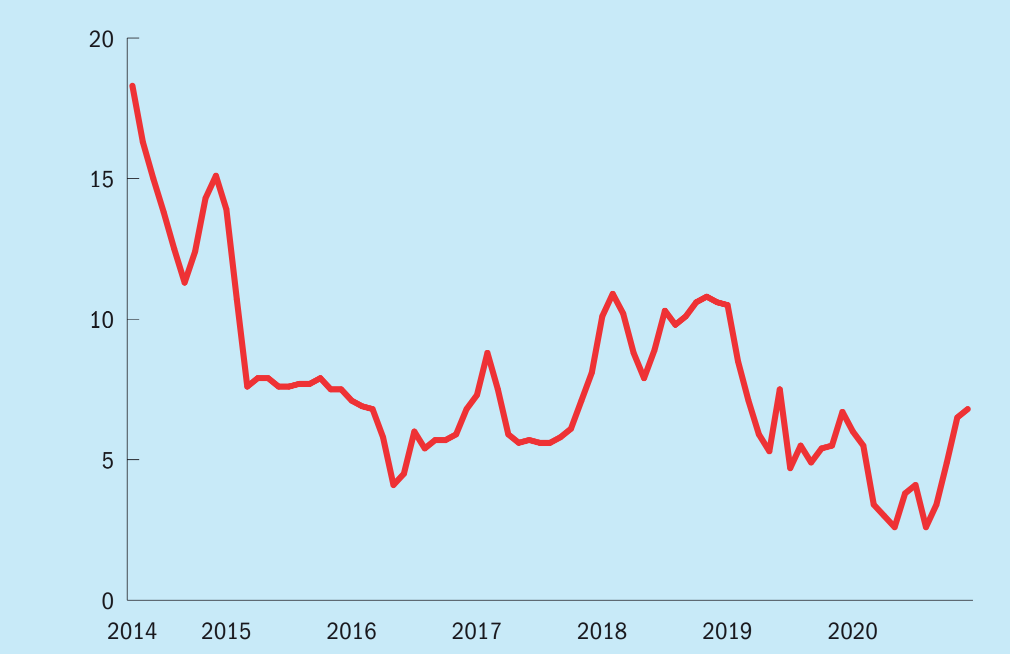
The continuing growth of the global LNG market has transformed and is continuing to transform the way that the world uses natural gas. Production and consumption of liquefied natural gas reached 485 bcm in 2019, representing 12% of the global gas market, and 38% of internationally traded gas. LNG trade has virtually doubled over the past decade, and growth continues – the higher gas prices of 2017-18 encouraged another wave of new investment decisions, which totalled 120 bcm/year of nameplate capacity in 2018-19. There were a record number of decisions to proceed with new LNG projects in 2019, including Sabine Pass LNG train 6, Golden Pass LNG trains 1–3 and Calcasieu Pass (all in the US), Mozambique LNG trains 1 and 2, Arctic LNG 2 in Russia and Nigeria LNG train 7.

LNG was in oversupply in 2020, exacerbated by the fall in demand due to Covid-19, and is set to be in oversupply in 2021 as well. A sustained period of lower oil prices and increased competition among gas supply sources as new supply reaches the market have combined to erode margins, putting pressure on gas and LNG producers.

At the same time, this pressure is helping to change the LNG market. In its early days, the huge costs of liquefaction and regasification terminals meant that LNG tended to be supplied on long-term, oil-indexed contracts. But the growth in the quantity of LNG being shipped, the greater spread in the number of countries both supplying and able to receive LNG, and its move away from oil-associated gas as a source of supply encouraged a gradual move away from long term fixed price contracts, albeit still indexed to oil. But the oil market has major players working in concert to restrict supply at times of low prices, especially via OPEC. While there has been an attempt to produce a similar body for the gas market – the Gas Exporting Countries Forum (GECF), it has not been able to enforce supply cutbacks, and of course does not include some of the largest suppliers such as the US and Australia. So now, the relatively high price for oil and widespread availability of LNG is leading to a decoupling in LNG prices from oil, in a similar way that happened to gas pipeline contracts in Europe and elsewhere. Spot LNG cargoes are being offered at discounts of up to 50-70% of the prevailing price of oil, and the cheapness of LNG is helping to incentivise consumers, especially large scale industrial consumers, to switch to gas. Likewise, while from 2000-18 LNG averaged more than three times its coal price equivalent, it is now at rough parity, again encouraging switching by power generators. Gas is also able to compete on carbon intensity and other pollutants compared to competing fossil fuels, important in a gradually decarbonising world.

LNG's greatest potential remains in Asia, where coal still meets 47% of energy consumption, particularly in China and India. China is now moving steadily but decisively away from coal use. McKinsey reckons that if gas increased its share of primary energy consumption in Asia from just 12% to 20%, this would require up to 400 million t/a of LNG demand, doubling the size of the LNG market from what it is at present.

Fig. 1: **Japanese delivered LNG spot price, monthly average, $/MMBtu**

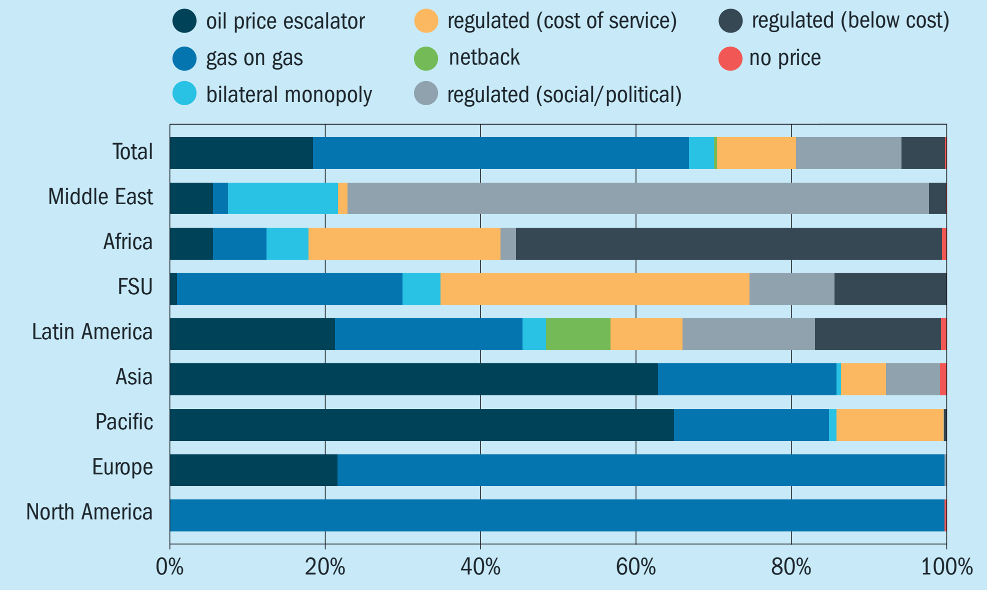


Source: MITI

Gas pricing

Natural gas is priced in different ways. The International Gas Union, in its annual survey of wholesale gas price fixing mechanisms, distinguishes between: 'GOG' – gas-on-gas competition – where there are multiple producers selling into a price unregulated market via trading hubs; OPE – oil price escalation – where the price of gas contracts is tied to oil prices by an escalation factor; and various forms of regulated prices: regulated cost of service (RCS), where a company is allowed to make back

Fig. 2: **Make-up of gas pricing contracts, major markets**



Source: IGU

costs plus a fixed increment; regulated social and political (RSP) and regulated below cost (RBC), where a company, usually state-owned, sells gas below the cost of delivery for political or other reasons.

Figure 2 shows the balance between these types of price mechanism for all gas consumed in various regional markets.

Figure 2 shows that North America essentially functions as a pure gas-on-gas market, having deregulated its gas markets during the 1990s. So does most of Europe, where gas deregulation began in the UK in the 1990s and has gradually spread to the rest of the continent. Over the period 2005-2019, most of Russia's pipeline exports into Europe also moved from OPE to GOG pricing, and the remaining OPE slice shown in Europe for Figure 2 comes from imports of LNG. Conversely, Asia and the Pacific remain strongly based around oil price-linked gas, again due to the prevalence of LNG in these markets. Latin America is a patchwork of pricing mechanisms, while the FSU is moving to gas on gas competition from a regulated cost of service system. The Middle East and Africa still rely upon government-set pricing mechanisms however.

Major developments over the past 15 years have included:

- The move away from regulated pricing in the Russian market to gas on gas competition as independent producers have begun to compete with each other and Gazprom to sell gas to the power sector and large industrial consumers.
- Similar deregulation has occurred in Argentina, and more recently Nigeria.
- From 2013, China has begun to move away from regulated cost of service (RCS) to oil price escalation, initially in two provinces but gradually nationwide, most recently extending into the residential sector via city gate pricing. Some of this OPE pricing has moved to GOG. The main remaining regulated gas market in China is for fertilizer production.
- India also began price reforms in 2014, gradually moving from regulated (social/political) to GOG pricing.
- There has been a rise in new LNG importers, importing at OPE and/or GOG, which is replacing domestic production operating at regulated prices.
- As noted above, there are signs that the link between oil and gas pricing is slowly being broken in the LNG market. Around 40% of LNG is traded via GOG rather than OPE pricing, and with the discounts that were being operating on OPE prices last year some of that was in effect partially GOG.

While Europe and North America both now have mature gas trading hubs, there is still no real equivalent in Asia. As 90% of traded gas in Asia is shipped as LNG, the most logical hub would be one that could see both import and re-export of significant LNG volumes. But the preponderance of LNG demand in east Asia as opposed to other regions still distorts the LNG market and prevents it from becoming a truly global market; there are still significant regional variations in delivered LNG prices.

The future for gas

Most of the gas demand lost in 2020 is expected to be recovered this year, in mature markets such as Europe, Eurasia and North America, as demand from industrial and power generation sectors gradually returns. Some marginal gains are also expected from coal-to-gas switching, helped by low gas prices and continuing abundant supply. Additional demand growth over the next five years will come from faster-growing markets in the Asia-Pacific region (and to a lesser extent the Middle East). The Asia Pacific region accounts for over half of projected new incremental consumption from 2022-25, led by China and India. Additional demand in the Middle East (about a quarter of the total increase) is primarily driven by large gas-producing markets such as Saudi Arabia and Iran.

As well as power production, industrial uses are expected to drive this consumption increase, with around 40% of new gas demand coming from industry, and much of this industrial demand will come from fertilizer and methanol production. New ammonia and methanol production is expected to lead to 3.4% year on year growth in industrial consumption of gas. India of course represents a large slice of this with its import replacement programme. The US meanwhile is leading growth in methanol, via export-oriented projects such as Northwest Innovation in Washington State. Globally, use as methanol feedstock represents over 30% of the growth in the industrial gas demand sector.

China will add the most new demand for gas, with a projected demand increase of 60 bcm/year total over the period 2019-25, as power generators and industrial consumers are encouraged to move from coal to gas, and some vehicles are converted to run on natural gas. While China is making large investments in shale and other unconventional gas production, this will also necessitate much greater import of LNG. This will be good news for the US shale gas industry, hit hard by the run of low gas prices last year. New gas supply is expected from the US, Russia and especially the Middle East, the latter region adding 120 bcm/year of extra supply from 2019-25. ■

Towards a sustainable nitrogen fertilizer industry: Part 1: Nitrogen use

Part 1 of a two part look at a potential sustainable future for the nitrogen industry, looking at sustainable nitrogen management and nutrient use efficiency.

The development and use of nitrogen fertilizer during the 20th century has been one of the great success stories of scientific development. Born out of fears of running out of mined nitrate sources during the late 19th century, particularly Chilean potassium nitrate deposits, which represented most artificial nitrogen applications at the time, the Haber-Bosch process has moved ammonia production from a 3 litres/day laboratory-scale experiment in 1909 to a 180 million t/a industry today. In the process, it has been responsible for a 'green revolution' in agricultural output which has allowed the world to move to a population of 7.7 billion without mass starvation. About 3.5 billion of these could not be fed without the use of artificial nitrogen fertilizers.

However, at the same time, this huge benefit has not come without some significant drawbacks. Synthetic ammonia production is a highly energy-intensive process, and the partial oxidation of fossil fuels to generate syngas produces on average 2.9 tonnes of CO_2 emissions per tonne of ammonia. This makes the ammonia industry alone responsible for 520 million t/a of CO_2 emissions, or just over 1% of the global total. We will deal with ways of reducing this figure in the next issue. At the same time, over-application of nitrogen fertilizers leads to release of nitrous oxides into the air and nitrates into water, the former adding to greenhouse gas emissions, and the latter causing rapid growth of algae (eutrophication) which deplete the oxygen content of water, leading to the death of fauna. At the extremes, this can lead to large scale aquatic 'dead zones' such as appear seasonally in the Gulf of Mexico and Baltic Sea due to run-offs from major rivers.

With the global population projected to rise to 9.8 billion by 2050, and the amount of arable land limited at roughly its current level, it is projected that another 60% increase in agricultural productivity may be required over the next 30 years. Fertilizer will no doubt play a part in this, but that means that unless the way that it is used changes, the problems will merely get worse.

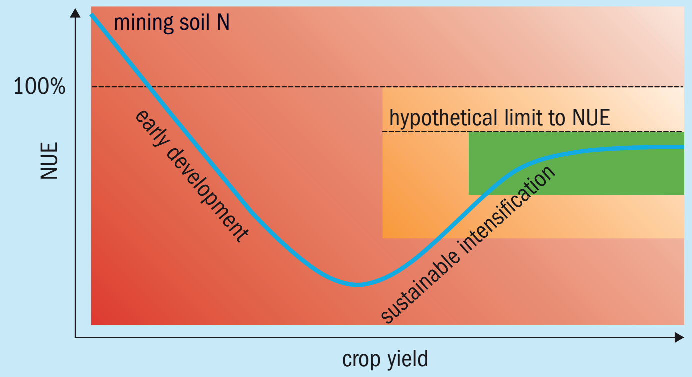
UN resolution

Efforts to tackle this issue have been gradually moving up the political agenda over the past few decades, mainly via local or national regulations or industry-led voluntary schemes and best practice promulgation. In March 2019, they made it to the United Nations Environmental Assembly (UNEA), when delegates adopted a resolution calling for "a coordinated and collaborative approach to sustainable nitrogen management". The resolution recognised "the multiple pollution threats resulting from anthropogenic reactive nitrogen, with adverse effects on the terrestrial, freshwater and marine environments and contributing to air pollution and greenhouse gas emissions", and highlighted ways to better manage nitrogen.

Precision farming can help boost nutrient use efficiency.

PHOTO: PIXABAY

Fig. 1: **Typical progress of nutrient use efficiency**



Source: IFA[4]

The resolution supported exploring options for better management of the global nitrogen cycle to achieve sustainable development goals, including through the "sharing of assessment methodologies, relevant best practices and guidance documents and emerging technologies for recovery and recycling of nitrogen and other such nutrients."

Its suggested options for better nitrogen management included: consideration of an intergovernmental coordination mechanism on nitrogen policies based on existing networks and platforms; ensuring coordinated management of relevant datasets relating to the environmental, food and health benefits of possible goals for improved nitrogen management; promotion of appropriate training and capacity building for policymakers and practitioners for developing widespread understanding and awareness of the nitrogen cycling and opportunities for action; and supporting member states with sharing and making available existing information and knowledge on developing an evidence-based approach to nitrogen management.

Nutrient stewardship

One of the key ways in which eutrophication and other issues can be tackled is by more efficient use of fertilizer. Globally, agricultural soils received an average total of 73 kgN per hectare per year. Of this, 61% came from fertilizer and manure, 10% from atmospheric deposition, and 29% from natural nitrogen fixation. But around half of the nitrogen applied to fields is not taken up by plants. Nutrient use efficiency can vary widely. For example, in Eastern China it is around 33%, whereas in the United States it can be 65%, and 61% in Western Europe. Losses to the atmosphere from ammonia volatilisation range from 17% in Europe and the US to 22% in China.

Using nutrient more efficiently has led to the concept of nutrient stewardship, developed by the International Fertilizer Industry Association (IFA) in conjunction with regional industry bodies including The Fertilizer Institute (TFI) in the US, Fertilizers Canada, Fertilizers Europe and the (now sadly defunct) International Plant Nutrition Institute. This in turn has led to the '4R' initiative, aimed at getting farmers to apply the: Right fertilizer source, at the Right rate, at the Right time and in the Right place. A key concept is balanced nutrition, so that a lack of one nutrient, whether potash, phosphate, sulphur or micronutrients, does not prevent the plant from taking up nitrogen during its growth.

This forms part of fertilizer best management practices (FBMPs) which are actively promoted by the above organisations, developed through research and verified and continuously adapted in the fields, to manage the flow of nutrients in the course of producing affordable and healthy food in a sustainable manner.

Other FMBPs include site-specific nutrient management (SSNM), i.e. supplying plants with nutrients to optimally match their inherent spatial and temporal needs for nutrients; integrated plant nutrient management (IPNM) – applying available on-farm organic fertilizers to crops and supplementing them with mineral fertilizers; microdosing – applying small quantities of fertilizers, either during planting or 3-4 weeks after plant emergence; and fertigation – combining fertilizers with irrigation water.

As part of their outreach to global farmers, IFA and the World Farmers' Organization (WFO) have produced a nutrient management handbook; a 25-page manual to help farmers achieve the goals of boosting productivity, achieving higher resilience and reducing greenhouse gas emissions.

Other initiatives

In November 2019, IFA instigated a new Scientific Panel on Responsible Plant Nutrition to meet the growing need for scientific research and expertise to further improve nutrient stewardship, in line with the outcomes of its IFA2030 strategic review. Composed of prominent plant nutrition experts from leading research organizations around the world, the Scientific Panel's mission is to advance sustainable plant nutrition as it plays a key role in solving the challenges facing agricultural systems around the world by improving agricultural productivity and soil health while minimizing nutrient losses to the environment.

Improving NUE worldwide

In May last year IFA reported[4] on progress in improving nutrient use efficiency (NUE) worldwide. Figure 1, abstracted from that report, shows the general trend in NUE trajectory observed in many countries, where consumption generally increases much faster than removal by crops and NUE drops rapidly. A turning point is reached once medium to high yields are attained, when farmers, policymakers, scientists and other stakeholders prioritise the improvement of NUE, after which surpluses stabilize or decrease owing to access to improved knowledge, inputs and technologies, finally approaching a theoretical limit in nutrient use efficiency.

Looking at the way that NUE had changed from the 1960s to the 2010s in six countries; Brazil, the US, Denmark, China, India and Nigeria, the report concluded that:

- too high and too low output/input ratios (NUE) levels are equally unsustainable;
- countries typically follow the U-shape NUE trend seen in Figure 1;

- NUE must be interpreted within the context of crop production systems;
- countries with a large share of their area planted to leguminous crops have a higher NUE while countries with a high proportion of less N use efficient crops (e.g. fruits and vegetables) have a lower NUE;
- countries where farmers use improved crop varieties, irrigation, fertilizer best management practices and technology (e.g. precision farming) have a higher NUE;
- countries where the fertilizer price is heavily subsidized (eg India) have a lower NUE;
- countries with high livestock production density (i.e. higher percentage of total inputs as manure N) have a lower NUE;
- Sub-Saharan African countries (and countries with similar low fertilizer application rates and low crop yields) can learn from experiences elsewhere and potentially avoid the U-shape trend.
- empirical evidence suggests that a combination of mineral fertilizer and organic fertilizer seems most promising for sequestering soil carbon in agricultural soils.

The report recommended adopting and implementing FBMPs tailored to site- and crop-specific conditions to enhance NUE and reduce losses to the environment while increasing yields and, in conjunction with the 4R message described above, that the fertilizer industry advance innovative products and technologies that enable further improvements in NUE. It also encouraged policymakers to take into consideration their countries' specificities in terms of soils, crops and climate, and to tailor their plant nutrient recommendations according to these.

It also noted that precision agriculture, aided by technology, has the potential to further increase productivity while reducing greenhouse gas emissions, steering agricultural systems towards a sustainable, input-optimised model. The fertilizer industry and its research partners have developed several precision agriculture solutions, including mobile applications that allow farmers to send pictures of their crops and receive tailored fertilizer recommendations; hand-held sensors can measure the N status of crops; water sensors can assess the water requirement of plants by measuring pressure on leaves; and even simple tools like a leaf colour chart can guide farmers with their application of nitrogen fertilizer based on leaf greenness. An important challenge for the implementation of fertilizer BMPs is reaching out to the world's 500 million farmers, especially smallholders, to make them knowledgeable in site- and crop-specific plant nutrition. National governments can play an important role in that regard, by adopting policies prioritizing farmers' access to knowledge, inputs and markets. Subsidy schemes should also be tailored to each country's nutrient management performance, to promote the efficient and balanced use of plant nutrients, or to ensure farmers have access to inputs where they are under-used. ■

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4. Regional Nutrient Use Efficiency Trends and Sustainable Fertilizer Management, IFA, May 2020.

nitrogen+syngas index 2020

A complete listing of all articles and news items that appeared in *Nitrogen+Syngas* magazine during 2020.

Monetising stranded natural gas resources, Mar/Apr, p22.

PHOTO: GREYROCK

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

PHOTO: KBR

Learning from successful plant commissioning, Mar/Apr, p34.

Country	NITROGEN INDUSTRY NEWS	Issue	Pg
Africa	LNG projects likely to be deferred	Jul/Aug	10
Angola	Uralchem in joint venture fertilizer project	Jan/Feb	8
Australia	Burrup fertilizer plant moving ahead	Jan/Feb	8
	Dyno Nobel to pilot renewable ammonia	Mar/Apr	10
	Incitec abandons sale plans for now	May/Jun	8
	Incitec Pivot warns of threat from high gas prices	Sep/Oct	10
Bahrain	Saipem to conduct study on expansion plans	Mar/Apr	11
Bangladesh	Credit line for new urea plant	May/Jun	10
Bolivia	Urea plant could be moved	Mar/Apr	9
Brazil	Petrobras to sell Araucaria	Nov/Dec	10
	Petrobras tries again for Tres Lagoas sale	Mar/Apr	11
Chile	Green ammonia project for Enaex	Nov/Dec	10
China	Contract awarded for melamine plant	Sep/Oct	11
	Training on cloud-based urea plant simulator	Nov/Dec	10
Croatia	Petrokemija resumes ammonia production	Jul/Aug	10
Denmark	Haldor Topsoe joins UN Global Compact	Jul/Aug	11
	Report on ammonia as a marine fuel	Sep/Oct	8
	Topsoe extends scope of its ClearView service	Sep/Oct	8
	Topsoe to refocus its strategy	Nov/Dec	9
Egypt	Ammonia contract finalised	Jul/Aug	9
	KIMA commercial production planned for April	Mar/Apr	11
	Stamicarbon completes stripper for urea melt plant	Jul/Aug	9
Finland	Ammonia combustion trials for shipping and power	May/Jun	8
India	Bids invited for settlement of Matix debt	Nov/Dec	10
	Fertilizer restarts boost gas demand	Jul/Aug	10
	Government seeks to speed coal gasification project	Sep/Oct	10
	IndianOil to collaborate on DEF bulk dispensing	Jan/Feb	9
	KBR, Stamicarbon supply technology for Talcher	Jan/Feb	9
	NFL working to keep up fertilizer supply in lockdown	May/Jun	10
	Ramagundam aiming for March commissioning	Jan/Feb	9
	RCFL to begin production in late June	Jul/Aug	10
Japan	Feasibility study on renewable ammonia combustion	May/Jun	10
	Joint research on ammonia fuelled ship	Nov/Dec	9
	More interest in ammonia as a shipping fuel	Sep/Oct	8

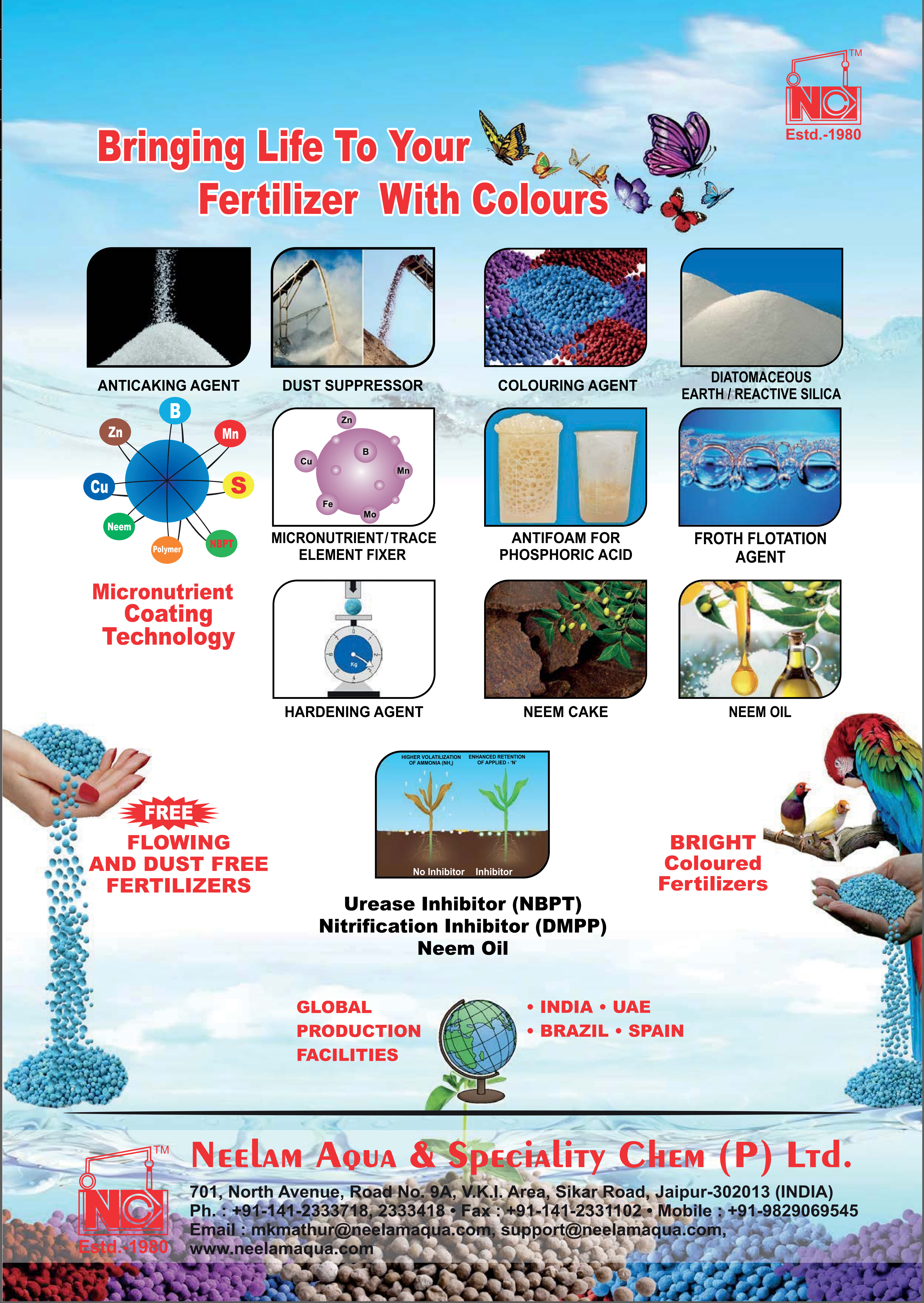
Country	NITROGEN INDUSTRY NEWS	Issue	Pg
Netherlands	Commercial reference for new catalyst	May/Jun	10
	Large scale electrolyser for ammonia plant	Nov/Dec	9
	Tecnimont and Stamicarbon celebrate 10th anniversary	Jan/Feb	8
	Topsoe launches TITAN steam reforming catalyst	Mar/Apr	8
Nigeria	Commissioning ongoing at Dangote	Jul/Aug	10
	Dangote plant in pre-commissioning phase	Mar/Apr	10
	Dangote still aiming for start-up this year	Sep/Oct	10
Norway	Vessel to run on ammonia powered fuel cell	Mar/Apr	9
Oman	Omifco signs three year offtake deal	Sep/Oct	11
Pakistan	Restart for Agritech urea plant	Sep/Oct	10
Poland	KBR technology selected for nitric acid plant	Jan/Feb	8
Russia	Casale says Metafrax AUM project making progress	Jul/Aug	10
	Dorogobuzh completes ammonia revamp	Sep/Oct	9
	EuroChem inks credit facility with Rabobank	Mar/Apr	10
	Uralchem resumes production at Berezniki	Sep/Oct	9
Saudi Arabia	'Blue' ammonia shipped to Japan	Nov/Dec	10
	CO_2 removal facility for Ma'aden	Nov/Dec	10
	Saipem agrees Saudi joint venture	Mar/Apr	10
	Topsoe selected for green ammonia project	Sep/Oct	10
Singapore	BW LNG looking to ammonia as a shipping fuel	Sep/Oct	11
Spain	Fertiberia to make ammonia from 'green' hydrogen	Sep/Oct	8
Switzerland	Sabic increases its holding in Clariant	May/Jun	8
T'dad & T'go	Nutrien ammonia plant closed 'indefinitely'	Nov/Dec	10
Turkey	Tecnimont wins urea/UAN plant contract	May/Jun	8
Ukraine	OPZ extends gas tolling while seeking new tenders	Sep/Oct	9
	Severodonetsk triples fertilizer output	Mar/Apr	11
UK	Royal Society endorses ammonia for shipping	Mar/Apr	9
USA	CF to boost nitric acid production at Donaldsonville	Nov/Dec	8
	EPA/USDA competition for new technologies	Nov/Dec	8
	Gulf Coast Ammonia to proceed with plant	Mar/Apr	8
	IFA holds first Global Stewardship Conference	Mar/Apr	8
	Large scale 'carbon free' ammonia plant	Nov/Dec	8
	Koch launches digital solutions business	Jul/Aug	11
	Settlement in lawsuit over plant reconstruction	May/Jun	8

PHOTO: CASALE

Tackling emissions in the nitric acid industry, Nov/Dec, p18.

Country	SYNGAS NEWS	Issue	Pg
Australia	Ammonia plant to produce renewable hydrogen	Mar/Apr	12
	BHP to recycle tyres via waste gasification	Sep/Oct	13
	Leigh Creek Energy looking to hydrogen market	Jul/Aug	12
	Renewables projects looking at hydrogen storage	Jul/Aug	12
Belgium	Belgium also looking to wind-powered hydrogen	Mar/Apr	13
	Sustainable methanol project	Jul/Aug	14
Botswana	Government renews push for CTL plant	Mar/Apr	13
China	Clariant reports on catalyst performance at H_2 plant	Jul/Aug	15
	Matthey to supply technology for largest methanol plant	Sep/Oct	12
Denmark	Topsoe and Sasol to offer joint GTL licenses	Jan/Feb	10
	Topsoe joins sustainable fuel project	Sep/Oct	13
Egypt	Feasibility study on new methanol co-production plant	Nov/Dec	12
Equ' Guinea	Companies shortlisted for methanol project	May/Jun	12
	Nexant to produce study on methanol derivatives	Jul/Aug	14
	Study on methanol plant conversion to refinery	Jan/Feb	12
France	France launches wind powered hydrogen plant	Mar/Apr	13
	Hydrogen powered fuel cell barge	May/Jun	11
	Integrated power to hydrogen to power project	Jul/Aug	14
Germany	A methanol fuel standard for Europe	Nov/Dec	14
	'Artificial photosynthesis' pilot plant	Nov/Dec	14
	Expanding electrolysis plants at a GW scale	Jul/Aug	13
	Hydrogen for electricity grid stabilisation	Sep/Oct	12
	Hydrogen for steel production	Jul/Aug	14
	Partnership for GTL technology commercialisation	Sep/Oct	12
	Siemens to build green hydrogen plant	Nov/Dec	14
India	Bids invited for coal-fired methanol plant	Nov/Dec	13
	December commissioning for Namrup methanol	Nov/Dec	13
	Start-up for Trombay methanol plant	Nov/Dec	13
Indonesia	Coal-based methanol plant planned for Bengalon	Jul/Aug	13
Iran	Apadana methanol plant to commission in 2021	Jan/Feb	12
	Start-up for Bushehr	Jul/Aug	14
Italy	Agreement on 'syngas fermentation' technology	Sep/Oct	12
Japan	Methanol from recycled CO_2	May/Jun	12
Malaysia	Samsung wins contract for Sarawak methanol plant	Sep/Oct	13
Netherlands	Koolen Industries invests in Proton Ventures	Jan/Feb	11

Country	SYNGAS NEWS	Issue	Pg
Nigeria	NNPC to increase stake in GTL plant	Jan/Feb	13
Norway	Fuel cell alternate power train for shipping	Nov/Dec	12
	Renewable aviation fuel project	Jul/Aug	15
Romania	Romgaz looking at new methanol plant	Jan/Feb	13
Russia	Topsoe wins license for Gaz Sintex methanol plant	Jan/Feb	13
Saudi Arabia	Air Products JV to build Saudi hydrogen hub	Mar/Apr	12
Sweden	Biomethanol for diesel production	Mar/Apr	13
	Crowdfunding for CO_2 to methanol project	May/Jun	11
	Fifth anniversary for methanol powered ferry	May/Jun	12
	Methanol from renewables project secures funding	Jan/Feb	12
Switzerland	Clariant to sell Masterbatches business	Jan/Feb	11
T'dad & T'go	CGCL loads first methanol shipment	Nov/Dec	14
	Gas price discussions get serious	Mar/Apr	13
	Methanex idles Titan plant	May/Jun	12
	Methanex secures gas for January	Jan/Feb	12
	Methanol plants idled, delayed	Jul/Aug	15
UK	Arup joins hydrogen global charter	Mar/Apr	12
	Carbon capture hydrogen plant submits proposal	Nov/Dec	12
	Matthey and KBR alliance on ammonia-methanol	Nov/Dec	12
	Planning approved for plastics to hydrogen facility	May/Jun	12
	Startup for waste to energy plant	Jan/Feb	11
	Topsoe wins IChemE award for TIGAS	Jan/Feb	10
	UK awards $36 million to hydrogen projects	Mar/Apr	12
	Waste to hydrogen plant secures funding	Jan/Feb	11
	WEC launches Hydrogen Global Charter	Jan/Feb	10
USA	Agreement for world-scale hydrogen plants	Sep/Oct	13
	Air Products and Topsoe sign global collaboration	Jul/Aug	12
	Construction on hold at South Louisiana Methanol	Jul/Aug	12
	FEED study on gas to gasoline plant	Jan/Feb	12
	Hafnia to take methanol from Kalama	Nov/Dec	13
	Kalama methanol plant saga rumbles on	Jan/Feb	12
	Methanex defers construction of third plant	May/Jun	11
	MOL to provide ships for NWIW project	Jul/Aug	12
	Nacero agrees methanol to gasoline license	May/Jun	11
Venezuela	Restart at Supermetanol	Nov/Dec	13



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CRU Nitrogen + Syngas 2021 Virtual Conference

This year the CRU Nitrogen + Syngas conference is going virtual. From 1 to 3 March 2021, the CRU virtual event will offer a live and on-demand agenda, interactive exhibition and enhanced networking capabilities on a platform tailored to make remote access as easy as possible.

The CRU Nitrogen + Syngas conference has a 34-year proven track record of bringing together senior technical professionals to share experience, troubleshoot operational problems, discuss best practice, and source new solutions. In 2021, the virtual event will again provide this crucial platform for professional development and networking, but from the safety of your plant, office or home. More than just a series of webinars, the virtual event incorporates a three-day, multi-streamed agenda of technical papers and presentations; a virtual exhibition for meeting with technical experts and sourcing solutions; and integrated networking including live video, audio and text chat, interactive discussion groups, and meetings scheduling.

The conference runs alongside an exhibition of world-class process, materials, equipment and technology solution providers who bring their expertise to the audience. Networking and meeting time is scheduled throughout the agenda to maximise interaction.

What you can expect from the virtual event is a fully immersive experience, with multiple interactive spaces:

- Keep up-to-date with the latest technology, process, materials and equipment developments in the technical agenda, with live Q&A – or you can watch on-demand at a time that suits you.
- Access from anywhere: The virtual venue requires no download, and is mobile-friendly, allowing you to join anytime, anywhere.
- Interact with expert solutions providers in the virtual exhibit hall: meet the exhibitors, explore their products and services and chat or submit an enquiry.
- Network with attendees – search the delegate list by keyword, name and more; see who's live online with you and reach out via voice or video call, text chat, email or request a meeting.
- Speed networking sessions will help to replicate those chance meetings you have in real life at conferences at the receptions.

The agenda has been re-imagined to allow delegates to attend sessions, explore the exhibit hall, network, and have time to check in on their day-to-day job.

At time of going to press the three-day agenda had just been announced. It includes 20 hours of technical content with 40+ technical presentations featured in the dual-streamed agenda. CRU's analysts and key industry experts will also be providing their industry insights.

Live Q&A sessions will follow each presentation, enabling delegates to engage directly with the presenters. In addition, the platform will remain open for 30 days after the conference, providing greater flexibility, allowing delegates to continue to watch the agenda on-demand, interact with exhibition booths and continue networking.

At a time of continued disruption to global travel, keeping connected and informed has never been more important. While travel and in-person events are not possible, CRU's Nitrogen + Syngas 2021 Virtual Conference offers information sharing and networking on a platform providing a highly immersive and interactive space designed to replicate the in-person conference experience.

Key themes of the agenda

- **Sustainability in nitrogen + syngas: new opportunities for green and blue production:** presentations by Casale, thyssenkrupp Industrial Solutions, Linde, Haldor Topsoe, T2M Global and Plasco Conversion Technologies
- **Emissions management:** presentations by BD Energy Systems, Saipem, and A.W.S. Corporation
- **Ammonia catalyst developments:** presentations by Clariant, Johnson Matthey and National Fertilizers Ltd
- **Urea operations and technology developments:** presentations by TOYO, Casale, Axo Welding, Engro Fertilizers, Stamicarbon and UreaKnowHow.com
- **Nitric acid and nitrates: operations and developments:** presentations by Heraeus Deutschland GmbH & Co. KG, Fertiberia, Casale, Umicore and Fluitec
- **Ammonia revamps and retrofits:** presentations by KBR, Johnson Matthey and Engro Fertilizers
- **Improving the efficiency and profitability of operating plants:** presentations by Haldor Topsoe, Engro Fertilizers, PT Petrokimia Gresik and thyssenkrupp Industrial Solutions
- **Incident analysis and troubleshooting:** presentations by Quest Integrity, Integrated Global Services and Kaltim Parna Industri PT
- **Synthesis gas generation and purification:** presentations by Clariant and Haldor Topsoe
- **Equipment developments:** presentations by Piller Blowers & Compressors GmbH and APEX Group


PHOTO: GE

Digitisation in the fertilizer industry: scope and potential

Dr MP Sukumaran Nair, policy analyst and director of the Centre for Green Technology & Management in Cochin, India, discusses the ways that digitisation is improving fertilizer plant operation.

Above: Digital twins are improving our understanding and control of plant operations.

The fertilizer industry is facing several challenges in these Covid-affected times. Several industry majors have seen a weakening in their financial performance due to curtailments in production caused by lockdowns and associated disruptions to logistics and supply chains, and ensuring the health and safety of staff, which are the most daunting among the many challenges being confronted by the industry. On the raw material front, consumer demands are changing, new energy resources are emerging, unconventional oil and gas resources are being developed. The significance of the role played by emerging economies such as China and India are increasing, and a host of other factors had contributed to depressing the market even prior to the onset of the pandemic. The ensuing Covid 19 pandemic has had widespread economic fallout in the industry. Oil demand is falling due to lockdowns and travel bans, and the oil price has plunged well below the level needed to turn a profit. For survival's sake companies are reducing expenditure, bringing down capital spending and trying to drive down operating costs. One good thing is that emissions have been reduced due to the dip in industrial activity.

Facility management

These days optimisation holds the key to survival. The effective functioning of modern industrial facilities involves a tremendous amount of planning and scheduling with regard to procurement, production, quality control, safety and environmental care, off-sites and utilities, and marketing and logistics, besides ensuring the optimal use of raw materials, energy and manpower. We have been using aspect-specific systems and tools to address optimisation in each of these areas for prudent decision making to improve the bottom-line, but digitisation can help to develop a holistic approach in the decision-making process.

Operational efficiency

Over the years, the industry has witnessed considerable improvement in its operational efficiency. This has been possible because of the timely adoption of innovative and commercially proven retrofit and revamp

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technologies. Modern managements try to strategically advance reliability, availability, operational efficiency of manufacturing systems and achieve increased production, yields and ensure profitable capacity utilisation. With advanced automation, rigorous and real time plant monitoring resulting in optimisation of all kinds of resources, better management through effective planning and scheduling becomes possible. Going further, highly connected open systems with real time domain and instant data integrated with enterprise resource planning (ERP) systems gives operators command over the increasing complexities in the industry.

Even in the best designed and well operated plants, there exists ample scope for improvement in operating efficiency through the adoption of digitisation and the industrial internet of things (IIoT). However, identifying where to look for further improvement can be a tough task. Technologies continue to develop; operating facilities adopt newer ones as and when they become technically proven and commercially viable and the operating results in the real time plant environment follow them. It is exactly within the gaps between these developments that there lies further scope for optimisation. The operator's response time to changes in operating parameters is also reduced considerably by digitised plant optimisers. A major technology company has shown through internal studies that 80% of production downtime is preventable, and much of it is due to operator errors. These errors cost that particular industry approximately $20 billion a year. A well-developed preventative maintenance strategy can bring down operating costs, including losses caused by downtime due to unexpected failures, by 25%. An advanced predictive maintenance program with the support of wireless technologies, IIoT and machine learning (ML) and artificial intelligence (AI) enables even greater savings. Under the challenging conditions unfolded by the outbreak of the pandemic, there is likely to be a growth of remote operations supported by modern artificial intelligent platforms.

Current developments in wireless technology, smart sensors, intelligent connectivity, mobile technologies, data storage, analytics and cyber security are increasingly contributing to advances in the operability, productivity, maintenance, safety, and environmental stability in the industry. The internet of things intelligently connects physical devices, driving improved operating efficiencies, business growth and environment friendliness. Industry engages with the IIoT and uses a number of sensors of different designs to capture the operating parameters in real time and use the output for decision making to ensure that the operation of the facility adheres closely to the designer's intent and enhances stakeholder value. Connected devices sense operating data and communicate the same to the data centre, where it is analysed with the support of big data analytics, artificial intelligence, and cognitive analysis. The output from the analysis is developed into actionable programs to operate the facility in the most optimised manner.

Digitisation and IIoT are engaged to monitor variations in operating parameters, detect leaks in pipelines, oversee the security and integrity of installations and check physical condition and location. Real time monitoring of pumping and compressor stations along cross country pipelines helps to instantly assess inhibitory factors depressing operational efficiencies and expose corrosion and erosion which may lead to failure situations. Such measures, taken in advance, improve productivity and thus reduce costs.

In recent years, the industry has been increasingly encouraged to use wireless sensor networks and supervisory control and data acquisition (SCADA) for monitoring of oil and gas installations. Compared to IIoT, wireless sensor networks (WSN) have limited transmission range, storage capacity and power backup, all of which need more improvements. On the other hand, SCADA systems are costly, difficult to maintain and are not scalable. In its place, digital twins are capable of multiple access of wide-ranging data of several equipment at a time at a lower cost. Thus, IIoT is capable of addressing the bottlenecks and improving productivity by enabling predictive maintenance in place of preventive maintenance, monitoring changes in operating conditions in real time, and reducing downtime due to accidents. The IoT architecture for the above purpose comprises a sensor (smart device), connectivity to the control centre (gateway) and control centre (server), responsible for the application and analysis of data gathered from sensors to generate information and support the decision making process for better asset management.

Digital twins are coming on in a big way in manufacturing industry, offering increased utilisation of capacity, improved product quality and output, forecasting deviations from the designer's intent with regard to processes and operating parameters, reduced specific consumptions of energy and feedstock, improved bottom lines and better workplace safety, and better achievement of environmental targets. A digital twin is a virtual model of an asset (e.g. compressor) or process (e.g. catalytic cracking), using IoT sensors to monitor and capture data from physical objects, process it in real time in combination with historical data to get a holistic view on the performance of manufacturing equipment and plants. These models are combined with advanced visualisation technologies and data analytics to fast track troubleshooting, forecast imminent failures, and innovate and retrofit new equipment designs in an existing facility. Often, a low turndown ratio arising out of over-design in term s of the size and capacity of equipment is a generic problem associated with design. Data driven models in the virtual environment provide the requisite inputs to improve future designs. Digital twins are used in brownfield projects to guide the revamp and modernisation of existing facilities to capture better operating efficiencies.

Shifting maintenance strategy

The shift from a reactive ('run to failure') to a reliability centred maintenance (RCM) model was gradual and successfully avoided costly equipment failures. Today, we have pro-active or predictive maintenance programs that use advanced AI-based analytics to identify the predominant factors and monitor parameters to fix variations leading to failures – abrupt or incipient. Moreover, advanced predictive systems are capable of accurately predicting remaining the life of furnace tubes and the likely failure time of rotating equipment. By this operators are empowered to extend equipment service life, avoid expensive repairs, and minimise unscheduled downtime.

Corrosion management

NACE International puts the annual cost impact of corrosion on the processing industry alone as $50 billion. A 30% savings via the adoption of best practices in corrosion prevention would amount to $15 billion – a very significant sum. Beyond economics, corrosion also adversely affects plant reliability, leads to accidents, damages assets and spoils the environment. Therefore, early detection of corrosion, its progress and the impact of the vulnerabilities of varying process parameters have to be understood through advanced monitoring techniques. In fact, we may have to prioritise inspections and strengthen predictive capabilities with regards to corrosion by improving upon data evaluation and better decision making using accurate and real time data.

Data security

In the digital world, data security is a prime consideration and responsibility. While current operating data is relevant for day to day business, historical data is useful for policy formulation and prediction of price and market trends. Maintaining the confidentiality and integrity of data via controlling its access are important from a security point of view. Digitisation and encryption helps to protect an organisation's electronic information systems from the attack of hackers and unauthorised access.

Turnaround management

Turnarounds inevitably contribute to significant downtime in operating plants. A lot of planning and scheduling is done before shutting down a productive plant for the purposes of inspection of vessel internals, catalyst change, equipment replacement, cleaning of fouled equipment or hooking up retrofit systems in order to ensure reliability of plant assets and ward off unexpected failures. Most often, turnarounds incur time and cost overruns due to faulty projections based on inadequate and primitive information about the condition of equipment, delivery schedule of critical supplies, and assessment of the amount of work and manpower required. Today, with the use of artificial intelligence and real time modelling of maintenance and turnarounds, debottlenecking and troubleshooting becomes easier and targets can be achieved within the required schedule.

The development of an app-based software approach is yet another means to enhance facility safety. Operating personnel exposure to hazardous areas in the plant can be limited via wirelessly monitoring process plant data through sensors. Online monitoring of the loss of heat transfer efficiency of heat exchangers, energy and steam loss through faulty traps, and predicting the end of run of reactor catalysts are all well established through app-based software. Abnormal situation monitoring is yet another area where smart wireless devices and sensors enable cloud computing of equipment data in various formats. Overheating, overpressurisation and excessive vibration limits are set to identify normal and abnormal operations. In AI based predictive solutions, deviations from the designer's intent or a set fault threshold initiates a warning to alert the operating staff.

Thus, the industrial internet of things allows delivery of a large volume of data at greater speeds and at lower costs. A recent Gartner survey suggests that nearly half of all organisations implementing IoT technologies were currently using or were planning to use digital twins. According to a recent research report, the market value of digital twins is estimated to grow from $3.8 billion in 2019 to $35.8 billion by 2025. Industry majors have been harnessing the power of digital transformation for over two decades to optimise operations and drive enterprise-wide performance. Indeed, a wedding of operational technology (OT) and information and communication technology (ICT) can result in a potential saving on the order of 25% on avoidable costs. Sharing this 15% and 10% respectively between the facility owner and the service provider seems like a fair apportionment.

Getting the job done during a global pandemic

The year 2020 will be remembered as an uncertain, demanding and challenging year. When faced with a global pandemic, companies have adopted new approaches and remote inspection, monitoring and training using the latest digital tools has been key for the successful completion of projects. Stamicarbon, Casale and KBR share some of their experiences of the past year.

The coronavirus Covid-19 pandemic is the defining global health crisis of our time and the greatest challenge we have faced since World War Two. The pandemic is much more than a health crisis, it's also an unprecedented socio-economic crisis, stressing every one of the countries it touches. During this time of unprecedented challenges companies have been forced to react quickly and creatively to overcome many hurdles. In this article we learn how Stamicarbon, Casale and KBR have successfully met project challenges thanks to a huge commitment, great leadership and strong co-operation between relevant partners.

Stamicarbon proves resilient amidst pandemic

When the Covid-19 pandemic started to spread around the world, Stamicarbon, the innovation and license company of Maire Tecnimont Group, was confronted with a new situation and swiftly reacted in synergy with the whole Group's network.

In response to the spread of Coronavirus Covid-19, Maire Tecnimont Group immediately committed itself to ensuring that all work activities in offices and sites were carried out in compliance with the maximum health and safety standards, closely following the protocols of the official bodies. The clear priority was to ensure the health and safety of its employees and collaborators and their families, while guaranteeing the continuity of the business in the countries where it operates.

The Group's continuous commitment to foster an already well rooted HSE-driven culture – which in mid-2019 gave birth to the branding of the HSE campaign "Safethink" – enabled all companies of the Group to rapidly adapt to the new situation. Thanks to significant investments in digital transformation technologies as well as in smart-working solutions and training both for executives and employees during the last four years, the Group was able to carry out remotely numerous working activities and to virtualise several processes, ensuring business operations and activities to keep running. Given the context of global health emergency, in which correct information is essential to face an ever changing situation and manage the risk effectively, Maire Tecnimont set up an HSE Crisis Coordination Team to coordinate actions in all Group locations, to issue guidelines for behaviour to be adopted by all employees. The spin-off of the Safethink brand, "Safethinkcovid-19" was rapidly conceived to cover all aspects of the pandemic emergency and the correct measures to be taken to conduct daily activities both in the home office and at sites were promptly implemented.

Business continuity

Stamicarbon rapidly adapted by increasing the use of videoconferencing and other cloud-supported software. The digitalisation exceeded meetings with clients, supporting webinars, remote equipment inspections, classroom training of client's plant operating personnel (launching their plant operator training simulator in the cloud) and even remote commissioning

Fig. 1: **Kima plant, Egypt**

Fig. 2: **The new Acron granulation plant**

PHOTOS: STAMICARBON

Fig. 3: **Stripper and pool reactor for Hubei Sanning, China**

PHOTOS: STAMICARBON

Fig. 4: **The Ultra-Low Energy pool reactor for transport to China**

and start-up support. The resilience demonstrated, stimulated all colleagues to continue looking for other solutions and ways to show Stamicarbon's continued commitment to clients. A proactive approach in each ongoing project and the ability to manage all steps of the crisis, fostering tailor-made solutions according to the latest advice, enabled all operators to handle a challenging situation while educating all involved.

Start-ups/training

One of Stamicarbon's first start-up projects that had to tackle the impact of the coronavirus was the performance test for the Kima ammonia-urea complex (Fig. 1) in Egypt. This was a joint project involving Stamicarbon as urea technology licensor and its sister company Tecnimont as EPC contractor.

The project teams were challenged to finalise the test run in the wake of increasingly difficult implications of Covid-19 in its early days in Egypt and Europe. Stamicarbon employees provided valuable guidance to Kima staff, helping them to run the plant smoothly and meet guarantee figures. They returned home just before the area went into lockdown and continued to provide remote assistance via digital communication tools. Meanwhile the Tecnimont team stayed on site and implemented new safety practices to protect the health of personnel. They helped each other 24/7 and worked as one team to successfully meet the challenge.

The second challenge was the commissioning of JSC Acron's urea granulation plant in the Russian Federation (Fig.2). Acron had to start up its new Stamicarbon granulator without any assistance of Stamicarbon representatives on site. Operators who normally operated prilling towers had to be ready to operate a granulation plant. It was the first time for remote operator training in which the client's video conferencing system had to be connected to the Stamicarbon system to give start-up instructions via the screen. The client discussions and training were carried out successfully despite the distance between all involved.

New build projects were not the only activities affected by the travel restrictions. A major urea revamping project in the United States also had to be realised without the on-site presence of Stamicarbon specialists. The old urea CO_2 stripping plant, was being revamped to increase capacity, reduce ammonia emissions, lower energy consumption and improve plant safety by using Stamicarbon's medium pressure add-on technology and the installation of a high pressure after-reactor. Stamicarbon was able to give remote start-up services. In the final stage, four engineers were on-hand to provide support, 16 hours a day, working in pairs across two shifts. By sharing a live video connection to the client's DCS system, Stamicarbon engineers received live images from the plant and were able to respond with advice, discuss settings with operators and other technical staff and immediately see the consequences of modifications of certain process parameters. The revamp was realised successfully.

Equipment deliveries

Proprietary equipment supply forms an integral part of Stamicarbon's business. High quality vessels, piping and other products complement and support their plant designs. This equipment is manufactured by different supplier workshops, inspected by Stamicarbon engineers and shipped and delivered to the construction sites.

As Stamicarbon has a well filled order backlog of proprietary equipment, it also has a busy schedule of equipment deliveries, which under Covid-19 circumstances and restrictions posed new challenges.

From mid-May until August, Stamicarbon had to deliver, on average, one major piece of equipment per week. The orders consisted of ten high pressure vessels (four pool reactors, three strippers, one reactor, two HP-scrubbers), plus a granulator and an MMV scrubber for clients in China, Egypt, the Russian Federation and the United States. Most items were for grass root projects (Figs 3 and 4), while two were replacements.

In addition to remote inspections, Stamicarbon arranged resident inspection engineers for several months for a few projects facing potential delays. The teams ensured the utmost commitment and highest performance to execute design and welding inspections in order to minimise delays and maximise production time.

Meanwhile arrangements had to be made to transport equipment. Many air and sea ports were closed or restricted and containers were held outside closed ports, making it extremely difficult to arrange sea and air cargo. Without an incredible team effort from all parties, it would not have been possible to maintain the fabrication sequence, solve technical issues and stay on schedule to deliver the equipment on time to the construction sites.

Events

As a consequence of the coronavirus virtually all industry events entailing physical presence were put on hold, including the well-known Stamicarbon Symposium, which is held every four years and was originally set for May 2020, but had to be postponed. In order to inform producers, contractors and suppliers about new developments and technologies, Stamicarbon started hosting a series of free webinars featuring some of the topics that were planned for the symposium. Engineers delivered live presentations on proper piping inspections, fighting corrosion by using Safurex, nitric acid technology, the Ultra-Low Energy design concept, revamping and scrubbing solutions. All webinars were well attended and highly appreciated by participants.

Pandemic long term effects

The Covid-19 pandemic has shaken up the whole world and has put everything in a new spectrum. It has changed our way of thinking and working. While face-to-face discussions with clients stay preferred in some cases, Stamicarbon has learned that there are more possibilities and opportunities to serve clients remotely than previously imagined. Covid-19 has certainly shifted the boundaries on what's possible. Without its strong partnerships with suppliers and the teamwork, commitment, perseverance, resilience and sense of ownership of its employees, Stamicarbon would not have been able to continue business in such a successful way in 2020. One thing is certain: the emerging "new normal" will be more flexible and innovative than ever before.

Casale commissioning and start-up of a new nitric acid plant

JSC Navoiyazot, commissioned in 1964, is the largest chemical company in Uzbekistan and a leading producer of mineral fertilizers and other products. The chemical complex is currently undergoing a major modernisation programme to meet modern energy efficiency requirements. As part of this modernisation, JSC Navoiyazot awarded Casale, as EPCC contractor, the project for a new nitric acid plant (Fig. 5), with a nominal capacity of 1,500 t/d 60 wt-% HNO_3, to replace the 50 year-old outdated production capacities. The project was managed and executed by Casale as a single point of responsibility from conceptual phase to EPCC lump sum turnkey phase.

The new nitric acid plant project was in the final stages of the installation and commissioning works when the Covid-19 pandemic made its impact in the first half of 2020. The water treatment section had not yet been completed and some key equipment such as the turbo-set were under mechanical completion, for instance the shaft alignment had not yet been completed.

Casale top management, the project director and the entire site team reacted promptly to rapidly assess the company capability and flexibility with respect to these challenges. Faced with strict travel restrictions, Casale and Navoiyazot were forced to think creatively and rapidly devise a new approach to accomplish the last phases of the project. A reduced Casale staff on site granted the minimum necessary operability, while Casale head office provided assistance and support remotely together with the manufacturers of key equipment. The strong commitment to proceed on site, was testament to the professionalism of the people involved, notwithstanding the personal issues that those involved had being absent from home during this time.

The global travel restrictions, in conjunction with internal HSE policies, forced key vendors to take the decision to rapidly demobilise their personnel from the site. Getting new specialists to the site, from Casale or from other key vendors, also became extremely difficult. As a result, the headcount of the Casale site team was badly impacted, putting the entire project schedule at risk. The situation also made it impossible to have the direct supervision of vendor specialists during the critical commissioning activities of key equipment. It is typically a contractual right of the vendors to witness the critical phases of installation and commissioning as conditions of the warranty. And, of course, there was the new and increased risk of starting such a complex plant with a reduced number of key personnel.

A dedicated technical risk assessment of the new scenario was carried out at Casale head office, taking into account the increased risks in starting the plant in this situation, including the risk of damage to equipment when starting the plant without direct supervision, as well as the HSE safety concerns in conducting the commissioning of the plant with a reduced

Fig. 5: **JSC Navoiyazot nitric acid plant**

PHOTO: CASALE

site team. Logistic solutions were identified to move materials and private jets were organised to enable key people to reach the site from Europe.

Key vendors placed trust in Casale's abilities and offered remote support for the completion of the critical activities which were still pending at site, and which normally require a mandatory presence of a vendor's specialist to assure correct installation.

Finally, after careful review of the situation, Casale top management gave the green light to complete the project with a world first approach based on remote assistance in commissioning the plant.

Solutions adopted by Casale to face the pandemic challenge included the following:

- remote support provided by MAN for completion of the cold and hot commissioning of the turbo-set;
- installation of the catalysts with remote assistance from the vendor;
- the DCS was connected to the head office for remote assistance by Yokogawa;
- several commissioning issues were encountered on the boiler, as usually happens in this phase when the equipment is loaded up for the first time, and were successfully solved with remote support from the vendor;
- a flexible approach to commissioning was adopted for the water treatment - in particular, a temporary solution was adopted to by-pass part of the system and achieve the requested demi-water production required for the commissioning of process unit and plant start-up;
- as anticipated, Navoiyazot provided several experts and specialists to support and reinforce the Casale site team. This experience increased the already high level of partnership between the two companies and allowed the customer to get familiar with the plant;

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Fig. 6: **Remote assisted commissioning of reactor catalyst**

Catalyst was installed using the Casale Dense Loading procedure.

Source: Casale

- Casale made the decision to invest some resources to transport key personnel to the site by private jet.

Commissioning of the turbomachinery

At the heart of the nitric acid plant is the turbomachinery equipment, supplied by MAN Energy Solutions, consisting of two compressors, one turbine, one expander and auxiliary equipment. The equipment was manufactured, assembled and packaged in Germany and delivered to site. At the beginning of 2020 the delivered equipment was mechanically complete and the “cold commissioning” had started.

In March 2020, due to Covid-19 and the lockdown, MAN experts left Uzbekistan and continued the cold commissioning remotely, from its offices in Germany, Casale offices in Switzerland, and with the support of the local Uzbek team.

MAN had trust in Casale’s capabilities and in the technical skills of Navoiyazot to give the green light to go ahead without direct supervision with the machines under warranty.

The daily activities on site were completely reorganised for better communication with the head offices, in particular:

- A daily conference call with participation of MAN and Casale head offices was set at a convenient time for Uzbekistan and Europe, to assist the site team with the required input information, to strictly monitor the status of completed activities and expedite the solution of issues and outstanding works.
- A dedicated WhatsApp group was created, to share instructions and information available on site.
- A mobile phone was dedicated to communication with MAN via its Primeserve Eyetech registered software.
- A Casale senior rotating equipment engineer was assigned full time to follow this activity.
- Two MAN commissioning supervisors were involved on a daily basis, ten hours per day, six days per week, one focused on the instrumental and control side and the other focused on the mechanical side.
- A Casale expert in the installation of turbomachinery and an expert of Siemens S7 PLC (MAN architecture), were specifically hired on a contract basis for this task, and urgently sent to site by private jet.
- Thanks to the MAN ES equipment being designed for digital, by using the installed hardware and software it was possible to remotely connect to the control system of the turbomachinery equipment from Europe via an internet connection and directly access the local programmable logic controller (PLC) and human-machine interface (HMI) for data analysis and tuning of control parameters.

The first task completed via remote support was the shaft alignment of this complex train that was finalised on 3 April 2020. During this month the instrumental loop checks were performed as well as the commissioning of the auxiliaries and of the process valves in MAN‘s scope (sealing system, condensing system etc).

Having successfully completed the cold commissioning and with the lockdown and travel restrictions still in place, Casale and MAN decided to continue remotely with the “hot commissioning” .

After the successful mechanical running test of the train, the surge test of the air compressor was performed. This was an especially critical test because the air compressor is an axial machine and is very sensitive to surge. On the day of the test key personnel on site were assigned to different tasks such as the monitoring of machine noise, machine vibration, or the control of integrity and noise in the suction filter. Personnel in charge of carrying out testing and tripping of the machine in case of issues, as well as MAN specialists, were online from Germany and connected to the graphic pages and via phone.

After the surge test, several other commissioning activities were carried out and on 16 May MAN gave the green light to start the entire train for plant operation.

During the initial plant operation intense troubleshooting was carried out to solve the kind of problems that normally occur in this phase. The troubleshooting process was particularly efficient thanks to the prompt attention of MAN’s head engineering department, which was basically on-line and connected in real time to the plant, able to direct support and knowhow by remote assistance.

During the cold and hot commissioning phases, besides applying their skills and experience, the customer was also fully immersed in on-the-job training, starting to operate the equipment after a few days of operation.

Platinum gauzes and installation of catalysts

The installation of the platinum catalyst gauzes, worth millions of euros, is critical for the performance of the plant, for the emission guarantee and for the relative guarantee of the catalyst performance itself.

Due to the pandemic, the original conditions of the contract were modified, according to the new work environment but maintaining the original performance guarantee.

The Casale field department provided remote training to the Casale site worker to clarify all steps of the installation for the platinum gauzes and the secondary catalyst. All of the activities were managed by Casale headquarters with the vendor Krastvetmet providing remote support during all installation phases. The installation of catalyst for the abatement system is also a critical and essential activity to guarantee the performance of the catalyst and to satisfy the atmospheric emission guarantee. Casale field workers on site managed all of the activities with headquarters providing remote support during all installation phases. Installation was performed following the Casale Dense Loading procedure and since the catalytic reactor is a proprietary Casale item, the catalyst vendor was not involved in the remote loading (Fig. 6).

Water treatment plant

The water treatment plant, supplied by Unidro Company, is composed of several items of equipment and sub-systems (like multi-media filters, reverse osmosis, EDI, lamella clarifier, centrifuge, resin tower, evaporator, chemical dosing systems etc.), some of which are supplied by Unidro's sub-vendors.

The equipment and sub-systems were manufactured, assembled and packaged mainly in Italy and then delivered to site.

A flexible approach to commissioning was adopted for the water treatment, in particular a temporary solution (with the use of desalted water from the client instead of raw water) was implemented to by-pass part of the system and achieve the requested demi-water production required for commissioning of the process unit and plant start-up.

By using this approach it was possible to bypass part of the system devoted to the demi water production during commissioning (filtration through multi-media filters, reverse osmosis for cooling water production, chemical dosing systems) and temporarily produce demi water with the support of only one commissioning supervisor, during border closure, at a time when other Unidro commissioning staff experts were unable to reach Uzbekistan. This approach also overcame the problem of pandemic-related delays to the delivery of some chemicals for demi water production, as chemicals were not necessary during operation with the temporary configuration of the unit. With Uzbekistan in lockdown, the earliest Unidro experts from Italy were able to reach Uzbekistan was early June 2020.

A limited group of Unidro experts dedicated to commissioning (a commissioning manager, an automation specialist, an instrument specialist and a mechanical specialist) reached Uzbekistan by private jet organised by Casale. Therefore part of the commissioning and start-up activities were remotely assisted from Unidro offices in Italy and from Casale head office in Switzerland, together with the local team in Uzbekistan, as follows:

- Two conference calls per week with participation of Unidro and Casale head office experts was implemented at a convenient time for Uzbekistan and Europe, to assist the site team with the required input information, and to strictly monitor the status of completed activities and expedite the solution for the issues and open points. Daily assistance was also assured from Casale head offices in Switzerland.
- A Casale packages section manager, utilities and off site manager and a senior process engineer E&P followed this activity from the Casale head office in Switzerland.
- A Unidro process specialist was remotely involved on a daily basis from the Italian office and then spent 15 days only on site for the most critical phase of the zero liquid discharge section commissioning.
- All sub-systems, in particular machinery, such as the centrifuge, were commissioned by Casale and Unidro commissioning specialists, by assuring the correct level of technical expertise without the support of Unidro sub-vendors specialists.

The first task which was completed in this way was the cooling and demi water production from raw water that was completed on July 30, 2020.

Successful start-up

Nitric acid production started successfully at the end of May 2020. This was a milestone for a new way of digital supported commissioning.

For the first time, tens of engineers assisted people remotely at site, coordinated the activities and the manpower in perfect symbiosis and were able to smoothly start a nitric acid plant.

This success story is a lesson for the future, and demonstrates that a remote assistance methodology during plant commissioning is not only a possibility, but also brings some great benefits: optimisation of costs, and the availability of the right competences and knowhow anytime.

KBR quality control, remote inspection & commissioning

During the coronavirus Covid-19 pandemic KBR has overcome unprecedented challenges to meet client commitments on delivery of equipment. The vital activity for manufacturing is quality control and Inspection. While quality control is a lead indicator where KBR has been a pioneer in laying out systems and procedures to surpass global standards in manufacture, inspection being a lag indicator is an essential check and balance for sound product quality. The inspection stages during manufacture and the inspection reports contribute to client satisfaction and confidence on the product delivered.

In the pandemic situation when global travel is limited, including inland travel, remote inspection, which was already in vogue, on an as needed basis, has become critical to success. KBR has swiftly adapted to the situation and implemented remote inspection with the support of manufacturing partners. Remote inspection is an alternative to an onsite physical inspection in which the person performs inspection activities remotely using sophisticated technological tools.

Benefits of remote inspection

- Efficient – flexibility
- Access global expertise without constraints of travel
- Enables concurrent decision making
- Data can be captured and recorded for future reference.
- IP Protection
- Elimination of personnel risk exposure to hazardous conditions and dangerous tasks in harsh environments
- Sustainability
  - Business continuity in pandemic type situations
  - Removes geographical boundaries
  - Better customer experience
  - Saves money, time and travel
  - Reduces organisational carbon footprints
  - Identifies and mitigate risks in real time

What is quality? Quality means doing it right when no one is looking (…by Henry Ford). This is the most apt meaning under the current pandemic situation.

Why inspection? Inspection is like a medical check-up before term insurance, it meets contractual requirements and local regulations requirements.

Remote inspection, although not a new concept, has recently been getting more attention due to the Covid-19 pandemic and can also be the future of digital offerings.

The following digital tools were successfully deployed for carrying out inspection and commissioning functions remotely by KBR (see also Table 1):

- Google Glass/Epson Smart Glass;
- MS Teams/Star Leaf/Skype Business;
- tablets/mobiles/cameras;
- KBR's Insite offerings.

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

Table 1: **Digital media adopted for remote inspection and commissioning**

Area of inspection	Digital media adopted
Workshop audits	smart digital glasses
Pre-inspection meetings	VC tools
Stage inspection	digital snapshots/smart glasses/ VC tools
Final inspection	smart glasses/digital snapshots & recordings/VC tools
Commissioning and start-up services	KBR's Insite offerings digital snapshots/smart glasses/VC tools

During the pandemic KBR has inspected and supplied many items of proprietary equipment (PEQ) to clients across globe. All inspections and commissioning operations were monitored remotely using high end digital tools. One grassroots ammonia plant, an FCC revamp and commissioning support for an ethylene cracking plant were all carried out remotely by KBR (Fig. 7). There are a number of prerequisites for successful remote services (monitoring/ inspection/commissioning).

Supply chain partners should have:

- Digital tools such as:
  - Google glass, VC Tools (MS Teams, Skype Business etc.)
- Advanced NDT gadgets
- Laser scanners
- Good internet connectivity

KBR and client should have:

- Technical and product knowledge
  - understand the potential of cutting-edge ideas and apply it pragmatically
  - technical expertise to create long-lasting value through collaboration
- Cloud based database to capture all real time data
  - for reference in trouble shooting, maintenance and repair
  - to support standardisation

Over the last nine months, equipped with all the requisite digitisation tools and with client acceptance of the remote offering procedures in place, KBR has been able to offer the following services:

- technical assessments;
- pre-inspection meetings;
- shop survey and audits;
- in-process surveillance, notified witness or hold points, and final inspection;
- site commissioning and start-up services.

KBR is now getting actively engaged with all of its stake holders to upgrade their systems and procedures with:

- Advanced NDE examinations/techniques.
  - Digital radiography of PEQ offerings
  - TOFD / PA ultrasonic examinations This will enable the client/KBR to access all NDE records of a vessel from their desks.
- Laser metrology instruments for dimensional inspections – This will enable all dimensional inspections to be viewed through reverse engineered drawings.
- Drone-assisted inspection services.

With the successful implementation of these digitisation tools KBR aspires to a fusion of remote offerings with artificial intelligence (AI) for a future of safe and sustainable operations.

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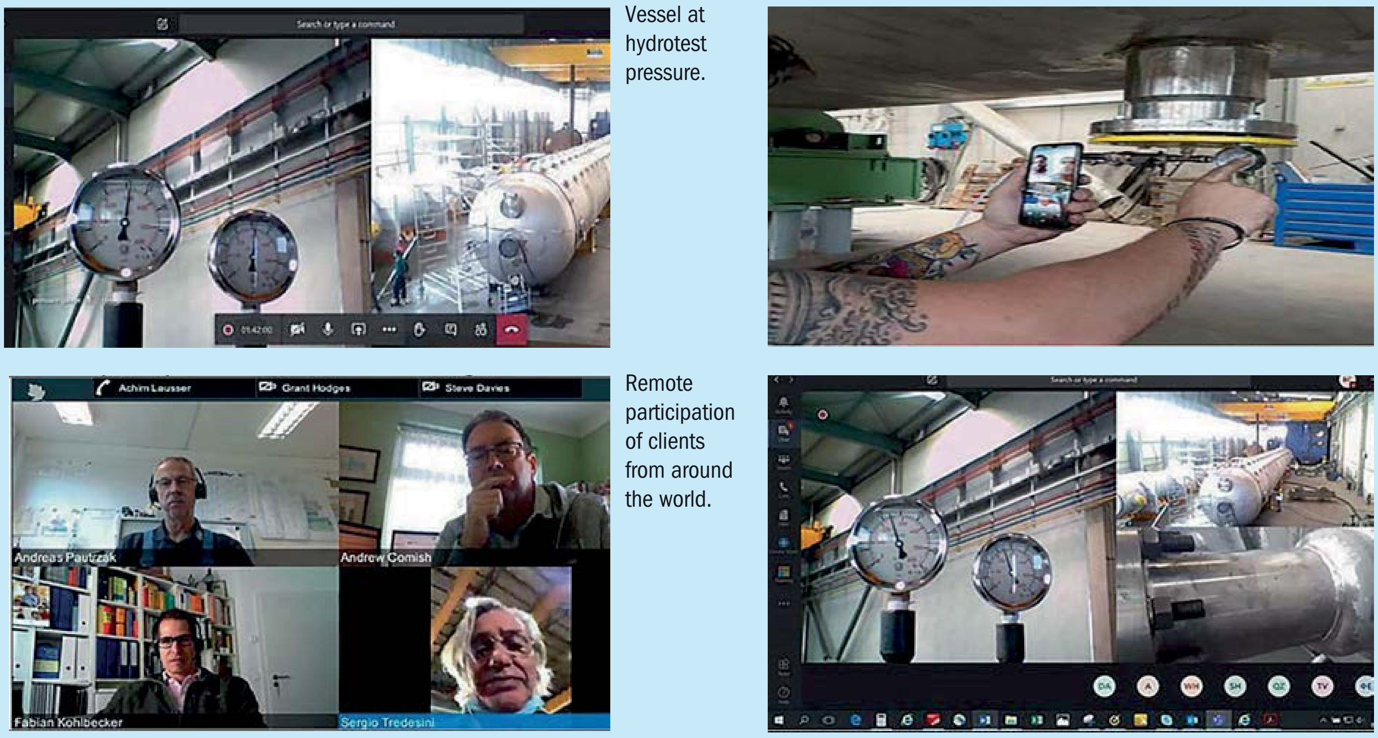
Fig. 7: **KBR global inspection and supply operations**



Vessel at hydrotest pressure.

Nitrogen pressure check of equipment.

Remote participation of clients from around the world.

Examination of vessel at test pressure.

Source: KBR

Reducing CO_2 emissions with AdWinMethanol CC®

PHOTO: THYSSENKRUPP

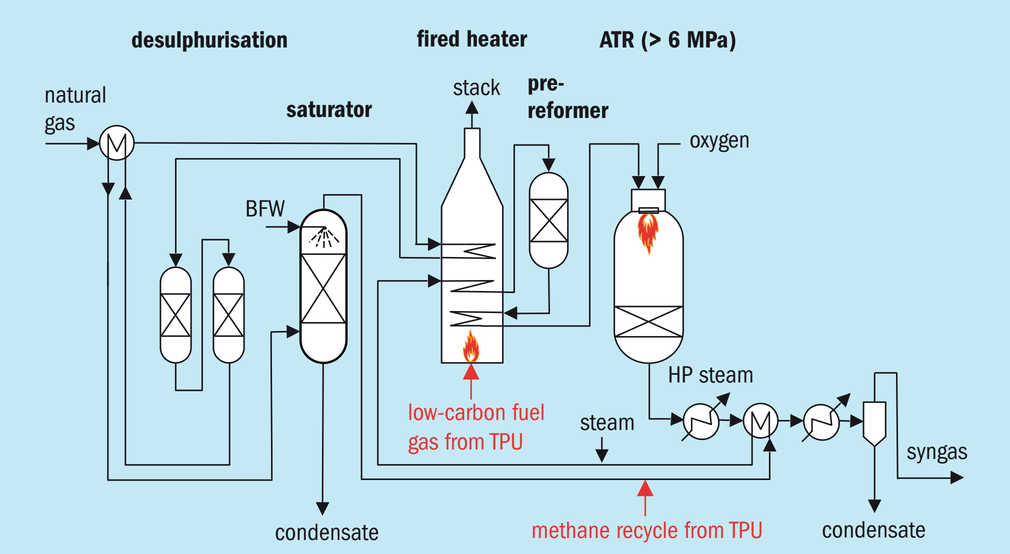
In a carbon-constrained world, carbon capture and utilisation or storage (CCUS) installed on a methanol plant is a necessary and feasible solution. The new, patented AdWinMethanol CC® technology, jointly developed by thyssenkrupp Industrial Solutions AG and GasConTec GmbH, integrates carbon capture into large-scale, natural gas-fuelled methanol production to yield a drastically reduced carbon footprint. **U. Koss** and **W. Balthasar** of **GasConTec** and **J. Wagner** of thyssenkrupp Industrial Solutions discuss how it removes CO_2 emissions in an efficient, cost effective, and environmentally friendly manner, taking advantage of the design features of AdWinMethanol®.

Global demand for methanol is growing continuously, with market volume and production capacities predicted to rise by around 4.3% p.a. over the next ten years[1]. Without mitigation measures in place, this will inevitably lead to a corresponding growth in associated CO_2 emissions. The CO_2 emitted by the world's methanol plants is already significant. In 2018 methanol production contributed 24% (211 million tonnes out of 875 million tonnes[2]) of the total CO_2 emissions from the production of primary chemicals, a contribution that is trending upwards. The reduction of emissions from methanol plants will be of paramount importance on any road-map towards a carbon-neutral chemical and petrochemical sector which currently accounts for approximately 20% of total industrial CO_2 emissions[2,3]. In view of the lively activity of the respective regulatory authorities, methanol producers can expect the imposition of emissions regulation which will, on one side, penalise high CO_2 emissions and on the other side, yield a competitive edge for plants with a small carbon footprint. This will drive the need for new and innovative technologies that can deliver affordable methanol with a low or zero CO_2 emissions footprint.

To achieve this goal, there are several technological pathways[4]: "Green" methanol can be produced from "green" hydrogen, produced from renewable power, and CO_2 from biogenic sources or direct air capture (DAC) by means of power-to-methanol (PtM) technology. Sourcing the CO_2 from industrial processes will lower production cost, but the product will be qualified as conventional "grey" methanol instead of "green". Where it finds public and political acceptance and (post-Fukushima) costs are not prohibitive, the electricity could also be generated by a nuclear power plant, whereby "pink" methanol is obtained as a product. Although PtM technology is improving and prices are falling, the electricity-based production routes remain expensive. Methane pyrolysis, another future technology option, can separate natural gas into solid carbon black and hydrogen, whereby the latter can then be used to produce "turquoise" methanol. "Green" methanol can also be produced from biomass. However, availability of biomass resources is finite, and its green credentials can be undermined where its production conflicts with food supply and where associated indirect land use change (ILUC) leads to increased greenhouse gas emissions.

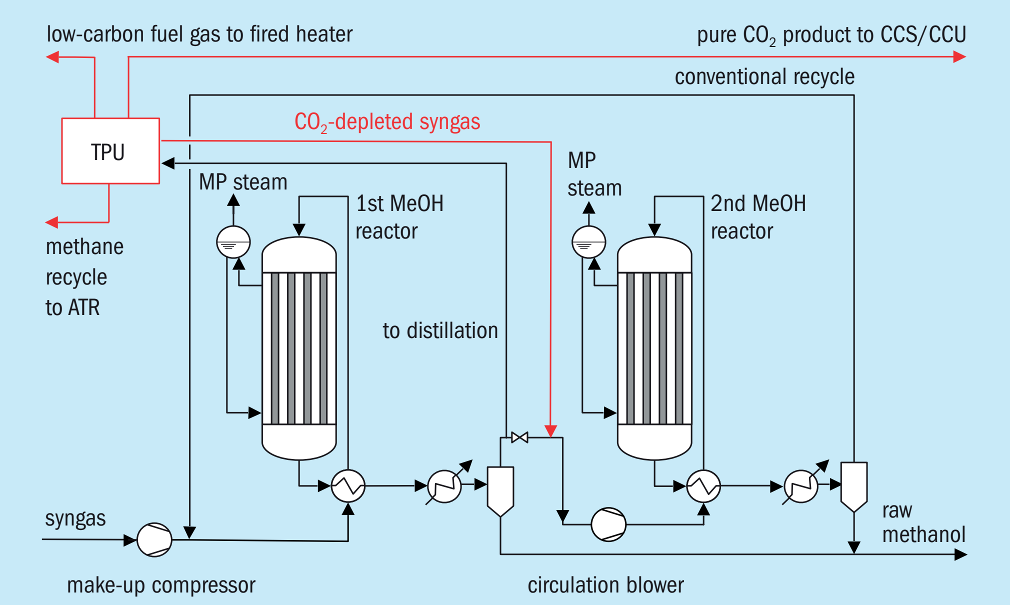
All of the above implies a quite substantial technological change, so the conversion of today's fleet of methanol plants to a quantitatively decarbonised production fleet will take decades before taking effect. An alternative and immediately effective decarbonisation strategy consists in fitting conventional "grey" methanol production, using syngas generated from fossil-based feedstocks, with carbon capture and utilisation or storage (CCUS) to produce "blue" methanol. This article introduces the new and patented AdWinMethanol CC® process which enables the production of blue methanol from natural gas and has been developed to meet these challenges.

Fig. 1: **Syngas generation of AdWinMethanol® and AdWinMethanol CC®**



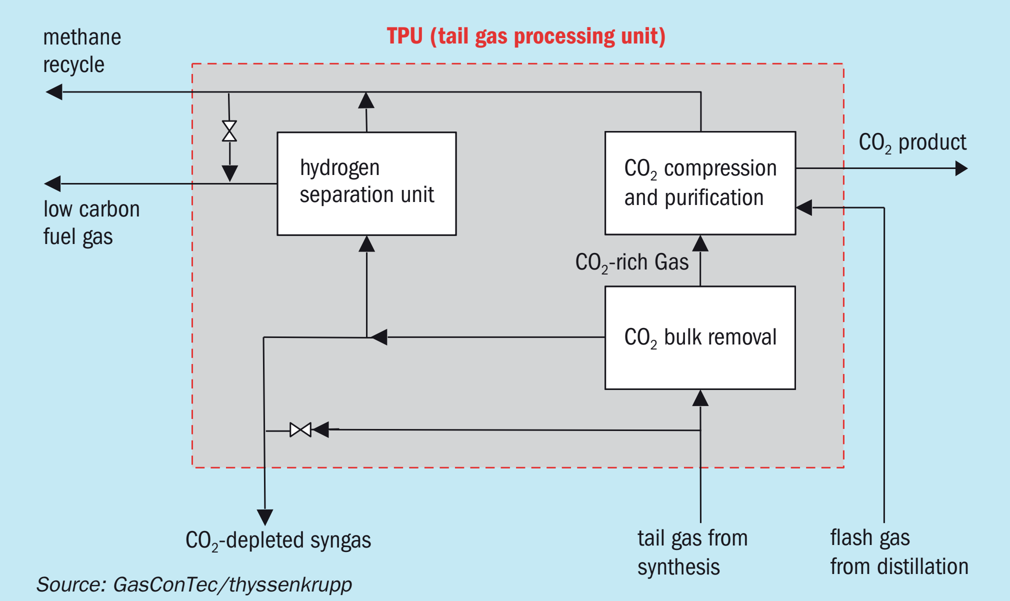
Source: GasConTec/thyssenkrupp

Fig. 2: **Methanol synthesis of AdWinMethanol CC®**



Source: GasConTec/thyssenkrupp

Fig. 3: **AdWinMethanol CC® tail gas processing unit**



Source: GasConTec/thyssenkrupp

A revival of CCUS

The production of methanol from fossil-based feedstocks is a mature technology benefiting from several decades of development. As such the potential for any significant reductions in CO_2 emissions through improved production efficiency is limited. Only by adding CCUS can a substantial reduction of CO_2 emissions be achieved. Luckily, large-scale methanol plants represent easily accessible and large point sources of CO_2 emissions, such that implementation of CCUS can be very cost effective.

Despite significant efforts during the first decade of the millennium, aimed primarily at the power generation sector, deployment of CCUS has remained sparce and sporadic. Nevertheless many technologies and solutions have been developed for each part of the CCUS process chain, from capture through transport to storage (or utilisation). With growing public pressure, attention is turning to decarbonisation of other sectors including industry. This has led to renewed interest in CCUS where in many cases, it is the only viable method for carbon emissions abatement at large scale. Recently the EIA reported that 30 large-scale integrated CCUS projects have been announced world-wide since 2017[3].

The storage of CO_2 in underground formations commenced in the early 1970s in the US where naturally occurring CO_2 was transported by pipeline for enhanced oil recovery (EOR) in the Gulf region and the Permian Basin. Today there are many noteworthy CCUS projects in operation, including the Petra Nova power plant in Texas, US[5] and the Boundary Dam power plant in Saskatchewan, Canada[6]. Norway's Sleipner West platform, which stores 900,000 t/a of CO_2 in a saline aquifer formation below the co-located gas-bearing formation, has been in operation since 1996[7]. The Great Plains Synfuels plant in North Dakota, US, was equipped with carbon capture in 2000, and has delivered CO_2 to the Weyburn oil field in Canada for more than two decades[8].

Developments in large scale CO_2 transportation systems from sources to sinks are also developing rapidly. In North America extensive infrastructure already exists based on the enhanced oil recovery (EOR) business, including the Denbury pipelines and the Cortez pipeline in the US[9] and the Alberta Trunk line in Canada. In the US alone over 7,600 km of pipeline infrastructure has been installed (2015) with more being planned. Significant CO_2 transport and storage infrastructure is also being planned in Europe, including for example the Port-of-Rotterdam PORTHOS project in The Netherlands[10,11] and the Humber CCUS trunkline project in Yorkshire, England[12], amongst others.

The objective

GasConTec and thyssenkrupp Industrial Solutions set out to jointly identify the optimum strategy and find the optimum solution for adding carbon capture to the AdWinMethanol® technology. AdWinMethanol®, like all members of the AdWin™ process family, includes a syngas generation island, the core of which is an oxygen-driven, high pressure catalytic partial oxidation reactor called "cPOX" or "ATR" (autothermal reformer). Fig. 1, shows the AdWin™ syngas generation process modified with the quite subtle changes required for carbon capture highlighted in red. The syngas produced is then converted into crude methanol in two sequential isothermal reactor stages, which is processed to product quality using a standard three column distillation system. AdWinMethanol® enables methanol production with considerable economic advantages, in particular at large capacities from 3,000 t/d up to 10,000 t/d, which can be single-train.

The key objectives for the new development were:

- capture 90% of the CO_2 emitted from the methanol plant;
- minimise the penalty on plant efficiency;
- minimise the environmental impact;
- minimise the additional capex required;
- minimise the new technology risk (be innovative, but avoid unproven unit operations).

Three basic strategies to select from

The first, and perhaps most instinctive strategy to decarbonise methanol production, is to install a post combustion carbon capture ("PCC") system in the flue gas path of the plant. Available PCC technologies include flue gas wash systems using solutions of MEA, advanced amines or cooled ammonia solution. Experience from various demonstration plants and in particular from the newer large-scale installations at Boundary Dam and Petra Nova has revealed the weaknesses of the PCC approach. In particular the use of MEA and advanced amines, when applied to pressure-less flue gases, has proven to be more challenging and less compelling than initially thought. The principal challenges include the following:

- Oxygen and oxidised components in the flue gas cause drastically increased amine degradation, which is at least one order of magnitude greater than that encountered with amine units used more conventionally in natural gas clean-up or refinery applications[6,13].
- Amine degradation products circulating in solution lead to the emission of critical volatile trace contaminants such as ammonia, piperazine, formaldehyde, nitrous amines and particularly undesired aerosol mists[14,15]. To resolve these issues a sophisticated flue gas post-treatment system (water wash, acid wash) is required which inevitably adds complexity and cost. Any residual components that pass through the post-treatment system, will be emitted atmosphere. Moreover, degradation speeds up corrosion which in turn accelerates amine degradation[13].
- Operation of the amine plant has an impact on the overall efficiency of production. Modern amine plant designs result in a regeneration energy demand of 2.5-3.0 GJth/t CO_2[16,17]. This translates to an estimated LP steam consumption of 125-150 t/h of LP for a plant cycling 1,800-2,000 m^3/h of amine solution to capture 2,500 t/d of CO_2 from the flue gas of a 5,000 t/d methanol plant.
- Amine and amine plant effluent handling facilities increase the chemical and environmental footprint of the plant[18].
- Amine make-up, contaminant removal, wastewater treatment and CO_2 compression all add significantly to the operating cost[19].

In summary, adding a PCC system is technically possible, but has many drawbacks, in particular when looking at the environmental problems and risks associated with capturing CO_2 from flue gases using amines and venting of the scrubbed gas to atmosphere. On this basis PCC was rejected as a strategy for integrating carbon capture to the AdWinMethanol® process.

A second alternative strategy is to install oxy-combustion technology on all of the plant furnaces. Oxy-combustion produces a flue gas rich in CO_2 by combusting the carbon-containing fuels in a mixture of oxygen, from an air separation unit (ASU), and recycled CO_2[20]. The idea seems compelling, as in modern methanol technology an ASU is readily available producing oxygen to feed the ATR. However, in order to keep combustion temperatures under control, as much as 80% of the CO_2 captured has to be recycled and mixed with the oxygen to yield a moderated combustion atmosphere. As a result five times more CO_2 is in circulation through the process than ultimately will be sent to battery limits impacting capex and opex. Moreover, the CO_2-rich stream contains excess oxygen, inert components, and other contaminants which have to be removed by means of a sophisticated oxy-fuel tail-gas treatment unit (TGTU), to meet the required purity specification for the export CO_2 product stream[21]. For these reasons the oxy-combustion option was also discarded.

The third strategy is to deploy CO_2 removal in the pressurised syngas loop combined with 'pre-combustion decarbonisation' for the plant furnaces:

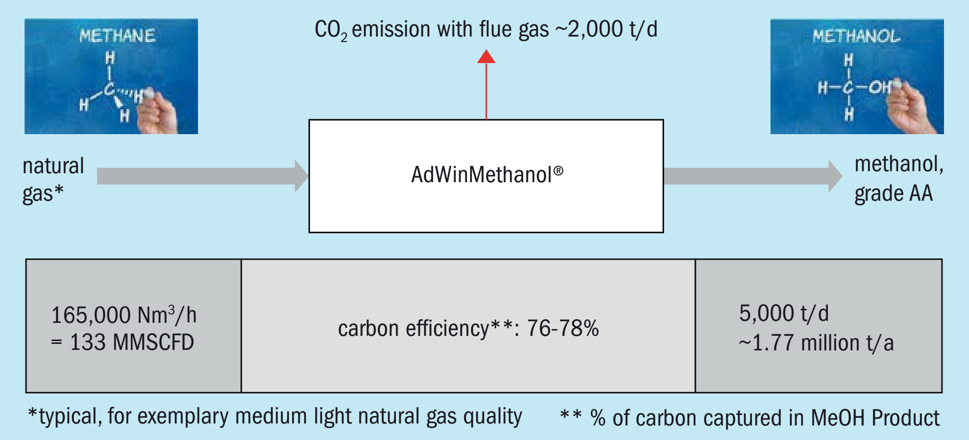
- The pressurised syngas loop of the AdWinMethanol® technology provides an attractive opportunity to remove the bulk of the CO_2 with the least effort. Technology for the removal of CO_2 from syngas is mature and widely available benefiting from more than 100 years of development with hundreds of references in operation at any scale.
- In pre-combustion decarbonisation, carbon-containing compounds are removed from the fuels prior to combustion. In essence, the plant furnaces in the methanol plant are fired with a hydrogen-rich stream, resulting in very low residual carbon emissions in the flue gas.
- The AdWinMethanol® process is ideally suited to the beneficial deployment of these techniques and as such has been selected as the basis for further development of a new and innovative methanol process with integrated carbon capture – AdWinMethanol CC®.

AdWinMethanol CC®

Within the two-staged methanol synthesis loops of AdWinMethanol®, CO_2 is available at a high concentration and a high pressure. For the AdWinMethanol CC® process a tail gas processing unit (TPU) is added which replaces the PSA of the conventional AdWinMethanol® design (see Fig. 2). The TPU has the following functions:

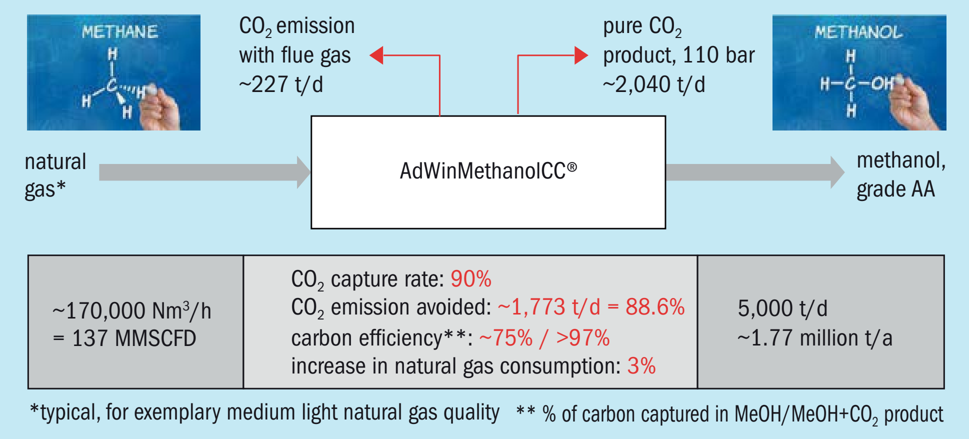
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56

Fig. 4: **Production figures of a 5,000 t/d AdWinMethanol® plant**



Source: GasConTec/thyssenkrupp

Fig. 5: **Production figures of a 5,000 t/d AdWinMethanol CC® plant**



Source: GasConTec/thyssenkrupp

- bulk removal of the CO_2 from the syngas loop, whilst adjusting the stoichiometric ratio in the reactor feed to that required by the synthesis reaction;
- generation of a hydrogen-rich fuel gas for the fired heater;
- generation of a hydrocarbon-rich stream, recycled into the syngas generation feed stream;
- purification and compression of the CO_2 to the required export quality and a pressure above 110 barg.

Fig. 3 shows the main components of the TPU. At the conditions prevailing in the syngas loop, CO_2 can be efficiently absorbed by means of cold methanol, a liquid absorbent which is naturally and readily available on site. In the CO_2 absorber, CO_2 is physically absorbed by methanol and sent to the CO_2 flash tower. Here, simple stepwise de-pressurisation releases the CO_2 at descending pressure levels, simultaneously regenerating the absorbent, before it is cycled back to the absorber. No regeneration steam is needed. With the high CO_2 loadings achieved, a solvent loop of only 850 m³/h is required, which is 50-60% less than that of a comparable post combustion amine plant. The auto-refrigeration effect occurring during flash regeneration cools the methanol to the desired low absorption temperatures. Only a minor portion of the cooling duty has to be supplied by heat exchange against an evaporating refrigerant, which in this case can simply be liquid CO_2 derived from the CO_2 product stream. The resulting CO_2-rich gas stream is sent to the CO_2 compression and purification unit, where co-absorbed gases are separated, traces of methanol removed, and the concentrated CO_2 stream compressed to product pressure. Methanol-based CO_2 capture systems as described here are not novel and have been used many times, for example, as part of Rectisol® flow schemes. Indeed they are a common element of the technology toolbox of the AdWin™ process family.

The high pressure in the synthesis loop leads to compact equipment with sizes significantly smaller than those typical of an atmospheric amine absorber and regenerator loop. A small fraction of the CO_2-depleted syngas coming from the CO_2 bulk removal is sent to a hydrogen separation unit (HSU), where it is split into a hydrogen-rich fraction and a hydrocarbon-rich fraction. The hydrogen-rich fraction is used as a fuel in the fired heater. The hydrocarbon-rich fraction is mixed with the stream of methane recovered from the CO_2 compression and purification unit to form the methane recycle to the syngas island. As the hydrocarbon rich stream is the retentate from the HSU membrane system, it will have a pressure high enough to directly tie in to the synthesis gas generation feed. In the absence of any particularly stringent purity requirements, on both the hydrogen-rich stream and the hydrocarbon-rich stream, the separation can be done by a commercially available membrane system. For example, Air Product's PRISM membrane systems are well-referenced for this kind of application. The hydrogen-rich fuel gas stream is the permeate from the membrane unit, with a low pressure, but still adequate for the burners of the fired heater. The balance of the CO_2-depleted syngas is fed to the second methanol reactor for further methanol production.

Production and consumption figures

Fig. 4 shows the production figures of a 5,000 t/d high efficiency state-of-the-art AdWinMethanol® plant. Fig. 5 shows the same data for an AdWinMethanol CC® plant which has the same methanol production capacity, but delivers in addition a CO_2 product ready for transport and utilisation or storage.

The CO_2 stream sent to the battery limit of the AdWinMethanol CC® plant contains 90% of any carbon that does not end up in the product methanol. At the same time the plant has a slightly increased natural gas consumption, therefore the resulting overall reduction in CO_2 emissions is 88.6%, if directly compared to the plant without carbon capture. All in all, 97.5% of the carbon in the natural gas fed to the plant is either captured in the methanol or in the CO_2 product stream.

The AdWinMethanol CC® plant is equipped with an efficient, optimally integrated Rankine cycle using an off-theshelf steam turbine/generator set and electric, frequency-controlled drives on all rotating machinery, including the ASU, syngas compressor and CO_2 compressor. Consequently, the plant remains largely autonomous regarding electric power requirements meaning that import of electricity neither has to be considered in the energy efficiency nor in the carbon footprint of the plant. Due to the fact that readily available methanol is used as the solvent for carbon removal, no new chemicals have to be imported to operate the plant. Degradation of the methanol solvent does not occur removing the possibility of unwanted contaminants and emissions.

When it comes to comparing literature data on capture economics it is important to make sure that the battery limits are comparable, i.e. it is important to ensure that the capex and opex required to purify the CO_2 and compress it to export conditions are included. AdWinMethanol CC® delivers the CO_2 to battery limits as a pure stream, pressurised to 110 bar and ready for any utilisation or storage designation. This duty comes at a very low increase in natural gas consumption of 3%, compared to AdWinMethanol® which however, already boasts a 2-3% lower natural gas consumption compared to third party technology, such that the production efficiency of AdWinMethanol CC® is well within the ballpark of existing methanol synthesis technology without carbon capture. Because of the high pressure and small effective gas volumes, the TPU equipment arranged into the synthesis loop is compact and simple. The capex for the overall plant will increase with carbon capture, but mainly due to the cost of the CO_2 compression and purification system, which is equally present in any CCUS installation, be it post- or oxy- or pre-combustion.

The resulting cost-of-emission-avoided will range well below \$20/t of CO_2. Ultimately, economics will depend on the future CO_2 emission certificate prices, however the resulting production cost will be highly competitive, once CO_2 emissions come with a cost.

AdWinMethanol CC® also allows for a so-called capture-ready concept. Designing a futureproof plant to mitigate against future carbon emissions standards can be easily achieved by considering the minimum required design adaptions now, allowing for an easy conversion to AdWinMethanol CC® later.

A complement to "green" methanol

"Blue" methanol does not compete against "green" methanol, but rather complements it. "Green" methanol from biomass will be markedly insufficient to satisfy global demand. In the long term, "green" PtM methanol, as available from thyssenkrupp Industrial Solutions AG, is more promising. However, as long as the availability of renewable power limits deployment, CCUS represents the most effective solution to drastically reduce the carbon footprint of methanol production.

Future PtM plants will create a demand for CO_2 opening up the possibility of integrating an AdWinMethanol CC® plant with a PtM plant creating a winning combination, providing a zero-emission methanol production, whilst eliminating the need for CO_2 transport and storage.

For example, the CO_2 captured from a 5,000 t/d AdWinMethanol CC® plant could be used to produce an additional 1,490 t/d of methanol by means of a PtM plant consuming ca. 680 MW_{el} of renewable electricity. ■

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NOx reduction from steam methane reformers

NOx emissions from chemical processes such as steam methane reforming contribute to air pollution. The chemical industry is required to take steps to lower such emissions. Technology, developed for related industries, can be designed and optimised to reduce NOx emissions from steam methane reformers. Emission control experts can use a combination of modelling and experience to guide plant operators in recommending and designing optimum, sometimes tailor-made solutions. In this article different options are discussed including low NOx burners, selective catalytic reduction, selective non-catalytic reduction and high emissivity ceramic coatings.

PHOTO: IGS

Steam methane reformer (left) in an ammonia plant.

Oil refineries, petrochemical and chemical facilities are widely considered as some of the main sources of air contaminants, including sulphur oxides (SOx), nitrogen oxides (NOx), and carbon dioxide (CO_2). These pollutants pose an environmental hazard.

Multiple independent and not-for-profit organisations, including the Oil and Gas Climate Initiative and the Organisation for Economic Cooperation and Development (OECD), provide advice on emissions reduction. A report by OECD states that several countries attained the emission ceilings of the Gothenburg Protocol for 2010, but other countries had difficulties in doing so. Further efforts will be required to meet the new objectives for reducing emissions by 2020 and beyond.

ESG initiatives around emissions reduction

Reducing emissions while ensuring adequate supply of hydrocarbon derivatives is a complex issue for refinery operators and chemical producers. At a company level, Environmental, Social, and Corporate Governance (ESG) initiatives have been put in place to provide practical solutions to these emissions issues, while continuing daily operations. Many industries and economies rely on hydrocarbon derived products. Our everyday products, including medicine, clothing, toothpaste and even solar panels start their lifecycle as unrefined petroleum. Demand for most of these items is not expected to drop with our growing population, while initiatives focusing on production from plant-based materials are still in their infancy.

The problem with NOx

Nitrogen oxides (NOx), is the generic term for a group of highly reactive gases, all of which contain nitrogen and oxygen in varying amounts. Many are colourless and odourless but one common pollutant, nitrogen dioxide (NO_2) is identifiable as a yellowish-brown layer over many urban areas.

Nitrogen oxides form when fuel is combusted or oxidised at high temperatures, such as an internal combustion engine or in industrial processes such as steam methane reforming. The primary sources of NOx are motor vehicles, boilers, furnaces, and other industrial, commercial, and residential sources that combust hydrocarbon fuels.

NOx and sulphur dioxide react with other substances in the air to form acids which fall to earth as rain, fog, snow or dry particles. Acid rain causes deterioration of car finishes, buildings and historical monuments, and causes lakes and streams to become acidic and unsuitable for many species of fish.

NOx reactions can also cause the formation of small particles that penetrate deep into the lungs and can cause or exacerbate respiratory disease such as emphysema and bronchitis, and aggravate existing heart disease.

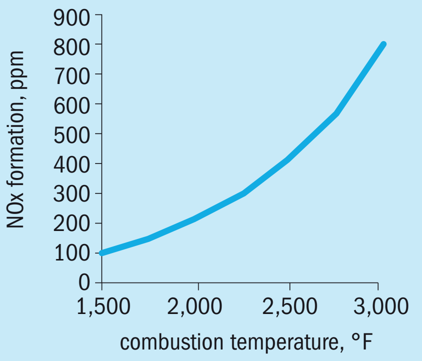
Nitrate particles and nitrogen dioxide can block the transmission of light, reducing visibility. Ozone (O_3) is a gas that occurs in the Earth's upper atmosphere and at ground-level. In the upper atmosphere ozone acts as a protective layer against ultra-violet (UV) radiation. Ground-level ozone, is created by a photo-chemical reaction between nitrogen dioxide and volatile organic compounds (VOCs). Formation of ground-level ozone is dependent on weather and concentrations are typically the highest on hot summer days, with little or no cloud cover and very little wind. Motor vehicle exhausts and industrial emissions are two of the major sources of NOx and VOC emissions that help to form ground-level ozone. Rural areas can also experience increased ozone levels when wind carries ozone hundreds of miles from its original source.

Even at low levels, ground-level ozone triggers a variety of health problems including asthma attacks, reduced lung capacity, and increased susceptibility to respiratory illnesses like pneumonia and bronchitis. Ozone can cause permanent lung damage after long-term exposure and can irritate lung airways and cause inflammation. People with respiratory problems are most vulnerable to elevated ozone levels. Ground-level ozone also damages the leaves of trees and other plants, ruining the appearance of cities, national parks, and recreation areas. Ozone reduces crop and forest yields, and increases plant vulnerability to disease, pests, and harsh weather.

Sources of NOx emissions

NOx emissions are derived from three sources: fuel NOx, thermal NOx and prompt NOx. The predominant sources of NOx emissions from petroleum refineries and petrochemical plants are combustion sources and the predominant NOx emissions, in terms of concentration, are nitric oxide (NO) and nitrogen dioxide.

Fig. 1: Thermal NOx formation



Source: IGS

In high temperature, gas-fired process heaters, including refinery fired heaters, steam methane reformers and steam crackers, the NOx emissions originate mostly from thermal NOx. These are formed when nitrogen and oxygen in the combustion air combine at the high temperatures in a flame and combustion products (see Fig. 1).

Fired heaters are increasingly looked at by ESG committees as both sources of high NOx emissions and potential candidates for a good percentage of NOx reduction, contributing to the total emissions reduction across the facility. Steam methane reformers (SMRs), in particular, are inherently higher NOx producers than conventional fired heaters because of their higher firebox temperatures.

NOx reduction methods and technologies

As per normal practice, NOx reduction methods and technologies are based on the following fundamental assumptions:

- Nitric oxide (NO) is the predominant form of NOx that is formed in the combustion zone and emitted from the combustion device.
- The formation of nitric oxide is very dependent on the concentration of available oxygen and on the reaction temperature.
- Fuel-bound nitrogen is a major contributor of NOx.

Based on these assumptions, NOx reduction control technologies are focused on:

- preventing the formation of NOx during the combustion process, either by reducing the nitrogen content in the fuel, by limiting the access of the reaction to oxygen or by reducing the reaction temperature;
- destroying the NOx after combustion but before the combustion products leave the facility.

The following four cases provide examples of Casale case studies where reducing NOx emissions was one of the main requirements.

Case 1

Casale was awarded an EP base project for an ammonia plant revamp to reduce energy consumption and increase plant production capacity as well as reducing the NOx emission from the steam methane reformer.

The plant data showed a very high NOx emission level at the reformer stack (about 500 mg/Nm^3). The combustion parameters of the burners and the plant data reconciliation results showed that the combustion system had many issues that were affecting the emissions:

- purge gas from the synthesis loop sent to the burners had a high hydrogen and ammonia content;
- the burner flame envelope was not properly shaped meaning that the combustion itself was inefficient;
- excess air to the burner was higher than the design figure;
- the high fuel gas pressure to the burners was limiting the burner operation.

By adopting several solutions, Casale was able to solve all of these issues. The purge gas stream was treated in order to recover the hydrogen and ammonia, both identified as the main cause of the high NOx emission. With this simple modification the emission level was halved and the pressure at the burners decreased to a controllable range. The draft into the radiant chamber was slightly increased to straighten the burner flames and the combustion air was balanced for each burner, improving the distribution and targeting the lower design excess air foreseen.

To further reduce the NOx emission level, an off-gas stream containing ammonia was injected into the reformer radiant chamber flue gas tunnel. The application of selective non-catalytic reduction application requires a deep evaluation of the system in terms of reactants concentration involved, residence time, flue gas temperature variation during operation and, most importantly, mixing distribution (analysed extensively by CFD software).

As a result of these solutions, the NOx target figure of less than 200 mg/Nm³ was achieved.

Case 2

Casale was awarded a feasibility study project for an ammonia plant NOx emission reduction from the steam methane reformer via the flue gas recirculation method.

This technique generally involves forced return of flue gas to the burner and introducing the air/flue gas mixture into the combustion zone so that the NOx emission can be reduced by means of oxygen dilution and peak flame temperature decrease. In this specific case the scheme adopted limited the recirculation to about 10 to 15% of the products of combustion. The low flame temperature and susceptibility to flame instability limits the use of recirculation in high temperature applications.

The results showed that a 20% reduction on the NOx emission level can be achieved, but several inherent drawbacks include a large capital outlay because of the need for high temperature fans and extensive ductwork and piping modifications. In addition, this technique can only be used on balanced draft heaters.

Case 3

Casale was awarded an EP project for a methanol plant capacity increase and NOx emission reduction from the steam methane reformer.

In this case the old burners were at the end of their life so it was decided to replace them with ultra low NOx type burners. After retrofitting a 35 % reduction on NOx emission was achieved.

However, in order to limit pollutant emissions, ultra low NOx burners are forced to operate with an inefficient combustion, staging the fuel into many zones (two or more). In general, these burners are larger in muffle throat size then conventional burners and in some cases may require some modifications to meet the existing reformer design. The resulting flames are different from the conventional burner so the radiant chamber and reformer design have to be carefully checked.

It is therefore essential to deeply evaluate the performances of this type of burner technology. For this reason, Casale foresees an extensive combustion test witnessed by a Casale specialist, along with plant operating personnel. The objective of the test is to evaluate the flame characteristics and emissions throughout the design firing range and establish the upper and lower limits of flame stability.

Case 4

Casale was awarded a basic design project for a new methanol plant where the main critical equipment is the new fired heater.

One of the main challenges of the project is to achieve a very tight emission level due to the very stringent values required by the local authorities.

The new fired heater completely designed by Casale was able to target the following figures:

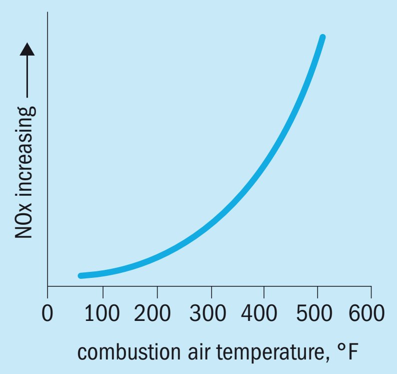
- 1 ppmv of NOx;
- 1 ppmv of NH_3 at the stack.

To achieve the required target, in compliance with current Best Available Technologies (BAT) an extensive study was carried out considering the best compromise between system feasibility, operability and cost. The technical solution adopted was based on an ultra low NOx burner technology in combination with a selective catalytic reduction (SCR) unit. The system was designed to provide the maximum flexibility in term of rangeability and operation, maximising the onstream factor, providing the possibility to solve many maintenance issues with the furnace in operation and at the same time without compromising the safety.

NOx formation in steam methane reformers

For steam methane reformers (SMRs) using gas-based fuels, thermal NOx is the primary contributor to overall NOx production, although levels can be increased further by contribution from any fuel-bound nitrogen such as purge streams that may be used as fuel containing ammonia (NH_3). As combustion temperature increases there is a direct relationship with thermal NOx increase. Preheating the combustion air adds sensible heat to the flame reactants which increases the heat in the products of combustion and, thus, increases the flame temperature. Fig. 2 shows the effect of air preheat temperature on NOx. Note that the NOx essentially follows an exponential increase with increasing air preheat temperature. A rule of thumb is that the thermal NOx emissions will double as the combustion air temperature is increased from ambient to about 260-316°C (127-158°F).

Fig. 2: **NOx vs combustion air temp.**



Source: Johnson Matthey

To mitigate this burner designers can reduce overall NOx emissions by decreasing the peak flame temperature, which can reduce thermal NOx, these 'low NOx burners' typically work by delaying the rate of combustion. This is often achieved by either staged combustion, in which combustion air is added in two stages, or by designing the burner so that there is internal flue gas recirculation whereby the products of combustion are fed back into the combustion zone. Experience has shown that well designed low NOx burners can reduce the NOx levels to <100 ppm in a typical top fired reformer firing natural gas/hydrogen mixtures. Although ~50ppm is much lower than the NOx level from earlier generations of combustion technology it is still higher than that required for many regions where NOx emission levels of 5-10ppm are desired, meaning an SCR catalyst will be necessary, in addition to low NOx burner combustion.

Regulatory drivers for installing catalytic after-treatment

Concerns over air quality and its impacts have encouraged regulatory bodies across the world to impose limits and offer guidance to industry with respect to emissions of pollutants such as NOx. In the US the National Emission Standards for Hazardous Air Pollutants, NESHAPs rules are set to curb the formation of ground level ozone and in the EU the Industrial Emissions Directive (IED) aims to minimise pollution from various industrial sources throughout the EU. Both NESHAPs and the IED use a permitting mechanism to monitor and control. For the IED, for example, operators of industrial installations targeted by the directive – some 50,000 in total – have to obtain a permit from the authorities. The permit

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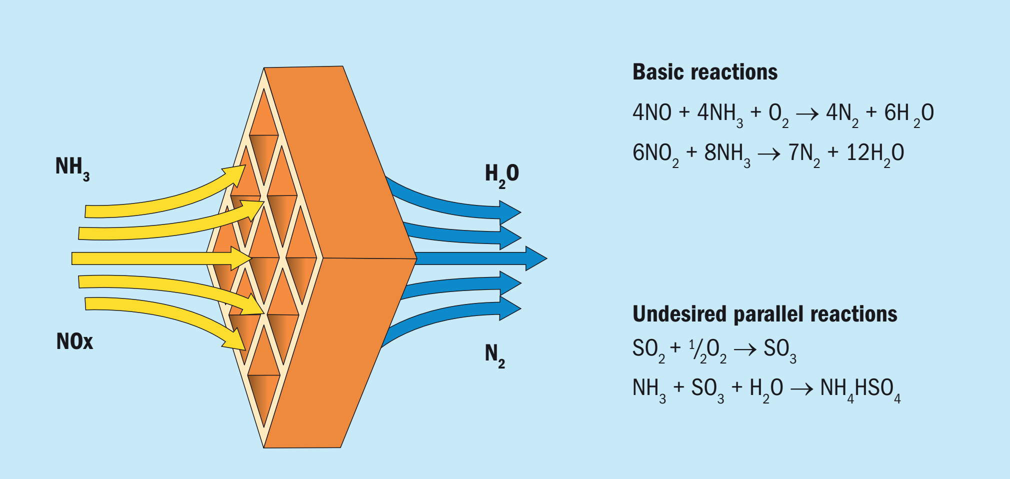
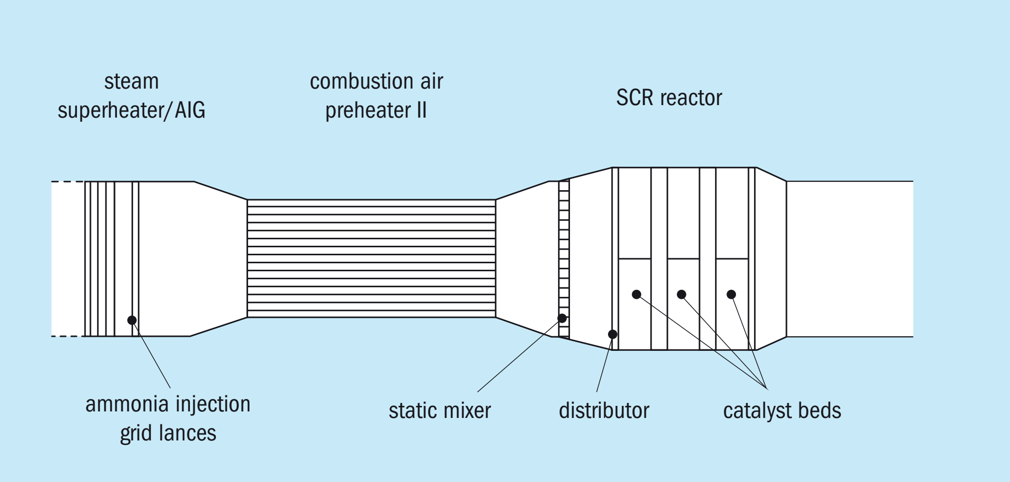
Fig. 3: **A simplified depiction of SCR**



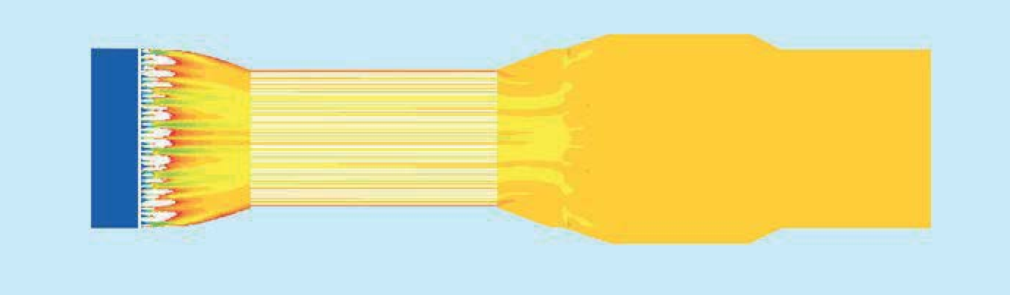
Source: Johnson Matthey

Fig. 4: **Section of flue gas duct modelled**



Source: Johnson Matthey

Fig. 5: **Contours of mole fraction of ammonia-air**



Source: Johnson Matthey

takes into account the whole environmental performance of the plant, including emissions, waste generation, raw material use and other aspects. The permit conditions under the current directives and the IED are based on defining the best available techniques (BAT). These are state-of-the-art techniques that can be used to achieve a high level of environmental protection as a whole. They can be implemented in the relevant sector under economically and technically viable conditions, taking into account their costs and benefits. The issues related to increased levels of NOx and other pollutants in the air were recognised in the 1940s and since the 1960s significant steps have been taken to develop technology to limit such emissions at source. Most effective of these are catalytic after treatments, such as SCR, capable of removing more that 95% of NOx in gas stream. SCR is increasingly specified as a best available technology with the majority of the new methanol and ammonia plants being engineered for the "shale gas project wave" in North America all including an SCR system in the SMR system to reduce NOx emissions to the lowest possible levels of 5-10ppm. Increased concern and control of emissions means SCRs are now common projects in many regions including FSU, Middle East, China and Europe

How SCR works

SCR is a relatively simple acid base reaction where ammonia reduces acidic NOx on the surface of a catalyst (see Fig. 3). This occurs at temperatures typically available in the exhaust gas, 250°C-450°C (482-842°F).

NOx reduction occurs as the SMR flue gas/ammonia mix passes over the catalyst surface in the reactor chamber. Before entering the catalyst chamber, ammonia is injected and allowed to mix with the exhaust gases. The chemical equation for a stoichiometric reaction using either anhydrous or aqueous ammonia for a selective catalytic reduction process is:

$$4NO + 4NH_3 + O_2 \rightarrow 4N_2 + 6H_2O$$

$$2NO_2 + 4NH_3 + O_2 \rightarrow 3N_2 + 6H_2O$$

$$NO + NO_2 + 2NH_3 \rightarrow 2N_2 + 3H_2O$$

Secondary reactions include:

$$2SO_2 + O_2 \rightarrow 2SO_3$$

$$2NH_3 + SO_3 + H_2O \rightarrow (NH_4)_2SO_4$$

$$NH_3 + SO_3 + H_2O \rightarrow NH_4HSO_4$$

When urea is used as the source of the reductant, (not the norm in the chemical industry application of SCR), the reaction is

$$4NO + 2(NH_2)\ 2CO + O_2 \rightarrow$$
$$4N_2 + 4H_2O + 2CO_2$$

The NOx abatement reaction has an optimal temperature range between 357 and 447°C (675 and 837°F), but can operate from 227 to 447°C (441 to 837°F) with longer residence times. The minimum effective temperature depends on the various fuels, gas constituents, and catalyst geometry.

Given the operating temperature range of 250-450°C (482-842°F) in a steam methane reformer, the location where the SCR system will be typically located is at the end of the flue gas duct immediately before or after the air preheater.

Fig. 6: **SCR catalyst is formed as extruded monoliths, arranged in modules to form the SiNOx SCR unit**

Source: Johnson Matthey

High efficiencies typically over 95% have been reported, in order to achieve successful reduction in NOx a number of factors need to be taken into account, particularly the uniformity of the mixing of the flue gas stream with the reductant, typically an ammonia mixture which is injected across the flue gas duct using an ammonia injection grid (AIG). During the design process by the use of CFD modelling an analysis of the flow regimes can be made to ensure that the quality of mixing is of sufficient quality.

Fig. 4 shows the scope of CFD analysis of a flue gas flow from the AIG positioned immediately downstream of the steam superheater coil, a static mixer to complete the mixing process and reduce temperature variations upstream of the SCR catalyst.

As a result of the CFD study, Fig. 5 shows the ammonia-air mole fraction on a vertical plane through this section of the flue gas duct, from the AIG in the left through the combustion air heater and the mixer before the SiNOx catalyst beds.

After the static mixer the flow into the SiNOx SCR catalyst bed was demonstrated to be very well mixed with a uniform velocity.

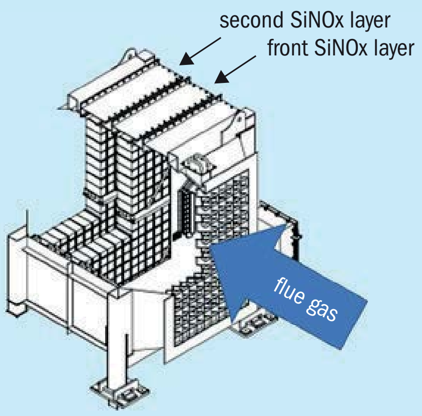
The catalyst is formed as extruded monoliths, which are arranged in modules which form the SiNOx SCR unit (Fig. 6).

The extruded monolith catalyst structure gives a very high specific surface area for a low pressure drop, the monolith catalysts are available in various lengths and number of cells, with the size and shape of the catalyst modules are selected to meet the project specifications for pressure drop and expected life.

Efficiencies of above 90% are typical and efficiencies of over 95% have been reported. In order to achieve years of successful reduction in NOx emission a number of factors need to be taken into account:

- flow rate;
- NOx in/NOx out;
- temperature;
- pressure;
- poisons;
- NH_3 slip;
- sulphur;
- pressure drop.

Fig. 7: **SiNOx SCR unit design**



Source: Johnson Matthey

The operation of SCR technology, including the sizing of the reactor, needs consideration of a number of different, sometimes opposing, factors. The desired or required limits for NOx and unreacted ammonia emissions, (referred to as ammonia slip) are fixed and factors such as pressure drop have to fall within acceptable parameters. There is an element of trade off or compromise in catalyst and reactor design and the space available and the time of operation (interval before servicing/shut down) are additional concerns. In operation blocking or poisoning of the catalyst is of critical concern.

SCR technical issues and their resolution

Catalyst pores can be blocked/plugged by material present in the exhaust stream. Examples include particulate material, (e.g. refractory ceramic fibres), ammonium bisulphate salts (ABS) and silicon compounds. Many can be removed when the unit is in operation, for example by dust blowers. For the case of ABS, the catalyst and system can also be regenerated or cleaned by raising the exhaust temperature. Of greater concern for SCR performance in the chemical industry (such as SMR) are poisons, which will disrupt/modify the chemistry of the catalyst and render the SCR ineffective or worse, affect oxidation of ammonia (forming more NOx). Some of these poisons include: halogens, alkaline metals, arsenic, phosphorus, antimony, chromium and copper. Of these poisons it is chromium in particular that is a feature of SMR operation.

In recent years the effect of water vapour on the volatilisation of chromia has been studied:

$$Cr_2O_3(s) + xO_2(g) + 2H_2O(g) \rightarrow 2CrO_2(OH)_2(g)$$

Depending on the plant design there are different fuel compositions, for example higher hydrogen purge gas which can be routed to fuel. In these plants the level of hydrogen in the fuel directly impacts the percentage water vapour present in the flue gases.

Volatilisation occurs at rates in parts-per-billion (ppb) or less from the SMR reformer catalyst tubes in the radiant section. Awareness of SCR catalyst chromium poisoning is factored into the SCR design (Fig. 7) providing additional catalyst volume in the design to compensate for the Cr-poisoning rate anticipated, plus the SCR system can be designed to help management and monitoring, such as including sample coupons and designing the catalyst bed as layers so that the front section of the bed which is most impacted by Cr-poisoning can be changed out more often if it becomes poisoned.

Effect of SCR catalyst design

The number one priority from a utility point of view is to reduce the total catalyst volume as much as possible when reducing emissions from a steam methane reformer or other refinery unit. This will save both pressure drop and space in the convection section, but with emission requirements getting more and more stringent it is often a difficult task. The emissions are often reduced by installing a catalyst in the convection section, preferably at temperatures between 250°C to 380°C (480°F to 715°F), while adding ammonia to the flue gas stream upstream. So finding space in the correct temperature window is often a challenge. The SCR catalyst is normally supplied in elements that can be built to modules of any size (Fig. 8).

During the design phase of the plant it is often tempting to go with low catalyst pitch as this will reduce overall catalyst volume but also reduce the footprint of the convection section. However, it may not be the right approach from an operational point of view.

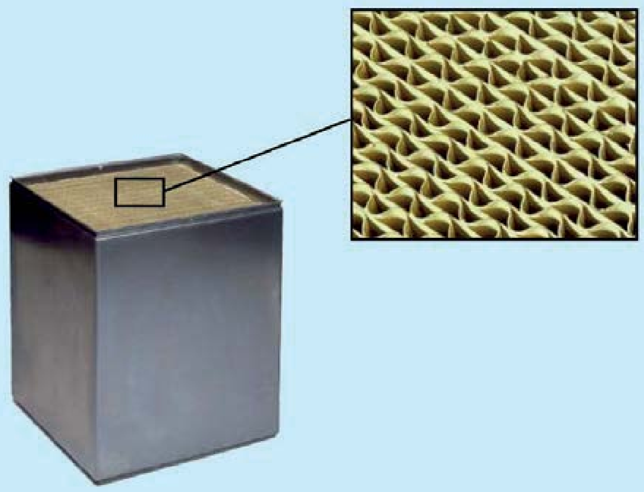
Experience also shows that catalytic systems with smaller pitches tend to plug sooner which eventually will result in unplanned outages for cleaning or in worst cases replacing the catalyst to a type with a larger cell opening. When the latter is the case it is relevant to have the extra space available in the convection section to compensate for the reduced catalyst surface area because if not, it won't be possible to fit in enough catalyst volume to provide enough catalyst activity to operate a full turnaround cycle and that again will result in premature outages or lower production rates by the end of the cycle.

Existing plants are commonly shielded to some extent from new and tighter regulations but that is not always the case. It is therefore becoming more common for licensors to involve Umicore in FEED studies of new plants to make sure enough space is available and the right catalyst defined from the beginning. Burner replacements/upgrades on existing plants may also have an impact and it is thus relevant to have some flexibility by sizing the catalyst correctly the first time.

In some territories it is not only required to remove NOx with a low ammonia slip, but VOC and CO oxidation is also required from steam methane reformers or other refinery units. Umicore has developed a combined catalyst which reduces NOx while oxidising CO and/or VOCs. This is specifically beneficial when having a fixed reactor cross section for existing plants or having less space available in the convection section. In SMRs where chromium poisoning is a very well described challenge a porous catalyst structure will provide extended operational life compared to a typical wash coat oxidation catalyst. The reason is that chromium will not be able to block the flow in the macro pores but easily can sit on other catalyst surfaces without the larger pore system. Fig. 9 shows how solids or specific poisons can mask the catalyst if the catalyst type is incorrectly chosen and doesn't have a tri-modal pore structure. Both the active ingredient for the SCR reaction (vanadium) and the active ingredient for the oxidation reactions (palladium) are homogenously distributed across the catalyst wall and here illustrated by the WDS (wavelength dispersive X-ray spectroscopy) intensity maps (Fig. 10).

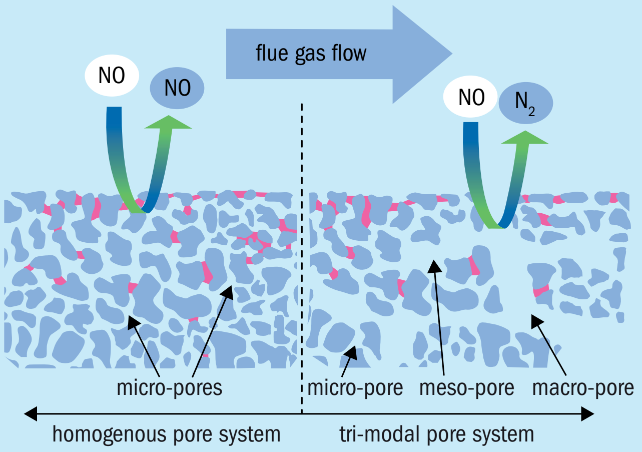
From an operational perspective the only drawback of using a combined catalyst is a slight increase in ammonia consumption. The actual ammonia consumption rate is normally defined by a mass balance that considers flue gas flow rate and NOx content (and required NOx reduction rate) but since Umicore's dual function catalyst is so efficient it may also oxidise remaining ammonia from the SCR reaction. It is possible to differentiate the dual function catalyst into multiple zones within the same catalyst bed with a standalone SCR catalyst part and the remaining part a dual function catalyst. The advantage by doing this is that the concentration of ammonia is reduced drastically at entrance to the dual function catalyst part, and also the investment cost is reduced since the cost of the DeNOx part is lower than the oxidation part which contains noble metals. Since the dual function catalyst (the last part of

Fig. 8: **SCR catalyst module**



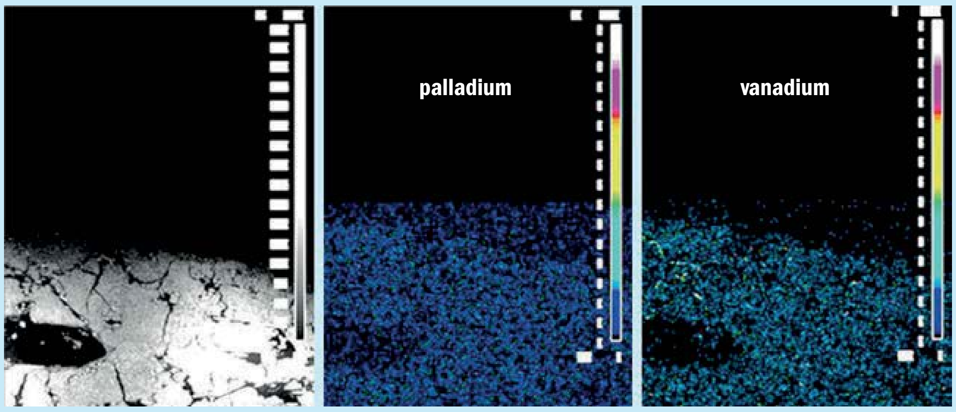
Source: Umicore

Fig. 9: **Comparison of different catalyst types in SMR and refinery applications**



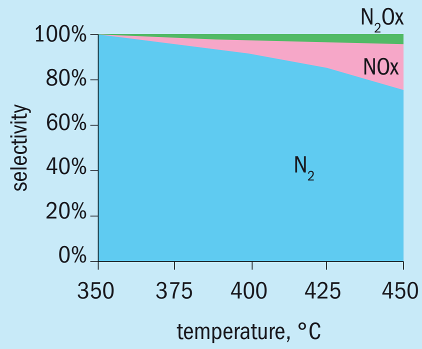
Source: Umicore

Fig. 10: **WDS intensity map of palladium and vanadium on a dual function catalyst**



Source: Umicore

Fig. 11: **NH_3 oxidation selectivity on a dual function catalyst**



Source: Umicore

the bed) is supposed to both oxidise CO/VOCs and reduce NOx in the typical SCR reaction, some NH_3 will be present here. Some of the ammonia may get oxidised and it is therefore relevant to look at the oxidation product and selectivity of the oxidation process. Fig. 11 demonstrates the selectivity of ammonia oxidation over the dual function catalyst at 25-50 ppmv concentrations of NH_3. As is clearly seen in the plots, very little to no NOx or N_2O emissions are measured after the catalyst at temperatures below 370°C (700°F).

The manufacturing process has been optimised so the typical SCR catalyst is impregnated in an additional step with palladium. A proprietary process applies the palladium very uniformly near the surface of the catalyst. The process requires only a small quantity of palladium to achieve a very high CO oxidation rate. Less palladium means lower NO oxidation, lower SO_2 oxidation, and lower NH_3 oxidation. The dual function catalyst has already been installed in a number of SMRs as well as other refinery units.

SNCR application in a down-fired steam methane reformer

Changes in NOx emission limitations in the Middle East have required producers to find ways to retrofit NOx reduction technologies into existing furnaces. In Qatar, the NOx limit was reduced to 125 mg/m³. While this is not a difficult number to achieve for a new furnace, attaining this value in an existing high temperature furnace poses challenges.

One of BD Energy Systems' customers operates a large down-fired methanol reformer with a radiant section flue gas exit temperature (bridgewall temperature) of approximately 1,000°C (1,832°F). Previous issues with thermal cycling in the reformer were successfully addressed by modification to the burners. Additionally, mechanical issues suffered in low NOx burners had been a problem.

For existing high temperature furnaces there are four basic options that were considered for reducing NOx. The first considered is operational changes to reduce temperatures of the radiant section and targeted maintenance to address air infiltration, particularly in the radiant section. This method is usually the low-cost option but the reduction attainable is limited.

Changing the burners to a design that produces less NOx is often one of the best options. Newer Low NOx burners are capable of limiting NOx emissions to well below 125 mg/m³ on a wide range of fuels and at high bridgewall temperatures. However, the technologies that reduce the NOx necessarily produce changes in flames. Characteristics such as burner spacing, flame shape and size, heat flux, etc. must be carefully considered to assure that the process is not limited, or the furnace adversely affected. For these reasons, this method was considered too risky for this reformer.

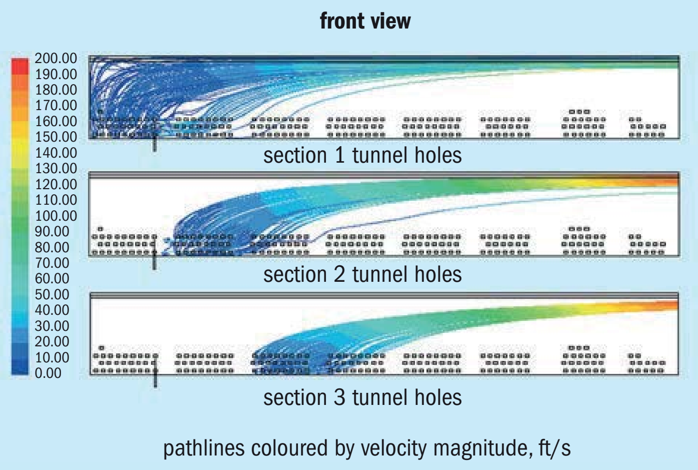
Another method of NOx reduction considered was selective catalytic reduction which can be designed to achieve high levels of NOx reduction that can be easily guaranteed. SCR presented several disadvantages for this reformer. The most significant was that the existing ID fan was already very large and capacity limited. Another issue is that SCR requires specific temperature ranges to be most effective. In this case it would have required significant modification to the convection section to make the required space available at the right temperature range. This would have been costly and taken considerable install time. A final concern was that fouling of the catalyst with atmospheric dust brought in through the FD fan could be problematic without installing a filter. This could have limited the FD fan.

Selective non-catalytic reduction (SNCR) is an alternative system that has not been typically used for high temperature furnaces, as the requirements for a successful installation are difficult to meet. One of those requirements is the appropriate temperature range. If the temperature is too low, the reaction is too slow, and there may not be sufficient reaction time, resulting in unreacted ammonia (ammonia slip) out of the furnace stack. Too high a temperature can result in relatively high ammonia consumption and an actual increase in NOx!

Generally, bridgewall temperatures of 980°C to 1,040°C can be considered candidates for an SNCR system provided good mixing can be achieved and there is adequate residence time available. Once the flue gases enter the convection section rapid cooling makes the reaction too slow to be effective. This can result in ammonia slip occurring. The allowable ammonia slip is also regulated in many areas. At higher temperatures a higher ammonia to NOx ratio is required to achieve the desired reduction. As temperature increases, the amount of ammonia converted to NOx increases instead of reducing. This can result in SNCR being economically unsatisfactory, ineffective in reducing the NOx, or even increasing the NOx.

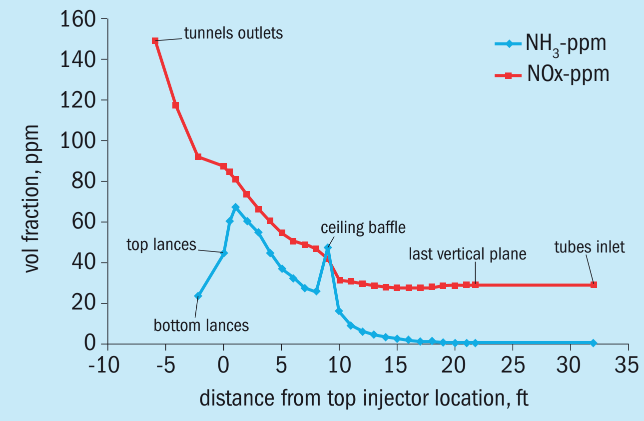
Adequate mixing is critical to achieve effective NOx reduction and minimal ammonia slip. Due to reformers' large size radiant sections, reagent injection into the radiant section would require many injection points

Fig. 12: **Typical flow path of flue gas entering tunnels**



Source: BD Energy Systems

Fig. 13: **CFD preditions for a configuration at 1,001°C and a NH_3 to NOx ratio of 1.9**



Source: BD Energy Systems

in the floor making for a cumbersome design. The typical flue gas tunnel design of a down-fired reformer with all the flue gas entering along the bottom of the tunnel causes stratification of the flow in the tunnel making good mixing difficult (see Fig. 12). Injection at the transition duct to the convection section can be practical but results in limited reaction time.

However, several CFD studies of the application of SNCR to this reformer were performed and it was determined that the conditions were well suited for effective SNCR performance. The size of this reformer provided a long transition duct, the temperature range considered was suitable, and rapid mixing was achieved through injection at carefully placed spray nozzles.

This SNCR installation had the added advantage that it required only minor modification to the reformer. Most of the work to install the system could be done ahead of time while the unit was in operation, requiring only a normal outage to make the final tie-ins to complete the system.

Selection of the reduction agent, urea, anhydrous ammonia, or aqueous ammonia was an important consideration for the design of the system. All three have advantages and disadvantages to consider such as safety, supply availability, storage and handling system, and injection characteristics. Anhydrous ammonia was eliminated as a choice due to significant environmental and safety concerns. Urea was eliminated due to concern about injection nozzle fouling and additional reaction time required. Aqueous ammonia solution (19%) was selected as the reagent for the system design. This had the advantages of being relatively safe, readily available, and suitable for the injection method designed.

Having determined that SNCR was suitable and after choosing the reagent, computational fluid dynamic modelling (CFD) was performed to predict performance and optimize the design sufficiently to prepare a quotation for supply of the entire system. This involved selection of the reagent injection locations and pattern based on mixing and residence time. With several design iterations the system was optimised for performance (see Fig. 13).

A technical and commercial offering was then presented to the customer and accepted. Detailed design and supply of the complete system then commenced. The supply and installation of most of the system components were completed before the next planned outage. During the outage, installation of the injection nozzles into the reformer and the final tie-ins took place without issue.

After start-up of the reformer the SNCR system was commissioned and put into service as planned. The system easily brought the NOx down to the required level, with room to spare for further reduction. It was found that the results obtained in the field matched the predictions of the CFD analysis well.

It should also be noted that care was taken to identify and remedy areas of air infiltration into the radiant section. Air leakage in the vicinity of the burners can increase NOx produced and higher oxygen levels in the flue gas work against NOx reduction.

With careful consideration, an SNCR system is a proven technique to achieve NOx reduction as much as 50-60% in reformer furnaces, alone or in conjunction with other technologies.

Emissions reduction using high emissivity ceramic coatings

Process heater environmental emissions reduction may be reduced without major investment or reconfiguration of the operating units by using high emissivity ceramic coating systems (Fig. 14). In a fired heater with low emissivity refractory surfaces, the radiation reflected from the refractory is readily re-absorbed by the flame and flue gases, superheating the flame and flue gases. The effect is to create a high level of NOx emission.

In a fired heater with a high emissivity ceramic coating, the re-radiated energy from the refractory surfaces is not readily absorbed by the flame and flue gases, eliminating the superheating and maintaining a relatively low NOx emission, up to 30% lower than a regular lining.

In gas-fired process heaters, etc. the CO_2 emissions are derived purely from the combustion of the hydrocarbon fuel. From the use of Cetek's high emissivity ceramic coatings, radiant section heat transfer efficiency may be significantly improved, providing up to 5% fuel savings and hence the same degree of CO_2 emission reduction.

Refractory surface emissivity

In the radiant section of the tubular reformer, much of the radiant energy from the flame/flue gas is transferred directly to the process/catalyst tubes; however, a significant proportion interacts with the refractory surfaces. The mechanism of this interaction has an appreciable effect on the overall efficiency of radiant heat transfer. A major factor in determining the radiant efficiency is the emissivity of the refractory surface.

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PHOTO: IGS

Fig. 14: Ceramic coating application on refractory brick lining.

At process heater operating temperatures, new ceramic fibre linings, for example, have emissivity values of around 0.4. Insulating fire brick (IFB) and castable materials have emissivity values around 0.6. These materials have been designed with structural considerations and insulating efficiency as the primary requirements. They tend not to handle radiation in the most efficient way. Cetek ceramic coatings, however, with emissivity values of above 0.9, have been designed specifically to supplement the radiation characteristics of the refractory surfaces.

How surface emissivity affects heat transfer efficiency

It is important to understand how the emissivity property of a surface can affect the efficiency of heat transfer. There are two factors which need to be taken into account. The first is the spectral distribution of the radiation absorbed/emitted from a particular surface and the second is the value of the emissivity of that surface. The amount of heat, Q, radiated from a surface (area, A; temperature, T; emissivity, ε) is given by the following, well-known Stephan Boltzman equation:

$$Q = A\varepsilon\sigma T^4$$

Where σ is the Stephan Boltzman constant.

Lobo & Evans (1) and others extended the calculation with reference to fired heaters and a simplified equation would appear as:

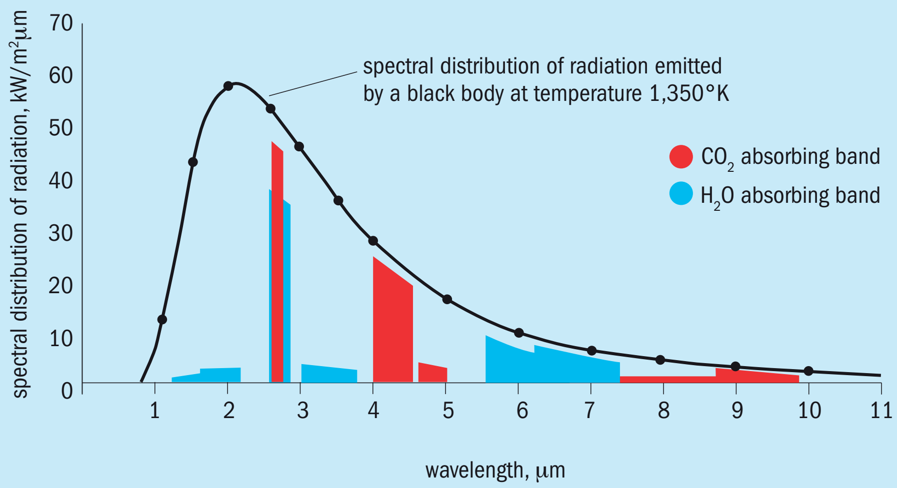
$$Q_R = A\sigma(T_1^4 - T_2^4)/F$$

Where

$$F = 1/\varepsilon_1 + \{A_1/A_2\}\{(1/\varepsilon_2) - 1\}$$

for tubes of area A_2, surface temperature T_2 and emissivity ε_2 are inside an enclosure, area A_1, with surface temperature T_1 and emissivity ε_1.

Fig. 15: **Energy spectra for CO_2 and H_2O vs a perfect radiator or black body**



Source: IGS

Table 1: **Debottlenecking a Foster Wheeler hydrogen reformer with high emissivity ceramic coatings to the refractory surfaces**

Plant parameters	**Before ceramic coating**	**After ceramic coating**
Total plant production, kNm³/h	31.5	33.3
Hydrogen production purity, %	97	97.2
Hydrogen in the feed, %	56.7	59.1
Steam to carbon ratio	4.6	4.6
Reformer inlet temperature, °C	450	436
Reformer outlet temperature, °C	816	809
Flue gas temperature, °C	1,007	974
Stack temperature, °C	301	291
Fuel gas CV, MJ/Nm³	35.1	34.8
Fuel gas flow, Nm³/h	4,419	4,358
Fuel gas molecular weight, kg/kg mole	19.1	18.6
Fuel gas nitrogen content, vol-%	5.7	6.0
Oxygen, %	2.6	3.4
NO, ppm	135	95.8
NOx, ppm	135	95.8
NOx reduction, %		**30**
H_2 production/fuel consumption	**140.3**	**130.9**
Energy savings/production*, %		**2.4**

**Corrected for excess oxygen* *Source: IGS*

The effects of maximising the emissivity ε_1 of the enclosure are obvious; there is a significant increase in radiant heat transfer to the tubes. As stated earlier, much of the radiant heat to the tubes travels directly from the flame/flue gas, but the emissive property of the refractory surface has a profound effect.

The chart in Fig. 15 shows the energy spectra for two major components of the combustion products of natural gas; water vapour and carbon dioxide. They are compared with the spectrum of a perfect radiator, or black body, at the same temperature.

The combustion products will radiate and absorb energy in the narrow wave bands shown, whereas a black body will radiate and absorb energy over a much wider wavelength range.

High emissivity surfaces are able to radiate energy across a broad wavelength band lessening the interference of the CO_2 and H_2O in the flue gas.

What is a black body radiation?

When the radiation from a flame strikes a perfect radiator, all the energy is absorbed and re-radiated, but most importantly, it is transformed into "black body radiation", as the wide waveband form. As the energy is re-emitted from the surface, it can penetrate the atmosphere in the furnace, composed of the combustion products, with little being re-absorbed and taken to the stack by the draft. Therefore, it is more readily available to heat the load in the furnace.

If the surface were a poor radiator, or one having a very low emissivity value, the energy striking the surface would be reflected back from the surface still in its untransformed state, therefore more readily absorbed by the furnace atmosphere. The effect is to "super-heat" the furnace atmosphere, or flue gas, resulting in wasted energy lost to the stack.

Reduction in flue gas temperature and heat transfer efficiency

The improvement in radiant heat transfer efficiency naturally leads to a reduction in flue gas temperature. This has consequences in the convective heat transfer in both the radiant and convection sections of the fired heater. In the convection section, heat in the flue gas is used to produce steam and preheating of combustion air and often process fluids. The heat transfer/absorbed duty balance should be examined closely to ensure that the balance is not adversely affected. There is also a contribution, though minor, from convective heat transfer in the radiant section, which may be characterised by the following equation:

$$Q_C = h_C A_2 (T_1 - T_2)$$

Where h_C, the film heat transfer coefficient, is an empirically derived factor related to the design of the radiant section and the tube configuration.

Steam methane reformer case study

Table 1 illustrates the benefits following the application of high emissivity ceramic coatings to the refractory surfaces in a Foster Wheeler design hydrogen reformer.

The goal was to increase the throughput of the heater without increasing fuel firing, essentially debottlenecking the constraint. The application of Cetek high emissivity ceramic coatings had a positive effect on this heater. After coating, the unit was able to produce more hydrogen with less fuel input lowering costs and carbon emissions. Additionally, by reducing bridgewall temperature, Cetek ceramic coatings lowered NOx emissions by 30%. ■

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