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 57 58 59 60

Number 365

May | June 2020

nitrogen+syngas

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Syngas in Southeast Asia

Methanol for olefins production

Reducing industrial carbon footprint

The importance of technical services


JM

1 47 2 48 3 49 4 50 5 51 6 52 7 53 8 54 9 55 10 56 11 57 12 58 13 59 14 60 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

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NUMBER 365
MAY | JUNE 2020

Cover: *Chemical plant for production of ammonia and nitrogen fertilizer.*
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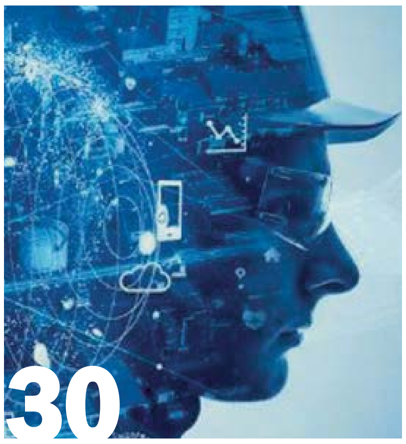
CONTENTS

Methanol to olefins

Clouded outlook for driver of methanol demand.



Technical services

An expanding range of resources for plant operators.

REGULARS

Read this issue online at: www.nitrogenandsyngas.com

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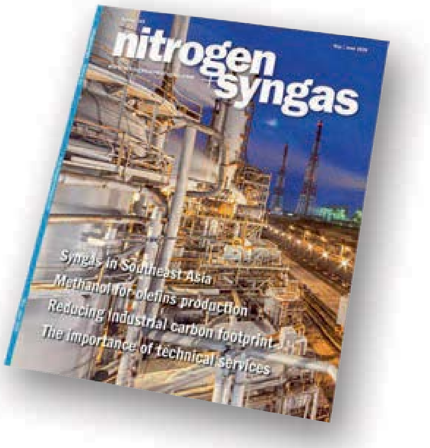
The new normal



> **"Agricultural demand... continues to be fairly strong."**

The devastating effects of the Covid-19 pandemic continue to be felt around the world. At time of writing, nearly 4 million cases have been recorded, and at least a quarter of a million people have died, with the suspicion of many more, either from accidental or deliberate undercounting. Figures for excess deaths above a normal seasonal baseline show that places such as Turkey, Ecuador and Indonesia have probably been far worse affected than the official statistics show. There are nevertheless finally hopeful signs that Europe, so far the worst affected region, is beginning to follow the pattern of East Asia and Oceania and that cases are falling. The infection also seems to have peaked in North America, though in the US there is a long tail of infections. Elsewhere, cases are still rising in countries such as Brazil and Mexico.

Now, however, while research on vaccines and palliative drugs proceeds at a rapid pace, and there are moves to gradually relax social restrictions imposed to halt the spread of Covid-19, there is the question of what a post-outbreak society will look like until a vaccine is finally in widespread distribution and use. Here in the UK, this concept has become known as the 'new normal' – a series of continuing restrictions that may last well into 2021, or even longer.

The economic impact of the pandemic so far has been a severe shock across all industries as countries closed down almost overnight. In terms of pure economic activity the effect is sure to be a global recession this year. China's GDP figures for Q1 2020 show a contraction of 6.8% compared to Q1 2019, and the country's chemical manufacturing output was down 21% for Jan/Feb 2020. But perhaps more important in the long run will be the impact of the 'new normal' on how businesses are able to operate across the rest of 2020 and into 2021. For the travel and restaurant sectors, for example, the outlook is a bleak one. In the publishing industry, we have moved reasonably smoothly to operating without an office, but getting physical copies of issues to customers remains a difficult and in some cases impossible process due to customs restrictions and border checks, or the partial or complete shutdown of postal services in some countries.

In the syngas-based chemicals sector, there seems to currently be a fairly sharp divide between agricultural nitrogen demand, which continues to be fairly strong, and where plant shutdowns and logistical issues have served to decrease availability and increase prices – and industrial sectors. Hydrogen use is constrained by refinery shutdowns as demand for fuels collapses, at least in the short term. Methanol demand rests upon industrial chemicals, often badly affected by closures of factories; as well as fuel uses, which may see a pickup as lockdown restrictions ease; and the all-important Chinese olefins sector. Demand for polypropylene fibres to make face masks has actually seen demand continue to be strong in that industry, but the crash in oil prices has made the oil route to propylene cheaper than coal-based methanol, as we note in our article in this issue. Feedstock prices at least are at several year lows, in some cases historically low levels, giving producers slightly more room for manoeuver, but the outlook remains very uncertain.

On the investment side, there is considerable momentum and significant sunk costs behind a number of current projects, but many companies are re-evaluating what until a couple of months ago had looked like sound business opportunities. It is currently very difficult to divine what the shape of a post-Covid world might look like, and much depends upon government responses over the next weeks and months. Under such circumstances, the willingness of banks to loan money outside of government backed schemes may be greatly curtailed. It could even be that increasing demand in some sectors suddenly finds that it is undersupplied because no-one was willing to build new plants for a couple of years.

The new normal will take some adjusting to for everyone, but like it or not, it is going to be with us for many months to come. ■

Richard Hands, Editor

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60

Price trends

MARKET INSIGHT

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

NITROGEN

The outlook for the global ammonia market has been thrown into uncertainty in March and April. In early March, the market was absorbing the impact of a potential downturn in Asian demand this year because of the emergence of coronavirus. But with the virus' swift spread around the world and subsequent national lockdowns, ammonia spot demand has been curtailed, most severely in the industrial sector.

Following on from the trend in China in the first quarter, industrial consumers of ammonia throughout the rest of the world are slowly cutting back production. In Europe, these cutbacks are estimated at around 30%, but in other countries, such as Taiwan, downstream demand is plummeting, and industrial plants are being taken offline. However, fertilizer-focused ammonia industries are still operating as they are categorised as key. In the US, the direct application season has been relatively strong and US demand continues at a close-to-normal rate.

Prices are steadily falling, reflecting a building surplus in the near term and reduced demand for the next few months in key markets. Asian prices have fallen by over $65/t since the emergence of coronavirus from $312.50/t c.fr in late-January to $247.50/t c.fr in late-April, although the rate of China's imports has not fallen sharply, with around 215,000 tonnes discharging at Chinese ports in January-March.

Urea prices peaked in early March around $260-265/t f.o.b. Egypt and the Middle East and have declined since then. Prices fell by about $30/t up to the end of April. There was strong demand for urea for April shipment, particularly from India, Australia, Europe and the US, but this was outweighed by uncertainty created by the coronavirus pandemic.

Overall, nitrogen fertilizer prices have held up better than for other energy-related commodities, partly because the pandemic coincided with peak demand periods in the northern hemisphere. India bought nearly 750,000 tonnes of urea for April shipment, and timely rain in Australia has seen 5-6 spot cargoes of granular urea purchased from the Middle East, southeast Asia and China. US prices remained at a premium to other markets in April, pulling in more urea.

The market is waiting for demand to emerge from other countries for May and is also focussed on likely export prices and volumes from China; lower gas and coal prices mean that Chinese suppliers can be competitive at lower levels than in 2019. Lower demand from the industrial sector on account of reduced economic activity, together with lower feedstock costs, imply falling prices going forward. ■

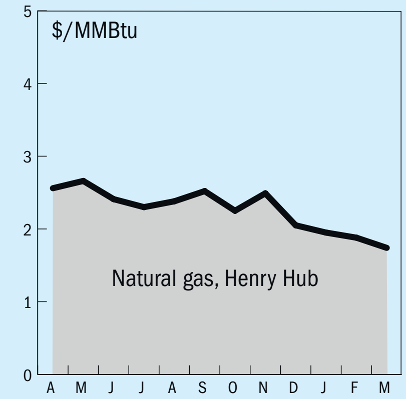
Table 1: **Price indications**

Cash equivalent	mid-Apr	mid-Feb	mid-Dec	mid-Oct
Ammonia ($/t)				
f.o.b. Black Sea	210-225	220-223	210-225	225-233
f.o.b. Caribbean	200-215	215	200-215	193-210
f.o.b. Arab Gulf	200-220	215-250	220-235	230-250
c.fr N.W. Europe	250-281	250-285	250-281	250-285
Urea ($/t)				
f.o.b. bulk Black Sea	215-228	212-215	203-220	225-240
f.o.b. bulk Arab Gulf*	226-245	222-235	238-250	244-260
f.o.b. NOLA barge (metric tonnes)	263	269	225-240	245
f.o.b. bagged China	250-283	240-245	252-270	263-280
DAP ($/t)				
f.o.b. bulk US Gulf	297-323	300	268-294	294-303
UAN (€/tonne)				
f.o.t. ex-tank Rouen, 30%N	172	146-148	199	200

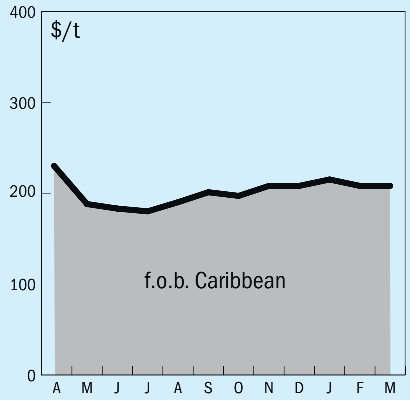
*Notes: n.a. price not available at time of going to press. n.m. no market. * high-end granular.*

END OF MONTH SPOT PRICES

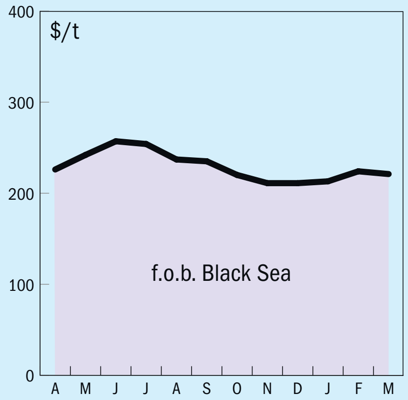
natural gas



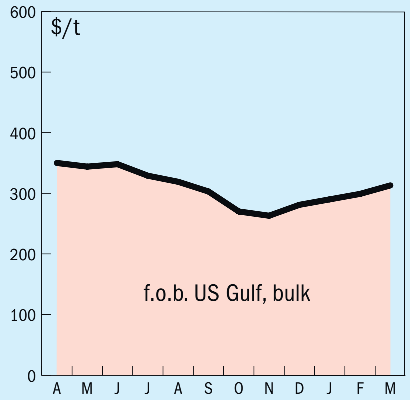
ammonia



urea



diammonium phosphate

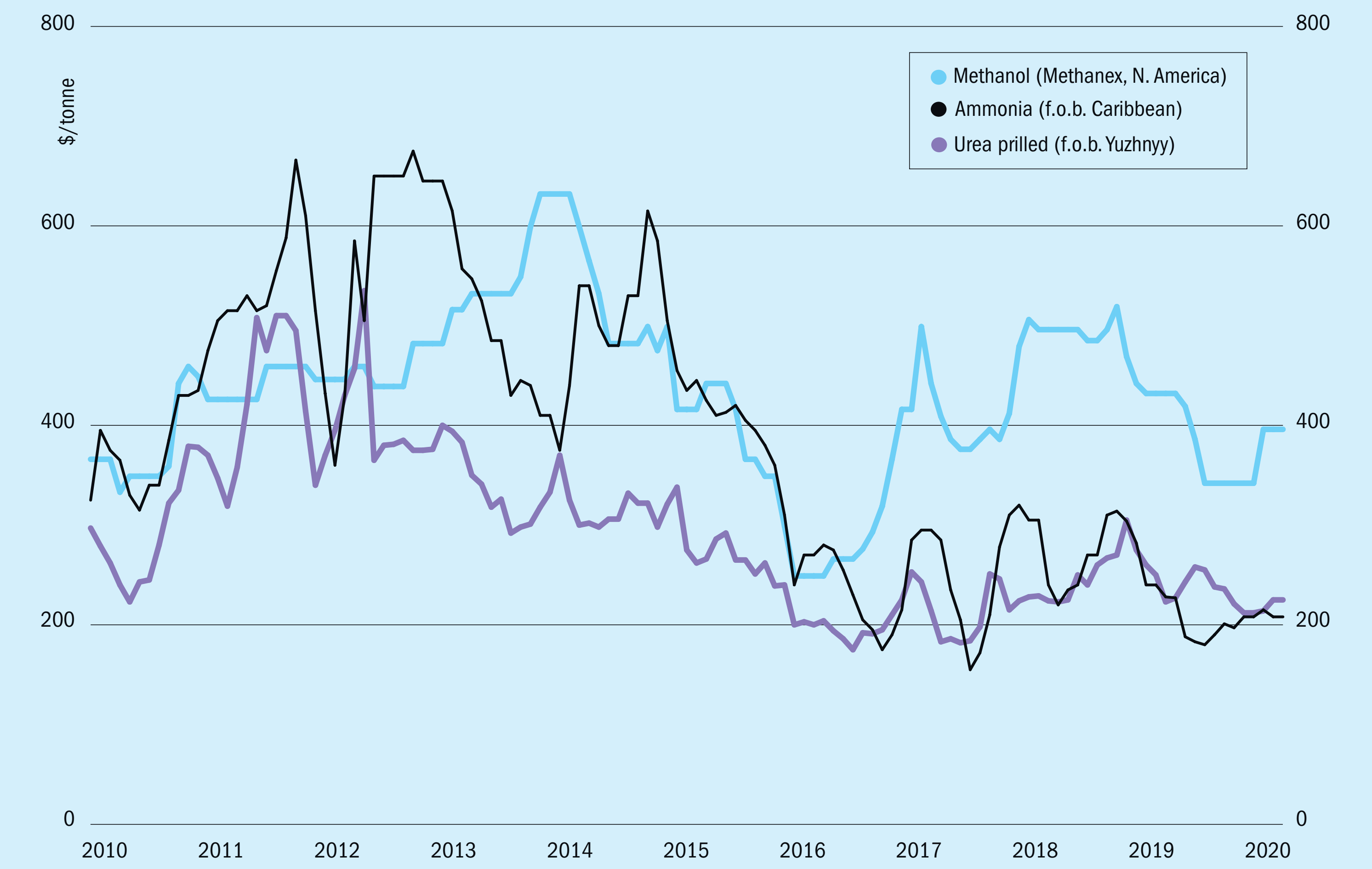


Contents ISSUE 365 NITROGEN+SYNGAS MAY-JUNE 2020 BCInsight

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46
47 48 49 50 51 52 53 54 55 56 57 58 59 60

Market Outlook

Historical price trends $/tonne



Source: BCInsight

AMMONIA

- The impact of coronavirus on both supply and demand continues to provide considerable uncertainty to the market. Industrial demand seems to have been worst affected, and fertilizer related demand has largely kept up, although shutdowns in India's ammonium phosphate sector have also affected demand. Spring is traditionally the strongest time for fertilizer demand, and this has helped support prices at least in the short term.
- However, the market was oversupplied before the Covid-19 pandemic, and falling demand has only exacerbated the situation. Fortunately feedstock, especially natural gas prices have been falling in tandem with ammonia, which eases some of the burden on producers.
- At the moment prices are holding steady at their new lower levels, and what happens next depends very much upon how and when the lockdown eases in major producing and consuming countries.

UREA

- Market uncertainty and peak demand for the spring application season led to a run-up in urea prices during February and March, boosted by a 750,000 tonne tender from India. However, with this past and demand from India more subdued than expected, urea prices have been falling from mid-March into April and remain relatively soft. Black Sea and Baltic rates dropped to $200/t f.o.b., with Arab Gulf prices about $220/t f.o.b.
- More demand is expected from India, with MMTC due to close a tender in May, and there are expectations Brazil will come back to the market by June, but there is still plenty of supply available.
- In spite of some shutdowns, availability continues to increase from new facilities. Egyptian Chemical Industries (KIMA) has announced that its new fertiliser facility in Aswan is now fully operational, with a capacity of 1,200 t/d of urea and 300 t/d of AN. Dangote Fertilizer's 3 million t/a urea complex at Lekki, near Lagos in Nigeria, is close to being commissioned with its various sections being test run, according to the company.
- On the other hand, many producers are expected to take plant turnarounds if prices remain low, which could see slightly tighter availability towards the end of the second quarter.

METHANOL

- Methanol prices peaked in mid-March, and then saw a precipitate fall. European methanol prices crashed at the end of March, falling as low as €150-158/tonne for spot cargoes f.o.b. Rotterdam before rebounding slightly, as lockdowns across the continent affected shipments and industrial production.
- Fuel uses, direct blending and DME and MTBE have all also been curtailed, and no pickup in demand is likely in the short to medium term.
- Falling methanol prices did mean that methanol to olefin demand remained relatively strong in China, however, which has helped absorb some of the methanol flowing out of Iran which is no longer able to find Indian buyers. ■

Nitrogen Industry News

TURKEY

Tecnimont wins urea/UAN plant contract

Tecnimont SpA has signed an EPC contract worth approximately €200 million with Gemlik Gübre Sanayii Anonim Sirketi for the construction of a new urea and urea ammonium nitrate (UAN) solutions plant at Gemlik, 125 km south of Istanbul. The plant will have a capacity of 1,640 t/d of granular urea and 500 t/d of UAN, and will be based on Stamicarbon urea technology, a fully owned subsidiary of the Maire Tecnimont group. The scope of work includes engineering, supply of all equipment and materials and construction and erection works. Project completion is planned within about three years of the contract beginning.

Gemlik Gübre is part of Yildirim Holding, a multi-billion dollar diversified group in Turkey active in several fields, from chemicals and fertilizers to ports and logistics, metals and mining. Ammonia and other fertilizers are already produced in the same industrial facility, with direct access to a Mediterranean sea port.

Pierroberto Folgiero, Maire Tecnimont Group CEO, commented: "We are extremely proud of this new achievement that confirms the Group leadership in the fertilizer sector and allows us to expand our geographical footprint in a strategic market such as Turkey".

AUSTRALIA

Incitec abandons sale plans for now

Incitec Pivot says that it has abandoned plans to sell its fertilizer business for the time being following difficulties caused by the Covid-19 outbreak, including travel restrictions and market uncertainty. Incitec Pivot announced that it was considering the sale in September 2019 following a strategic review of operations which also looked at a possible demerger or retention with increased investment. However, while some major names were initially interested in what is Australia's largest fertilizer distributor, North American fertilizer major Nutrien reportedly pulled out of talks in February due to the coronavirus epidemic. Incitec Pivot says that the pandemic has not had a "significant" impact on its operations so far, and added that the recent widespread rainfall across eastern Australia has created significant demand for its fertilizers.

SWITZERLAND

Sabic increases its holding in Clariant

The Saudi Basic Industries Corporation (Sabic) has announced that it has purchased additional shares in Swiss chemicals maker Clariant. The deal raises SABIC's stake in the Swiss firm from 25% to 31.5%, subject to regulatory approvals. Sabic noted that the additional stake purchase is part of its strategy to achieve a leadership position in the specialty chemicals business. The move brings Sabic close to a 33.3% ownership threshold in Clariant which would trigger a mandatory takeover offer under Swiss law.

Sabic took an impairment charge of 1.5 billion riyals ($400 million) on its investment in Clariant in its third quarter. The companies had planned to merge their pigments and Masterbatches business, but this failed over differences on asset prices. Sabic took its present 24.99% stake in Clariant after the signing of a memorandum of understanding (MoU) in September 2018, but Clariant subsequently agreed to sell the pigment and Masterbatches business to PolyOne for $1.6 billion. Sabic is in turn in the process of a formal 70% takeover by Saudi Aramco, though both companies are publicly owned.

FINLAND

Ammonia combustion trials for shipping and power

Finnish technology group Wärtsilä says that it has initiated combustion trials using ammonia to help the company to prepare for the use of ammonia as a fuel that can contribute to reducing greenhouse gas emissions in both the shipping's and energy sectors. As part of the tests, ammonia was injected into a combustion research unit to better understand its properties. Based on initial results, the tests will be continued on both dual-fuel and spark-ignited gas engines. These will be followed by field tests in collaboration with ship owners from 2022, and potentially also with energy customers in the future.

"The first tests have yielded promising results and we will continue to optimise combustion parameters," said Kaj Portin, General Manager, Fuel & Operational Flexibility, Wärtsilä Marine. "This is an important step in making sure that Wärtsilä can provide the engine and fuel systems that ship owners need, whichever fuel they choose in the future."

The company believes that ammonia is a promising, carbon-free fuel as the shipping industry explores how to fulfil the International Maritime Organization's vision of reducing greenhouse gas emissions from shipping by at least 50% by 2050, while the energy sector is developing optimal paths for 100% renewable energy systems. Although ammonia is derived mainly from fossil sources today, in the future ammonia's greenhouse gas footprint can be nearly eliminated if it is produced using electricity from renewable sources.

Wärtsilä acknowledges, however, that ammonia has a number of issues as a fuel; it ignites and burns poorly compared to other fuels and is toxic and corrosive, making safe handling and storage important. Burning ammonia could also lead to higher NOx emissions unless controlled either by post combustion treatment or by optimising the combustion process.

UNITED STATES

Settlement in lawsuit over ammonia plant reconstruction

A Southwest Arkansas Circuit Court has ruled against El Dorado Chemical Co and El Dorado Nitrogen in a lawsuit brought over the rebuilding of an ammonia plant at the company's El Dorado, Arkansas facility. The ammonia plant was part of reconstruction work following an explosion at the site in 2012, and involved moving and renovating an idled second hand ammonia plant brought to the site from Louisiana. Lead contractor Leidos Constructors subcontracted piping and mechanical works to Global Industrial Inc, but Global Industrial was released part way through the project after criticisms of its work. Global subsequently sued Leidos and El Dorado for $10 million in unpaid invoices. The court ruling allocates $8.8 million in payments, including costs and interest, to the two El Dorado companies.

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 57 58 59 60

JAPAN

Feasibility study on renewable ammonia combustion

Australian energy company Woodside has signed an agreement with Japanese companies JERA Inc, Marubeni Corporation and IHI Corporation to undertake a joint study examining the large-scale export of hydrogen as ammonia for use decarbonising coal-fired power generation in Japan. The consortium has received approval from Japan's New Energy and Industrial Technology Development Organization (NEDO) for a feasibility study covering the entire hydrogen-as-ammonia value chain. The study will examine the construction and operation of world-scale ammonia facilities and the optimisation of supply chain costs. As part of the study, Woodside will be investigating the transition from 'blue' to 'green' hydrogen for export. 'Blue' hydrogen is produced from gas using steam methane reforming, with related carbon emissions offset. Green hydrogen is produced from renewable energy using electrolysis.

Woodside CEO Peter Coleman said the agreement was another step forward in Woodside's exploration of the potential of hydrogen as a clean fuel of the future. "Woodside and its partners in Japan have forged new energy pathways before, and we can do so again, as we expect by 2030 to see large-scale hydrogen production around the world and we intend to be part of that."

INDIA

NFL working to keep up fertilizer supply during lockdown

India's public-sector producer National Fertilizers Limited (NFL) says that it is working to ensure an adequate supply of fertilizers to farmers during the country's extended lockdown, with its urea plants in Nangal, Bathinda and Panipat and two units at Vijaipur operating fully and producing at more than 11,000 t/d. This follows the Indian government's announcement that key industries such as agriculture, fertilizers and goods transportation will be allowed to resume fully from 20th April, lifting restrictions on farming, plantations and fertilizer units to allow harvesting operations. Labour and logistical shortages over the last two months as a result of India's lockdown measures have severely delayed the crucial rabi harvesting season, which normally ends in March. The kharif sowing period, which generally begins in April, has also been affected.

Commissioning at the new Ramagundam Fertilizers and Chemicals Ltd (RFCL) plant has also been interrupted by the Covid-19 outbreak. RFCL, a joint venture between NFL, Engineers India limited (EIL) the Fertilizer Corporation of India Ltd, GAIL India Limited, the HTAS consortium and local government, was to have begun commissioning in April at its new 3,850 t/d ammonia-urea unit. However, employees are now furloughed until the end of India's pandemic lockdown.

BANGLADESH

Credit line for new urea plant

The Multilateral Investment Guarantee Agency (MIGA), a member of the World Bank Group, has issued a guarantee for \$357 million to cover a non-shareholder loan from HSBC to the Bangladesh Chemical Industries Corp (BCIC) for the Ghorasal Polash urea project. The guarantee provides coverage for principal and interest payments on the loan for up to 14 years.

The project involves the construction, installation, and operation of the \$1.5 billion Ghorasal Polash urea plant in the Narsingdi district of Bangladesh. The new plant will have a capacity of 900,000 t/a of urea. State-owned BCIC will own and operate the plant, with engineering, procurement, and construction led by a consortium of Mitsubishi Heavy Industries and the China National Chemical Engineering Construction Company, with Marubeni acting as coordinating agent for the consortium, financing parties and the project owner.

The project aims to help Bangladesh reach self-sufficiency in fertilizer production, more than tripling the capacity of the two obsolete fertilizer plants it is replacing (Urea Fertilizer Factory and Polash Urea Fertilizer Factory), whilst using the same amount of natural gas, simultaneously reducing the environmental footprint of Bangladesh's urea production, generating less waste and incorporating carbon capture technology to significantly reduce carbon dioxide emissions. Overall around 433,000 t/a of carb on dioxide emissions will be saved. Furthermore, the new plant will produce urea at about \$140/t less than it costs to import fertilizer, resulting in significant cost savings and related reductions in the government's fertilizer subsidy bill. Agriculture contributes around 15% of Bangladesh's annual income and 45% of its total employment.

NETHERLANDS

Commercial reference for new catalyst

Clariant says that OCI Nitrogen's ammonia production plant in Geleen has seen significant performance improvements via what is the first commerical installation of its *ReforMax 330 LDP Plus* steam reforming catalyst. OCI Nitrogen is a major European fertilizer producer and the world's largest producer of melamine, both depending on ammonia from the company's AFA 2 ammonia plant; a Bechtel design with a capacity of 1550 t/d and a side-fired Foster Wheeler reformer. Before the turnaround in 2018, pressure drop over the front end was a crucial production limitation for OCI, but installation of the new catalyst, and optimisation of catalyst volumes in other reactors, have removed this limitation, significantly increasing the plant's energy and production efficiency. Clariant calculates that this will result in savings of more than €300,000 over the expected catalyst lifetime of 8 years.

ReforMax 330 LDP Plus owes its pressure drop reduction capacity to a proprietary 8-hole floral shape, which allows higher gas throughput and/or lower pressure drop as well as improved heat transfer.

PHOTO: NFL

NFL's Vijaipur urea plant.

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 57 58 59 60

Syngas News

UNITED STATES

Methanex defers construction on its third Geismar plant

Methanex has said that, in light of the uncertainty in the global economy from the Covid-19 pandemic, it will defer approximately $500 million of previously announced capital spending on its $1.4 billion Geismar 3 methanol project for up to 18 months. Geismar 3, which is intended to eventually produce 1.8 million t/a of methanol, will be placed on temporary "care and maintenance" for up to 18 months, enabling the company to complete the project when market conditions improve. Methanex says it will spend $100 million in Q1 2020 and a further $200 million from April 1, 2020 to September 30, 2021 on the project, the majority of which is spending that occurred or was committed during Q1 2020. This is approximately $500 million lower than the $800 million that was expected to be spent over that same period. Construction activity and procurement of non-critical equipment and bulk materials will be suspended until market conditions allow the Geismar 3 project to restart.

The company is also taking other steps to strengthen its financial position, including idling plants in Trinidad and Chile. John Floren, president & CEO of Methanex, commented, "We are taking proactive steps today during these unprecedented times to further strengthen our balance sheet, while maintaining long-term value and financial flexibility. We believe that deferring major capital spending on our advantaged Geismar 3 project, and minimising near-term spending, is a prudent decision in the current environment. We have ample liquidity today with approximately $800 million of cash on the balance sheet and we continue to evaluate all capital and operating spending as we navigate this challenging environment." ■

Nacero agrees methanol to gasoline license

Texas-based Nacero, formerly known as Coachella Energy, says that it has agreed to license technology from Haldor Topsoe for the company's planned $3 billion methanol to gasoline facility in Casa Grande, Arizona. The plant, which is intended to have a capacity of 35,000 bbl/d of gasoline, will use Topsoe's *TIGAS*™ process, including 10,000 t/d of large scale *SynCOR Methanol*™ natural gas-based methanol production. Pending a final investment decision, Topsoe will also supply proprietary hardware, catalysts, and services.

"By making an environmentally superior gasoline from natural gas rather than crude oil, Nacero will enable drivers to keep their cars and help the planet. Using existing vehicles, markets, infrastructure, and proven technology affords Nacero the opportunity to quickly and predictably create meaningful benefits at world-class scale," says Jay McKenna, CEO, Nacero.

"We are proud that Nacero has made *TIGAS* their technology of choice in their ambitious plan to bring gasoline security and jobs to Arizona. This cutting-edge technology will help communities and producers monetize natural gas resources, and reduce imports by producing high-quality gasoline locally," says Kim Knudsen, Executive Vice President, Haldor Topsoe.

FRANCE

Hydrogen powered fuel cell barge

The European Union (EU) has agreed €6.8 million of funding for its FLAGSHIPS hydrogen-powered boat demonstrator programme as part of its Fuel Cells and Hydrogen Joint Undertaking, and funded by the EU's Horizon 2020 framework programme. The project is supporting the construction of a hydrogen fuel powered barge tug in the French city of Lyon, which will use hydroelectric power from the river Rhone to generate hydrogen for the vessel's on-board fuel cells. There are 11 hydroelectric power stations on the 276 km stretch of the river between the port of Marseille and Lyon (two of the three biggest cities in France) and a regular convoy of barges carrying cargo upstream for import and downstream for export. The tug will be powered by two 200 kW fuel cells connected to a 300 kg mobile compressed-hydrogen fuel tank which can be removed and refilled with hydrogen created at an electrolysis plant using power from the Rhône hydroelectric dams. Vessel deliver is scheduled for mid-2021. Elsewhere, the FLAGSHIPS programme is also creating a hydrogen fuel cell and power system for a Norwegian public ferry service.

SWEDEN

Crowdfunding for CO_2 to methanol project

Liquid Wind AB, a Swedish green energy company, has initiated its second crowdfunding campaign.

The company says it has already raised about 1 million krone ($100,000) which will be used to fund engineering and permitting work and speed up the process of bringing its product to market at scale. The Gothenburg-based start-up focuses on the conversion of waste carbon dioxide (CO_2) and renewable power into renewable methanol. It intends to develop its first commercial-scale plant in Sweden and then build six more in the country, before expanding internationally. The plan is to reach financial close for the first facility in 2021.

Liquid Wind is operating in conjunction with a consortium consisting of Axpo, COWI, Carbon Clean Solutions, Haldor Topsoe, Nel Hydrogen and Siemens, supported by a €1.7 million investment from EIT InnoEnergy. Design work is under way

PHOTO: STENA LINE

Stena's methanol-powered ferry Stena Germanica.

on technology integration for the first facility, which expects to be producing 45,000 t/a of methanol by 2023, enabling a reduction of 90,000 t/a of CO_2. As part of the project, Haldor Topsoe is contributing its methanol process, hardware and catalysts.

Fifth anniversary of methanol powered ferry

Wärtsilä, Stena, and Methanex Corp are making five years of successful operation of the methanol-fuelled ferry *Stena Germanica*. This was the first ship in the world to run on methanol as a marine fuel, and the companies describe it as "a major milestone in the continued shift towards a more sustainable future for commercial shipping". The ferry was converted to run on methanol fuel in early 2015 at Remontowa Shipyard in Poland. The 240-metre ferry, with capacity for 1,500 passengers and 300 cars, was retrofitted with a first-of-its-kind fuel-flexible Wärtsilä 4-stroke engine that can run on methanol or traditional marine fuels. The ferry began the world's first methanol-powered sailings between Gothenburg, Sweden and Kiel, Germany in late-March 2015.

In the five years since the *Stena Germanica's* launch, the market for methanol-powered vessels has seen continued growth. Methanex via its wholly-owned subsidiary Waterfront Shipping, operates the world's largest methanol ocean tanker fleet with 11 vessels. Stena Bulk recently announced a joint-venture with Proman Shipping to build two methanol-powered vessels with delivery scheduled for the beginning of 2022.

TRINIDAD & TOBAGO

Methanex idles Titan plant

Methanex has idled its 850,000 t/a Titan plant on Trinidad from March 16th. Methanex president and CEO John Floren said that the closure was because of an anticipated fall in demand during the second quarter when there will be a substantial reduction in manufacturing activity caused by the coronavirus pandemic. Methanex is reducing production at facilities where it has flexibility in gas agreements, to prepare for this lower demand, Floren said. The company has also idled its Chile 4 plant from April 1st, for an indefinite period. The two facilities between them represent approximately 19% of Methanex's annual operating capacity of 9.2 million t/a.

PHOTO: AMPCO

The Atlantic Methanol Production Company (AMPCO) methanol plant at Punta Europa, Equatorial Guinea.

JAPAN

Methanol from recycled CO_2

Mitsubishi Power Systems (MHPS), Mitsubishi Heavy Industries Engineering (MHI) and Mitsubishi Gas Chemical Company (MGC) will work together to conduct research on 'recycling' of carbon dioxide into methanol. The companies have been selected by the New Energy and Industrial Technology Development Organisation to carry out research at a refinery at Tomakomai City, Hokkaido, where CO_2 is already captured and stored by an existing demonstration plant. The process will combine captured CO_2 with hydrogen obtained as a by-product from refineries or from water electrolysis within the existing facility to generate 20 t/d of methanol.

EQUATORIAL GUINEA

Companies shortlisted for methanol and other projects

The Ministry of Mines and Hydrocarbons (MMH) of Equatorial Guinea has revealed the companies shortlisted for execution of its major development projects at the Punta Europa gas and energy hub. Equatorial Guinea is looking to convert the existing Atlantic Methanol plant into a methanol to gasoline facility as part of a modular refinery concept, and has also discussed building other downstream methanol derivatives such as formaldehyde. Companies involved in the methanol derivatives project include South African-based Pan African Energy, Nigerian Bugabi Group, and Haldor Topsoe. MMH says that it is still registering interest from additional players, including Chinese companies. Atlantic Methanol Production Co Ltd (AMPCO) is 45% owned by Marathon Oil and 45% Noble Energy Inc. Marathon is conducting a feasibility study on the refinery development, as well as developing offshore gas fields which are due to begin production in 2021. A second LNG plant is also under discussion/development.

UNITED KINGDOM

Planning approved for plastic to hydrogen facility

A plastics to hydrogen facility has received planning consent at a site near Ellesmere Port, Cheshire. The facility will convert 35 t/d of unrecyclable plastics into hydrogen via a gasification and syngas generation step. It will also generate electricity, which it will provide to commercial users via a micro-grid. Last year, developer Peel Environmental signed a collaboration agreement with Waste2Tricity and Powerhouse Energy to build the facility at its Protos site. The £7 million (US$8.1 million) plant will be the first in the UK to use Powerhouse Energy's distributed modular generation (DMG) technology, which involves the plastics being shredded and then gasified to produce syngas.

Construction is expected to begin later this year and the facility is due to be operational in 2021.

Myles Kitcher, Managing Director at Peel Environmental, said: "The creation of this UK-first facility makes great strides to solve two important issues; the huge amount of waste plastic produced, and the over-reliance on fossil fuels for energy. The technology has been proven at Thornton Science Park and will now be commercialised at Protos, before being rolled out across the UK." ■

People

CRU has announced the appointment of **William Etchell** as Chief Financial Officer, based in the company's London headquarters. Etchell joins CRU from GUS Holdings, a global higher education provider. Previously, he was CFO at EPG, an education services provider, and prior to that he was Group Finance Director at BPP Professional Education Group. He has over 25 years' experience working in finance across a variety of sectors, having qualified with Arthur Andersen in the 1990s. Since then he has worked in a number of organisations including British Airways, Time Warner and Interpublic Group, as well as running his own nursery school business.

David Trafford, CEO of CRU Group said: "I am pleased to welcome William to CRU and the Executive Leadership team. William brings an extensive amount of knowledge to the business and I look forward to working with him on achieving the company's growth plans."

Nirlep Singh Rai has taken over as Director (Technical) of India's National Fertilizers Limited. He had previously been Executive Director of NFL. For the past 18 months he has also been the chief executive officer (CEO) of Ramagundam Fertilizers and Chemicals Limited (RFCL), a joint venture between NFL, Engineers India Limited (EIL) and the Fertilizer Corporation of India Limited (FCIL). Nirlep Singh Rai is a graduete of Thapar University, and has 35 years of professional experience, including heading NFL's Nangal Unit for more than two years and being in charge of technical services and projects at the Bathinda unit. His experience includes technical services and operation and maintenance of large scale fertilizer plants.

Mitsui Chemicals has appointed **Osamu Hashimoto** as its new president and CEO effective from 1st April this year, according to the company. Hashimoto is currently Mitsui Chemicals' senior managing executive officer and the president of the company's healthcare business. Current president and CEO **Tsutomu Tannowa** has been appointed as the company's chairman of the board, also effective from 1st April this year.

Siroj Loikov has been appointed First Deputy CEO of PhosAgro. Loikov, who was previously Deputy CEO in charge of international projects and personnel policy, will coordinate the work of the company's headquarters in Moscow, its management company in Cherepovets and the company's production sites. He will also oversee the implementation of the PhosAgro's priority development projects and will be responsible for the appointment, development and assessment of the work of the company's top management.

Evgeny Novitsky, also First Deputy CEO at PhosAgro, will continue working to improve the system for interaction between the Company and government agencies, and he will also continue to oversee PhosAgro's GR communications at the federal and regional levels.

Mikhail Rybnikov, who has been appointed as an executive director, will focus on the integration of production, logistics and sales, further improvement of the economic efficiency of production and supply processes and cost management. He will also oversee the implementation of key IT projects and integrated planning, as well as improvement of industrial safety standards and the occupational health system at PhosAgro enterprises.

PhosAgro CEO Andrey Guryev said, "Today, the company is facing external challenges that require a prompt response and serious international expertise. We have a great deal of work ahead of us to build new partnerships, to implement major international projects, including in terms of expanding the use of environmentally friendly fertilizers, research and international trade, and to support the creation of a Green Standard for agricultural products in Russia and for its recognition as a global quality standard. Also on the agenda is the implementation of in-house projects to digitalise production and to restructure our occupational health and industrial safety functions. Meeting these challenges will require a great deal of commitment and attention. With this in mind, I decided to make some changes to the organisational structure of the Company's management and delegate some of my duties as CEO. These changes will ensure that equal attention is paid to finding solutions to challenges both within the Company and in interaction with our partners, and they will enable us to develop in new areas and achieve the key performance indicators outlined in our Strategy 2025. I am confident that Siroj Loikov's previous work experience in the Company – managing international projects and personnel policies – will help him succeed with the challenges before him." ■

Calendar 2020

! 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.

MAY

20-22 CANCELLED

IFS Technical Conference,
THE HAGUE, Netherlands
Contact: International Fertiliser Society,
PO Box 12220,
Colchester, Essex
CO1 9PR, UK
Tel: +44 (0)1206 851 819
Fax: +44 (0)1206 851 819
Email: secretary@fertiliser-society.org

28-29 POSTPONTED TO 2021

NH3 Event,
ROTTERDAM, Netherlands
Contact: NH3 Event Europe
Tel: +31 10 4267275
Email: info@nh3event.com

JUNE

2-4 POSTPONTED TO 2021

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

11-12 CANCELLED

IMPCA European Mini-Conference,
PORTO, Portugal
Contact: International Methanol Producers and Consumers Association, Belgium
Tel: +32 (0)2 741 86 83
Email: info@impca.eu

AUGUST

30-SEPTEMBER 3

65th AIChE Annual Safety in Ammonia Plants and Related Facilities Symposium,
MUNICH, Germany
Contact: Ilia Kileen, AIChE
Tel: +1 800 242 4363/+1 203 702 7660
Email: iliak@aiche.org

SEPTEMBER

27-OCTOBER 2

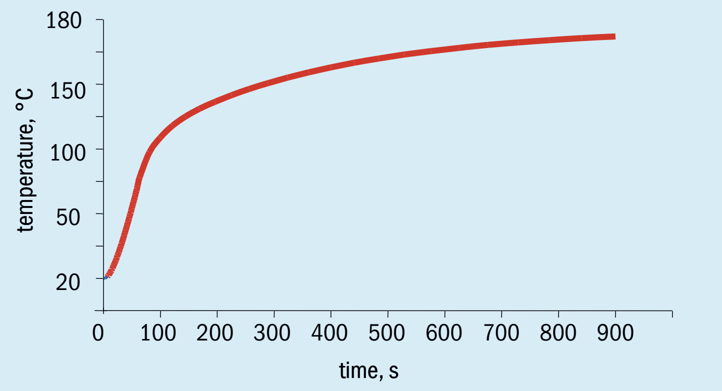
Ammonium Nitrate/Nitric Acid Conference 2020, HOUSTON, Texas, USA
Contact: Hans Reuvers, BASF
Karl Hohenwarter, Borealis
Email: johannes.reuvers@basf.com
karl.hohenwarter@borealisgroup.com
annaconferencehelp@gmail.com
Web: an-na.org

Plant Manager+

Problem No. 60 Urea process passivation and heating rate

A Stamicarbon urea plant attempts to start up after a scheduled turnaround. Due to maintenance issues, it is necessary to shut down and block in the synthesis section several times. Although licensor's procedures have been followed, several signs of active corrosion are noticed in the liner of the reactor. What could the cause be for this unexpected behaviour? Can sharing experiences from colleagues from other urea plants provide valuable support to find the root cause or even provide new insights into possible new causes? One observation is that the typical heating up rate of a liner in a reactor is much higher than recommended (refer to diagram). The condensation heat of steam heats up the liner much faster than the carbon steel pressure bearing wall. This creates stress on the liner and affects the lifetime of the liner. Another observation is a temperature rise in the reactor during a blocking in situation. This can be a cause for loss of oxygen required for passivation, resulting in higher corrosion rates.

Typical reactor temperature profile during heating



Cory Holt **of CF Industries in Canada initiates the round table discussion:** I was wondering if anyone could share their expertise with respect to urea process passivation and the possible modes of failure and if anyone has ever worked at a plant where passivation has failed. Our facility has recently shown physical signs of passivation failure in our reactor although all process data shows that we had oxygen in the system and proper passivation. We have recently come out of a scheduled shutdown and upon starting up we had a higher than normal N/C ratio as well as periods where we sat full in our HP loop while maintenance worked on some start-up issues.

Mark **of UreaKnowHow.com in the Netherlands asks for some clarifications:** Do I understand correctly from your story that you blocked in the synthesis section while dealing with some start-up issues? How long you did block in for? How many times did you block in and what was the time interval between block-ins?

Cory **replies:** There were a couple of issues and we attempted to start up three or four times. The longest period was a 22 hour period at which we know our ratio was greater than 4.

Mark **asks another question:** And how much time passed between the three or four blocking in periods?

Cory **answers:** For the first start-up we were nine hours into start-up when we went down for six hours. Then we attempted the second start-up over a three hour period and went down for five hours. The third start-up was over a two hour period and then we went down for 22 hours. We attempted the fourth start-up over a 22 hour period when we were again forced to go down due to our leak detection system ringing in exposing a leak. When we shut down to look at the leak we realised that our vessel had been stripped of its regular iron oxide coating due to passivation. Upon vessel entry we realised we had many more pin holes and advised that they were the result of active corrosion at accelerated rates. This tends to point a finger at loss of passivation but our DCS trends show that we had oxygen in our system for the duration of the start-ups.

We are wondering if our high ratio had something to do with losing passivation in the reactor or if it was consumed by a contaminant, perhaps something from turnaround cleanings.

Mark **replies:** No, never heard that a high N/C ratio causes active corrosion. On the contrary, Saipem claims a high N/C ratio reduces corrosion rates.

Blocking in is always a situation where hot carbamate solution is in a vessel where no new fresh oxygen can enter. The existing oxygen will be consumed by the normal passive corrosion and a chromium oxide layer will form as a passive layer. When the blocking in time is too long, the amount of oxygen becomes insufficient and active corrosion starts. Stamicarbon and Saipem claim that blocking in times should be limited to max 72 hours.

Your remark of a contaminant consuming oxygen is interesting, although I have never heard of that phenomenon.

Does anyone else have similar experiences of blocking in right after start up and seeing active corrosion?

To observe so many new pinholes after such a short time seems strange to me. One should realise that a pinhole is an area of low oxygen refreshment even if the bulk liquid has sufficient oxygen. I find it hard to believe that its growth would be accelerated so much.

Further stop-start and start-stop situations cause big stresses on the liner due to temperature differences between the liner and the carbon steel wall and weaker areas could form a leak.

Cory **replies:** Thank you for your expertise, it does allow us to eliminate our ratio concern. We will continue our investigation into the exact cause of our accelerated corrosion and loss of oxide layer. The active corrosion is hard for us to imagine as well but we

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 57 58 59 60

had the reactor inspected and some repairs during the turnaround which would not have missed these pinholes. We have found between 30 to 50 significant pinholes in just the bottom head alone and are inspecting the remaining zones now.

Muhammad Farooq of SAFCO in Saudi Arabia contributes to the discussion: I have some questions:

1. What is the lining material of your urea reactor and how long has it been in operation?
2. What is the inspection frequency?
3. What was the procedure applied for repair of previous pinholes and is it your annual practice or were these defects removed for the first time? Did you monitor the liner thickness yearly?
4. What is your feeding sequence and ammonia feeding temperature at start-up?
5. In the recent start-up, did you analyse the temperature profile for the urea reactor, especially at the reactor bottom?

Cory responds:

1. The lining material is a 316-SS and when we made repairs we used 25-22-2 SS as a weld material after grinding out the cavity. This liner is approx. 35 years old and the reactor was scheduled for re-lining in 2015.
2. We inspect during every scheduled maintenance outage which is every three to four years but due to other maintenance issues it has been every two years lately.
3. Repairs are always carried out in the same way as explained in point 1. As mentioned earlier, we were just coming out of a turnaround where minor repairs were being carried out and we had Stamicarbon do a pre-start-up inspection. They are currently doing our inspections now as well.
4. We usually warm the HP loop by feeding CO_2 and steam (CO_2 having oxygen from air blowers @ 0.6 vol-%) until we achieve 270°F at the top of the reactor. Then we feed in ammonia.
5. Yes, we looked at the temperature profile and actually realised we achieved the fastest heat up we have ever seen. Usually the heat up takes three to four hours but we almost achieved 270° within two hours. We are currently trying to prove whether the instrumentation was working properly as we cannot explain the accelerated temperature increase.

We are currently trying to narrow down our DCS data to see whether during our start-up attempts and block-ins we mismanaged the pulling of feed sequence or if somehow our instrumentation failed to show us loss of actual air. Initial data pulled has shown we were adding the right amount of air to our CO_2.

A question arising from this is whether circulating ammonia through the HP loop without CO_2 (which means no oxygen) could have somehow disrupted the passivation layer?

Kashif Naseem offers his advice: I think your heating rate is much too high. Keep it at around 30°C per hour and use fresh air instead of a mix of CO_2 and air for heating time passivation. I think the CO_2 mix during heating with steam as water is creating the corrosion issues. Both your materials are OK as SS316-L UG and BC.05. I don't think heating with a mixture of CO_2 and air is a good idea. Add the air separately during heating and then follow the start-up procedure. Consult your licensor, who can provide you with better information to resolve the issue of your liner thickness and whether electrodes used during welding are of proper material. Furthermore contact the material specialist of your licensor. We are also operating a 30-year-old plant. We inspect the plant every two years and we have replaced the liner material. The highest corrosion rates are in the vapour area at the top of the overflow funnel. The original material was SS316-L UG and the top portion has been relined with BC.05. The condition is now very good.

Cory replies: I agree that the heat up rate is too high. We usually stay around 30 to 50°F per hour during the heat up. With our process it is impossible to have the heat up rate that we had with just steam or CO_2 and we are not sure why it got as high as it did. We have our licensor involved but nobody knows yet how we got such a high heat up rate (almost 107°F per hour). We looked at our instrumentation to see if it was functioning properly and it looks like it was. Not sure if the heat up rate has anything to do with the active corrosion right now. It seems that all of our process data shows we had passivation (oxygen). We are now wondering whether we had a contaminant that might have given us an exothermic reaction of some kind that could have disrupted the passivation and produced a lot of heat? This theory seems unlikely to us now, but we cannot explain what happened.

Mark rejoins the discussion: Heat can be generated via: 1) condensation of steam and 2) formation of carbamate from NH_3 and CO_2. What were the pressures during the high temperature increase? Did you see temperature increase at all the thermowells or only certain ones?

I don't believe that circulating ammonia without CO_2 would cause problems with the passive layer. Is there any chance that chlorides or sulphur may have entered the synthesis? These components have an adverse effect on the passivation layer.

Cory replies: When the temperature took off, the loop pressure was roughly 20 psi (80°F) and increased to approx. 60 psi (240°F) within 1.5 hours. We have seen the temperature increase on all four thermowells in the reactor as well as the overhead gas line. I should also mention that the CO_2 flow was around 2,500 lb/hr during this time. At this time we have not found any indication of chloride or sulphur contamination.

Mark responds: Do you have graphs of the various temperatures versus time? Is 2,500 lb/hr the same amount of CO_2 you applied earlier? Passivation of stainless steels can be hindered by heat tints (as a result of welding) or by fouling caused by corrosion product (iron and chromium oxides) or metal parts (grinding).

Once active corrosion of carbamate starts it cannot be stopped and one needs to stop the plant, drain and re-passivate the surface. Is it possible that heat tints and/or fouling is playing a role?

Easa Norozipour of Khorasan Petrochemical in Iran shares his experiences: Please note that for passivation of all equipment in the synthesis section, one needs at least two hours injection of oxygen. That means if the plant was started and then stopped before two hours passivation had been achieved, in this case, the plant cannot be blocked in. In this scenario the synthesis section must be drained completely and re-passivated.

Did you check the interval of the start-up, shutdown and blocking in of your plant?

Cory replies: We do have trends, I have been trending every relevant DCS tag looking for discrepancies. Grinding or welding contaminants may be a possibility as we did do some repairs during the scheduled turnaround before these start-up events. This has been discussed and we are looking into that. What baffles us still is the significant heat up rate. We have looked at the intervals and discussed them with our licensor and everything looks like it was in place and confirmed with our DCS data showing we had oxygen.

Mark adds some further comments: It is not easy to control the temperature rise at the beginning, i.e. between 20 and 100°C. I don't think it's uncommon for plants to have a temperature increase higher than the recommended 30°C per hour during this range. Can anyone confirm this? Does anyone have actual temperature curves available?

Muhammad replies: I agree with Mark that the temperature rise during start-up when pressure is 20 kg/cm² and temperaure is more than 100°C (after passivation and heating) increases quickly especially during the first hour. However it is normal start-up behaviour at many plants. My other observations are:

- The reactor lining is very old and needs early replacement.
- The issue of passivation and heating up of the synthesis loop needs to be sorted out with the licensor's help. The impact on other equipment like the stripper, carbamate condenser and scrubber liner is not clear.
- The inspection frequency needs to be increased to yearly.

Muhammad comes back with a question: Have you analysed the CO_2 purity and concentration of H_2 in the CO_2 feed stream?

Cory replies: We have two oxygen analysers on the CO_2 compressor that were working fine and showed between 0.6 and 1 vol-%, which is normal. We have also trended the hydrogen content which was also normal (around 0.5 vol-%).

Mark replies: After evaluating the problems, this case has taught us that during blocking in of the synthesis section it is important to check the temperatures in the synthesis loop. These should show a downward trend. In case of upward trends it may mean some CO_2 or NH_3 is leaking into the synthesis section causing higher temperatures due to the exothermic carbamate formation reaction. In this case higher corrosion rates and active corrosion can occur.

Bob Edmondson, Technical Consultant in Canada shares his valuable experiences: I imagine highly improbable but a question to all is: with the reactor blocked in, "normal" oxygen would be about 0.02 wt-% in the reactor liquid. If, in one of the outages, the liquid level was above the funnel and steam was on the stripper at the normal pressure of some 11 bar, is it possible that a circulation loop is set up in which vapours are generated by the stripper and go to the reactor via the HPCC and over time drive off the dissolved oxygen which would be vented from the scrubber via a partially open vent (at minimum stop or worse, further open)?

If it is possible, somehow, to drive oxygen to below the level required for passivation it would be important to find the mechanism since it would be a risk for all 316L liners. It is a credit to CF Industries and to UreaKnowHow.com, that incidents like this can be made known and studied by other producers.

The Chengzhi Yongqing methanol to olefins unit, Nanjing, which began operations last year.

PHOTO: WISON ENGINEERING

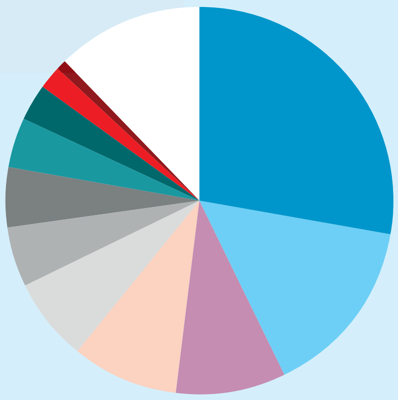
Methanol demand for olefins production

Olefins production from methanol, particularly in China, has come to dominate the methanol market over the past few years. However, environmental and market concerns complicate the outlook there.

As a syngas derivative, demand for methanol continues to see a faster rate of growth than ammonia. Over the past decade, methanol consumption has increased by more than 70%, from about 49 million t/a in 2010 to an estimated 84 million t/a at the start of 2020, representing an average annual growth rate of 6-7%. This is more than triple of the equivalent figure for ammonia, which has run at about 2% per year. Although methanol's rate of demand growth has slowed with China's slowing economy – now to closer to 4% year on year, it is still projected to reach more than 96 million t/a by 2023, by which time it would be just under half the size of the ammonia market.

Methanol's spectacular growth has been driven almost entirely by China's rapid industrialisation, and specifically due to two major strategic decisions by the Chinese government – firstly to try and replace oil-derived gasoline and liquefied petroleum gas (LPG) with coal-derived methanol and its derivative dimethyl ether (DME) as blendstocks to try and rein in China's increasing reliance on imported fuel. The second decisions has been to try and replace oil and gas-derived propylene and ethylene for plastics production with propylene and ethylene made from coal-based methanol instead; so-called methanol to olefins (MTO) production. MTO consumption has risen rapidly in China, from nothing in 2010 to millions of tonnes per year. So rapidly that, as Figure 1 shows, by 2023 it will have become the second largest end use for methanol globally, eclipsing more mature chemical uses such as acetic acid and methyl methacrylate (MMA).

Fig. 1: **Methanol demand by end-use, 2023**



Formaldehyde	28%
MTO	15%
Acetic acid	9%
MTBE/TAME	9%
DME	7%
Gasoline blend	5%
Solvents	5%
Biodiesel	4%
Methylamines	3%
MMA	2%
Chloromethanes	1%
Other	12%

Total: 96.7 million t/a

Source: IHS Markit

Methanol to olefins

The methanol to olefins process was developed by Mobil in the 1970s during their attempt to perfect the methanol to gasoline (MTG) process. Like MTG, MTO uses a zeolite catalyst in a fluidised bed to convert methanol into longer chain molecules, but stops the reaction sooner to produce predominantly a mix of ethylene and propylene. Zeolites are on a microscopic scale an aluminosilicate framework which can act as a 'molecular sieve', and this can control access to reactive sites. Mobil's work did not go beyond the demonstrator stage, but in the 1980s UOP (formerly Universal Oil Products, now owned by Honeywell) replaced silicon with phosphorus at some of the active sites to produce the SAPO-34 zeolite catalyst, which became the genesis of a commercial MTO process. UOP installed the technology at a demonstrator site in Norway in 1995 using commercial methanol as feedstock and showed that it could produce a tuneable mix of ethylene and propylene, as well as some higher chain molecules. In conjunction with a downstream olefin cracking process (OCP) provided by Total, which broke down higher chain hydrocarbons, and a polymerisation process, such as had been developed by ExxonMobil, commercial polyethylene and polypropylene could be produced.

However, there was limited interest in the methanol industry at the time, mainly because the process was perceived as being too expensive to compete with olefins produced the traditional way, from steam crackers. This began to change during the 2000s, for two reasons. Firstly, methanol plants were getting bigger, with 5,000 t/d becoming a standard size. This made achieving economies of scale easier. Secondly, UOP continued its catalyst development, producing UZM-8, which made the process more economical. A 10 t/d unit started up at Total's petrochemical complex in Feluy, Belgium in 2008- the first commercial UOP MTO plant. By now other companies were developing processes. Lurgi (now Air Liquide), already a major methanol technology licensor, introduced its methanol to propylene (MTP) process in 2002, and a unit was built in Iran in the mid-2000s. In China, the Dalian Institute of Chemical Physics had used a modified SAPO-34 catalyst to develop its own process in the 1990s, which was scaled up to a 16,000 t/a unit (in terms of methanol feed) at Sinopec Luoyang in 2006. Sinopec subsequently developed this into its own MTO process, and another came from China's Tsinghua University.

It was China which proved to be the game-changer, with methanol derived from coal rather than natural gas as the feedstock. The first commercial-scale plant became operational in 2010 at Baotou in Inner Mongolia. Since then, from 2010-2019, 25 plants have been built, with a total capacity of 15 million t/a of olefins production (equivalent to 26 million t/a of methanol demand). About 60% of this (9 million t/a olefins, 16 million t/a methanol equivalent) was in integrated facilities where the full production cycle of coal gasification, methanol production and olefins manufacture were present, mainly in the northeast of the country; the majority of coal production lies in the northern provinces of Inner Mongolia, Shanxi and Shaanxi, responsible for over 60% of domestic supply. However, the remainder depend on 'merchant methanol', and are often in coastal locations, buying methanol either from other producers within China, or on the international market, and these plants are responsible for China's rising tide of imports of methanol from overseas.

Changing environment

However, China's methanol and MTO capacity building is slowing down, for a number of reasons. The first and perhaps most important has been economic. When oil prices were high and coal prices were low, coal-based MTO capacity enjoyed a considerable margin over rival naphtha crackers. In the early 2010s, Brent crude prices were trading between $100-120/bbl. But from mid-2014, oil prices started to slide, as the Chinese economy started to slow, and increased production started coming on-stream from US tight/shale oil producers. At the same time, methanol prices were high, as demand from the slew of new Chinese MTO plants occasionally outpaced supply. From 2016, Chinese coal prices also started to rise, driving methanol prices back up at a time when oil prices remained more subdued, and leading to shutdowns in some Chinese MTO capacity.

The second reason has been environmental. There has been a concerted government crackdown on pollution, especially of coal-burning factories close to built-up areas. There is also an attempt to tackle the country's greenhouse gas emissions by encouraging moving to natural gas for

The Shenhua Baotou MTO plant; the world's first large-scale methanol to olefins facility.

PHOTO: SHENHUA BAOTOU

power and chemicals production. During the current Five Year Plan, China is targeting a reduction in coal's share of energy from 68% in 2015 to 58% in 2020.

Ethylene and propylene

The ethylene and propylene markets are also changing. On the propylene side, a switch to lighter crude slates and more ethane use at steam crackers, especially in the US, due to shale oil and gas production, has reduced propylene production from these plants. That has led to the development of more "on-purpose" propylene production facilities. There were some ideas that this could drive demand for more MTO production, especially focused upon propylene production. However, in the US on-purpose propylene production has mainly been filled by propane dehydrogenation (PDH) plants instead. MTO has captured only 6% of the propylene market in 2018, at 7.1 million t/a.

On the ethylene side, in 2019, total ethylene capacity from MTO units reached 5.21 million t/a, accounting for 21% of China's total ethylene capacity. However, China has decided to build a massive swathe of new ethylene steam crackers to take advantage of cheaper oil and gas prices. Between 2020 and 2025, 15 new steam crackers with a combined capacity of 17 million t/a are due to come onstream in China.

China is still building MTO plants. Ningxia Baofeng started up a 600,000 t/a MTO plant in September 2019, with a 1.8 million t/a captive methanol unit due to begin production in April 2020, and Nanjing Chengzhi Yongqing Energy's 600,000 t/a MTO plant, which depends on buying methanol from the merchant market, came on-stream in June 2019. Connell Chemical commissioned a new 300,000 t/a MTO plant in April 2020, using UOP's technology. Around 20% of China's new ethylene capacity out to 2025, or around 2.4 million t/a (4 million t/a in terms of methanol demand), is expected to come from MTO production. Some of the steam crackers were due to run on ethane imported from the US, and the rocky US-Chinese trade relationship over the past few years have very much complicated investment decisions there. However, there is no doubt that the difficult economics of the recent past due to high coal and low oil prices has very much slowed Chinese MTO investment for now.

United States

At the same time that China has been rapidly increasing methanol demand, the US has been rapidly increasing methanol production. Cheap shale gas has transformed the US chemical industry, and led to the reopening of shuttered capacity and the building of new plants, including Methanex's relocation of 2 million t/a of capacity from Chile to Louisiana. The rapid rise of US methanol capacity has led a number of companies to look at building export-oriented plants aimed squarely at supplying Chinese MTO production, and a number of Chinese companies have become involved in trying to develop methanol projects in the US. IGP Methanol is looking at building a 1.8 million t/a methanol complex in at Myrtle Grove, Louisiana, in partnership with China Cosco Shipping Energy Transportation Co., Ltd, and Jinguotou (Dalian) Development Co., Ltd (JGT). Yuhuang Chemical Industries is in a joint venture Koch Industries to build the 1.7 million t/a methanol Methanol One plant in St. James Parish Louisiana, due for completion this year. However, ambitious plans by the Chinese-backed Northwest Innovation Works (NWIW) to build three 1.7 million t/a methanol plants in Washington and Oregon states have run into difficulties with environmental opposition and permitting.

Other projects

Outside of China, methanol to olefin projects are thin on the ground. India has looked at the possibility of duplicating China's success at monetising coal reserves to generate domestic chemical production, but beyond a coal-based urea plant being developed at Talcher most of this remains purely theoretical. Iran had planned to build a gas-based methanol to olefins unit at Chabahar as part of the Mokran petrochemical hub development, but the re-imposition of US sanctions has complicated financing and licensing, and there is little progress at present.

However, there are still two active gas-based MTO projects under development. In May 2019, Uzbekistan's Ministry of Energy signed a project development agreement with a group of investors including Uzkimyosanoat, Air Products & Chemicals, Uzbekneftegaz and Enter Engineering to build a 500,000 t/a MTO plant in the country. Honeywell UOP and Haldor Topsoe are also said to be involved. Landlocked Uzbekistan is keen to develop its domestic gas reserves into downstream production, and is involved in a gas to liquids development at Oltin Yol due to be completed by the end of 2020.

Meanwhile, in Oman, China's Mingyuan Holdings Group Company announced in 2017 plans to set up the 750,000 t/a SEZAD methanol-to-olefins (MTO) plant alongside a 1.8 million t/a greenfield methanol scheme at the China-Oman Industrial Park at Duqm in southern Oman, at a cost of around $2.8 billion. The project has spent some time in discussions over gas pricing and availability, but is said to be moving to tender at the present time.

A dose of reality?

China's MTO boom has changed the face of the methanol market. However, all things come to an end. China's coal-based chemicals sector is coming under increasing environmental pressure from the government to deal with emissions. It is also a major consumer of water; a significant problem given that these plants are often located in China's dry northwestern regions, close to coal mines. In 2015 the Ministry of Environmental Protection imposed a rule limiting water usage, and some plants in dry provinces have implemented an innovative water rights trade system with farmers. Coal-based plants also generate large volumes of waste water that are difficult to cleanse and safely release.

Higher coal prices and lower oil prices – especially in the wake of the current Covid-19 crisis and consequent supply glut – have also incentivised the development of steam cracker capacity that is able to operate more cheaply than MTO plants in the current price environment and which is discouraging new coal-based MTO capacity in China. Previously, integrated coal-based complexes were believed to offer the best margins for MTO conversion, as they were able to decide for themselves what they 'charged' as a nominal price for their feedstock, but in a low methanol price environment, merchant plants might seem to have more of an edge. They too have issues to consider however; while there is new methanol capacity being built around the world, it is mainly in the US and Iran, both of which pose potential political risks in terms of supply.

Oman and Uzbekistan still hold out some hope for non-Chinese MTO capacity, but it seems that, for now at least, the MTO boom may have been and gone. ■

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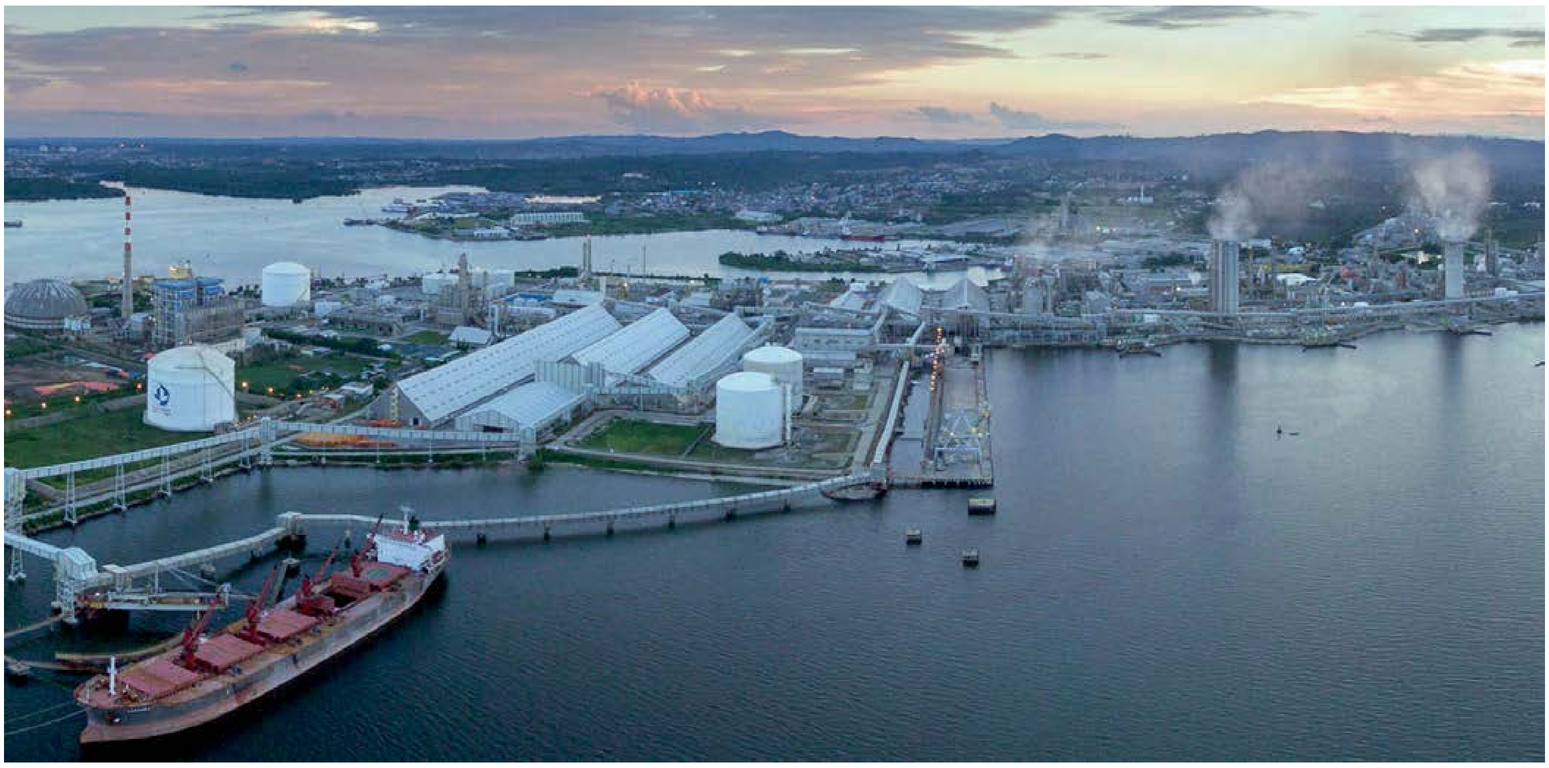

PHOTO: PT PUPUK KALTIM

Syngas expansions in Southeast Asia

Southeast Asia has been a major site for new syngas projects in recent years as countries such as Indonesia, Malaysia and Brunei continue to monetise their natural gas resources.

Above: PT Pupuk's Kaltim urea plant, Bontang, Indonesia.

From January 1st 2016 the 10 nations of the Association of South-East Asian Nations (ASEAN) formed the ASEAN Econ omic Community (AEC). Modelling itself on the European Economic Community (now the EU), the AEC aims to create a single market and production base for the free flow of goods, services, investment, capital, and labour within the ASEAN nations. The commitment marks another milestone on the road of the continuing economic development of this dynamic part of the global economy; the AEC countries between them now represent a $3 trillion economy, making it equivalent to the fifth largest economy in the world, and the third largest in Asia after China and Japan. However, of these, the five largest economies – the so-called ASEAN-5 – dominate the bloc's economic life; Indonesia, Thailand, Singapore, Philippines and Malaysia between them account for 85% of the AEC's economy. If Vietnam is added that figure rises to 94%; the relative contribution from Brunei, Cambodia, Laos and Myanmar is at present small one.

The AEC's GDP has continued to grow at a brisk pace, though slower than the 6.3% average it managed for the first half of the 2010s. Various factors such as the slowdown in the Chinese economy, US-Chinese trade tensions have slowed growth even as domestic demand continued to increase rapidly. In 2019 the Asian Development Bank calculates that the AEC economy grew by 4.8%, with Cambodia the fastest growing member at 7% and Brunei at just 1% on the back of falling oil prices. Projections for 2020 had been for 4.9% growth overall in the AEC, but the impact of the Covid-19 pandemic is likely to be a hard one, and the IMF now puts the prospects for the ASEAN-5 at a contraction of 0.6% for the year, albeit rebounding to a figure of 7.8% for 2021. The region's countries are highly open to trade and investment as well as tourism, all of which have been severely disrupted by the pandemic. Demand for exports such as palm oil and metals from Indonesia have fallen sharply, while the suspension of tourism has hit the Thai economy especially hard (tourism accounts for 20% of Thailand's

Table 1: **Gas reserves and production in Southeast Asia, 2018 (billion cubic metres)**

	Production	Exports	Reserves
Brunei	12.6	8.8	340
Indonesia	73.2	34.2	2,710
Malaysia	72.5	31.2	2,350
Myanmar	17.8	7.8	1,150
Papua New Guinea	11.2	9.5	175
Thailand	37.7	-12.2	180
Vietnam	9.6	0	630

Source: BP

GDP). Likewise the collapse in oil, gas and coal prices will have a major effect on Indonesia, Malaysia and Brunei. Indonesia and Malaysia's fossil fuel exports represent 25% and 16% of GDP respectively, but for Brunei the figure is 90%.

Feedstock resources

Southeast Asia remains relatively resource rich in terms of gas and coal reserves, the former as shown in Table 1. Indonesia and Malaysia are the regional giants in terms of natural gas production, but there are also significant reserves in Myanmar, and while Brunei and Papua New Guinea (the latter not part of ASEAN) have more modest reserves, their relatively small populations mean that they are still major producers and exporters of gas due to a lack of domestic demand. Vietnam's gas reserves have climbed rapidly in the past few years due to a string of new gas discoveries.

The scattered island nature of the east of the region, across Malaysia and Indonesia to New Guinea, and the mountain chains of the west of the region, have discouraged pipeline building, and prompted a focus on LNG development; Indonesia and Malaysia were among the pioneers of the LNG industry, dating back to the gas boom of the 1980s. As a consequence, most gas exports from Southeast Asia are as LNG, predominantly to Japan, but also to China and South Korea, although Myanmar exports gas by pipeline, mainly to neighbouring Thailand, but also some to China. Indonesia also exports gas by pipeline to Singapore.

There are also major coal reserves in the region. Indonesia has by far the largest reserves, and produced 323 million tonnes of oil equivalent (mtoe) in 2018, of which it exported two thirds, mainly to China. Indonesia is actually the world's second largest coal exporter, not far behind Australia. Vietnam is also a significant coal producer, at 23 mtoe in 2018, but it consumes more coal than it produces and imports coal from Indonesia to make up the difference.

The ASEAN nations have set an aspirational target to incorporate 23% of renewables into their energy mix by 2025. However, while Singapore is heavily focused on new solar generation, elsewhere progress is likely to be more incremental. Even so, there is a push to replace coal-fired power generation with gas and renewable electricity, and this is likely to be a factor in the energy mix of countries such as Indonesia and Vietnam going forward.

New gas development

Continuing development of gas projects in the region is driven by rapidly rising energy demand; twice as fast as overall global energy demand growth. Energy demand in the AEC grew by 80% from 2000-2020, and is forecast by the International Energy Agency (IEA) to grow another 60% from 2020 to 2040. This is leading to a major focus on gas exploration and development, such as the recent discovery at the Song Hong Basin offshore of Vietnam. A total of 54 oil and natural gas projects are expected to begin operation in Southeast Asia between 2019 and 2025, with particular focus on Indonesia, Malaysia, Vietnam, Cambodia, Thailand and Myanmar. Together these projects are projected to represent 8.1 billion scf/d of global gas production in 2025 (80 bcm/year). While Indonesia and Malaysia continue to represent the most developed regional gas players, countries such as Cambodia, Thailand and Vietnam have considerable potential for growth.

Major gas projects include the $6.8 billion Vietnam Gas Project, which is looking to exploit Vietnam's significant offshore gas reserves. PetroVietnam is working with Mitsui and PTT in developing the Kim Long, Ac Quy, and Ca Voi fields as the Vietnam Gas Project. Production at capacity will be 640 million scf/d of gas and 21,000 bbl/d of liquids, with operations due to begin in 2021.

In Indonesia, declining output from mature gas fields is leading to a search for more gas to maintain the country's LNG exports. Indonesia's LNG exports have fallen from 24 million t/a in 2010 to 13.5 million t/a in 2018 due to increasing domestic gas demand. Indonesia now plans to double LNG production by 2030 with a string of new gas developments. Largest among these is the $6 billion Chevron-operated Indonesia Deepwater Development (IDD). First gas is scheduled for 2024, from the Gendalo, Gehem, Bangka and Gandang fields in the Kutal Basin, but arguments over economics and production sharing may push this out to 2025-26. Peak production at IDD is forecast to be 1.1 billion scf/d of natural gas and 31,000 bbl/d of condensate, with the gas going to feed the Bontang LNG complex. Elsewhere, construction is progressing on the BP-operated Tangguh expansion, which will add a new 3.8 million t/a LNG train to the existing Tangguh LNG plant, taking capacity up to 11.4 million t/a. Gas feed to the plant is scheduled to begin next year and reach capacity in 2022. The Badak LNG plant is due to see a new gas tie-in from the Merakes field in 2021. Finally, INPEX and Shell are developing the huge Abadi field, with an associated LNG project, although the remoteness of the site is posing problems for the development and production may not begin until 2028.

In Malaysia, Petronas is deploying a second floating LNG (FLNG) plant in the Rotan field in the South China Sea off the coast of Sabah this year, at a cost of $2.5 billion, although plans to export LNG to Thailand were called off last year by the Thai authorities. Finally, Myanmar is building the Mee Laung Gyaing LNG import terminal and an associated 1.3 GW power station to generate power from gas supplied by floating storage regasification units (FSRU).

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 57 58 59 60

Fig. 1: **Southeast Asia's natural gas and nitrogen industries**

Fertilizer production

Regional ammonia and methanol production has developed, as in so many areas of the world, on the back of natural gas discoveries and exploitation. In the 1970s and 80s the fragmented nature of the region with its myriad islands meant that outlets for many gas finds were limited due to lack of pipeline capacity, and a number of ammonia-urea projects were built, particularly in Indonesia, based on what was then 'stranded' natural gas. A plant backed by ASEAN was also built at Bintulu in Malaysia in the 1980s. By 1989 Indonesia had 5.3 million t/a of urea capacity and was the largest exporter in the region.

Six more urea plants followed in Indonesia in the 1990s and 2000s; two at Bontang, one at Lhokseumawe, one at Cikampek, one at Gresik, and a replacement plant for Pusri at Palembang, which added in total another 2.7 million t/a of urea capacity. Malaysia also built two new plants, at Kerteh and Kedah, and also became a significant exporter. However, by now rapid industrialisation in the two countries was leading to greater demands for gas for power production, especially in Indonesia, while maturing gas fields began to reduce feedstock availability to some locations, leading to the closure of the ASEAN Aceh urea plant in 2004. Urea consumption also rose within Indonesia, and the government began to restrict exports at certain times of year. Urea exports peaked in 1997 at 2.4 million t/a, and by 2004 fell to below 500,000 t/a. Rising gas prices meanwhile were impacting upon company margins.

In spite of this, Indonesia has continued to build newer more modern facilities to replace older plants that are being taken out of service. In 2015, Kaltim started up its Kaltim-V urea plant, with a capacity of 1.1 million t/a of urea, to replace the ageing Kaltim-I plant, and in 2017 Pusri likewise replaced the Pusri II plant with the 900,000 t/a Pusri IIB. By 2018, Indonesian urea production had risen to 7.4 million t/a, and exports were back up to 1.1 million t/a. In December 2018, a new 700,000 t/a standalone ammonia plant was commissioned by PT Panca Amara Utama (PAU) in Sulawesi, Indonesia.

In Malaysia, Petronas has developed its Sabah Ammonia Urea (SAmUr) plant to monetise offshore gas from Sabah and strengthen Malaysia's position as a regional urea exporter. This plant started up at the end of 2019 with a capacity of 700,000 t/a of ammonia and 1.2 million t/a of urea, taking Malaysia's urea capacity to 2.6 million t/a.

Vietnam, meanwhile, had built two plants with assistance from the USSR based on coal gasification, but major offshore gas discoveries in the south of the country in the 1990s led to two large urea plants being built there, the second completed in 2012 to take capacity to 2.6 million t/a.

Myanmar built five small urea plants but ongoing sanctions relating to the military dictatorship meant that only three (currently just one or two) were able to operate, and those at reduced capacity (150-200,000 t/a) due to shortages of equipment and intermittent gas supplies. Plans from the 1990s to build a urea plant based on the Yadana gas project were stymied by sanctions and financing difficulties.

Methanol

On the methanol side, development has been more limited. Indonesia has two plants with a combined capacity of 1.0 million t/a. Malaysia's Petronas has built two plants at Labuan with a combined capacity of 2.4 million t/a, making it the fourth largest methanol producer in the world and the largest single company in Asia, but the two plants have been plagued by operating issues in the past few years. Brunei joined the region's methanol producers in 2010 with the 850,000 t/a Brunei Methanol Company plant at Sungai Liang Industrial Park. Domestic demand is limited in most countries, and most of the methanol is exported, with China the major customer.

New projects

At the moment new capacity is being developed in countries with significant gas reserves and surpluses which are seeking to monetise them, which essentially means Brunei, Malaysia and Papua New Guinea. In Brunei, a $1.8 billion ammonia-urea plant is under construction at Sungai Liang by Brunei Fertilizer Industries. The new greenfield fertilizer complex will have a production capacity of 2,200 tons of ammonia and 3,900 tons of urea per day. The EPC contract was won by thyssenkrupp Industrial Solutions, who also are providing their proprietary ammonia technology. Stamicarbon are licensing the urea plant, and TKIS their urea granulation technology.

In Malaysia, the state of Sarawak has the largest share of the country's gas reserves, around 54%. The state government is keen to develop this resource as a feedstock for chemical and petrochemical production, and so has sponsored state-owned Sarawak Petchem Sdn Bhd to build a new 1.7 million t/a mega methanol plant in the region. Petronas will market the plant's output via its marketing arm Petronas Chemicals Marketing (Labuan) Ltd (PCML). The project is expected to come on stream in 2023.

Papua New Guinea signed off last year on a new $13 billion LNG project at Port Moresby with 5.4 million t/a of capacity. A share of this capacity will be allocated to domestic supply, with the aim of helping PNG achieve its goal of expanding electricity coverage to 70% of the country by 2030. Also part of the project is a new $800 million methanol plant, being developed by Sojitz and Kumul Petroleum. Japan-based Sojitz already owns 85% of Kaltim Methanol Industri in Indonesia and sells its offtake regionally. The timeline for the LNG plant envisages a start-up as soon as 2024, though this looks ambitious in the current environment. There is as yet no firm timeline or capacity for the methanol plant.

Indonesia, meanwhile, has for some years been considering a coal gasification based plant. In 2019, a heads of agreement was signed between coal miner PT Tambang Batubara Bukit Asam (PTBA), fertilizer manufacturer PT Pupuk Indonesia and state-owned oil and gas holding company Pertamina – as well as chemical manufacturer PT Chandra Asri Petrochemical. The plant, to be built in the Bukit Asam Coal Based Special Economic Zone (BACBSEZ) on South Sumatra, is currently slated to produce 500,000 t/a of urea, as well as methanol with downstream 400,000 t/a of dimethyl ether (DME) capacity and 450,000 t/a of polypropylene via methanol to olefins production. After languishing for some years, the project seems to be moving forward again, with the government indicating that it would like to tender soon for completion in 2025. There is also a coal gasification project under discussion for Riau province, again with DME as the downstream product.

Table 2: **Urea production and demand, ASEAN countries, 2018, million t/a**

	Production	Consumption	Imports	Exports
Indonesia	7.4	6.3	0	1.1
Malaysia	1.8	0.8	0.3	1.2
Myanmar	0.1	0.5	0.4	0
Philippines	0	0.9	0.9	0
Thailand	0	2.6	2.6	0
Vietnam	2.2	2.5	0.5	0.2
Total	**10.4**	**12.2**	**4.0**	**2.2**

Source: IFA, APPI

Regional supply/demand balance

Almost all of the nitrogen production in the region is based on urea, apart from some ammonium sulphate and nitrate production in Indonesia. Table 2 gives a breakdown of urea production and consumption across Southeast Asia, listing the major producers and consumers.

Indonesia, and to a lesser extent Malaysia and Vietnam are the major producers, and of those, only Indonesia and Malaysia are major exporters. Vietnam, although it technically has a surplus of urea production, has remained a slight net importer in recent years because of domestic costs of production and production and financial issues with its coal-based plants. Indonesia is also far and away the largest consumer, consuming almost half of regional urea demand, with Thailand and Vietnam the other most significant users of urea, and Malaysia and Philippines more moderate consumers. Looking forward, nitrogen consumption in the region is relatively mature and unlikely to increase dramatically, although there is scope for future growth in Myanmar, Laos and Cambodia.

On the supply side, Malaysia, Brunei and Papua New Guinea are currently the main nations looking to monetise their natural gas surplus. However, there is certainly room for more gas development in Indonesia, depending upon government will. The current programme to double LNG production by 2030 may open up the possibility of more gas-based fertilizer or methanol export, but much depends on pricing. Indonesia's coal gasification plans, meanwhile, may find themselves constrained by the indebtedness of PT Bumi Resources, the main coal supplier. Bumi is aiming to settle a $1.7 billion debt in 2022 and conclude a mandatory bonds-to-equity conversion by 2024 following its debt restructuring process in 2017.

Myanmar, now that international sanctions have eased with the accession of president Win Myint, protégé of Aung San Suu Kyi, also has plenty of natural gas, as well as a ready made domestic market for fertilizer. At the moment the government is looking to modernise No. 3 Chemical Fertiliser Plant (Kyaw Swa), owned by Myanmar Petrochemical Enterprise, and re-start production there, but there is room for more capacity in the country beyond the 600 t/d this would add. However, ongoing criticism of the country's treatment of Rohingya Muslims has helped deter international investors. ■

A new generation of methanol catalysts

Haldor Topsoe has launched a new methanol synthesis catalyst, *MK-181 PRIME*, based on new technology developed via close study of copper-zinc interactions on the catalyst surface.

The methanol market has grown at a rapid pace over the past decade, virtually doubling in size from 43 million t/a in 2009 to 84 million t/a in 2019; an average annual growth rate of 7%. Much of this growth has been driven by rapidly rising demand in China, where methanol is widely blended as a vehicle fuel or converted into dimethyl ether or polyethylene and polypropylene – the latter via methanol to olefins (MTO) processes – in addition to the conventional chemical derivatives such as formaldehyde, methyl methacrylate and acetic acid which predominate in the rest of the world.

At the same time, however, producers are also under increasing pressure to lower the environmental footprint of methanol manufacture, in particular emissions of carbon dioxide and equivalent gases to the atmosphere, which contribute to climate change. A variety of different approaches are being pursued to achieve this, from the use of alternative feedstocks, including landfill gas, biogas from the degradation of organic waste, gasification of municipal waste or biomass, or even electrolysis of water using renewable electricity to produce hydrogen, which can then be directly combined with carbon dioxide.

These different approaches impose different requirements upon reforming and methanol synthesis catalysts. In Denmark, Haldor Topsoe has been engaged in intensive research and development efforts to produce a suite of catalysts suitable for such disparate technologies, one of the most recent fruits of which has been the *MK-317 SUSTAIN* methanol catalyst, designed for the direct conversion of carbon dioxide into methanol with high stability towards CO_2, and capable of operating at low temperatures to achieve better hydrogen efficiency. The catalyst is expected to be installed at a renewable methanol facility in Sweden.

Increased efficiency

However, as promising as these different approaches may be, most are experimental or in development phases and only represent a small slice of world methanol production. To achieve reductions in carbon footprint on a significant scale today, and indeed for the foreseeable future until there is widespread adoption of low carbon technologies, will mean utilising present methanol production technology, mainly based on natural gas feedstock or, in China, coal. In such a case, the target must be to increase the efficiency of the process as much as possible in order to lower the energy input requirement per tonne of methanol produced. On a global scale, even an increase in efficiency of 1 or 2% for the world's methanol production could lead to reductions in CO_2 output of up to 500,000 t/a.

For such applications, Haldor Topsoe have been working on improvements to their existing catalyst range, currently based around their high performance *MK-151 FENCE* catalyst. Launched just over 10 years ago as an upgrade to the previous *MK-121*

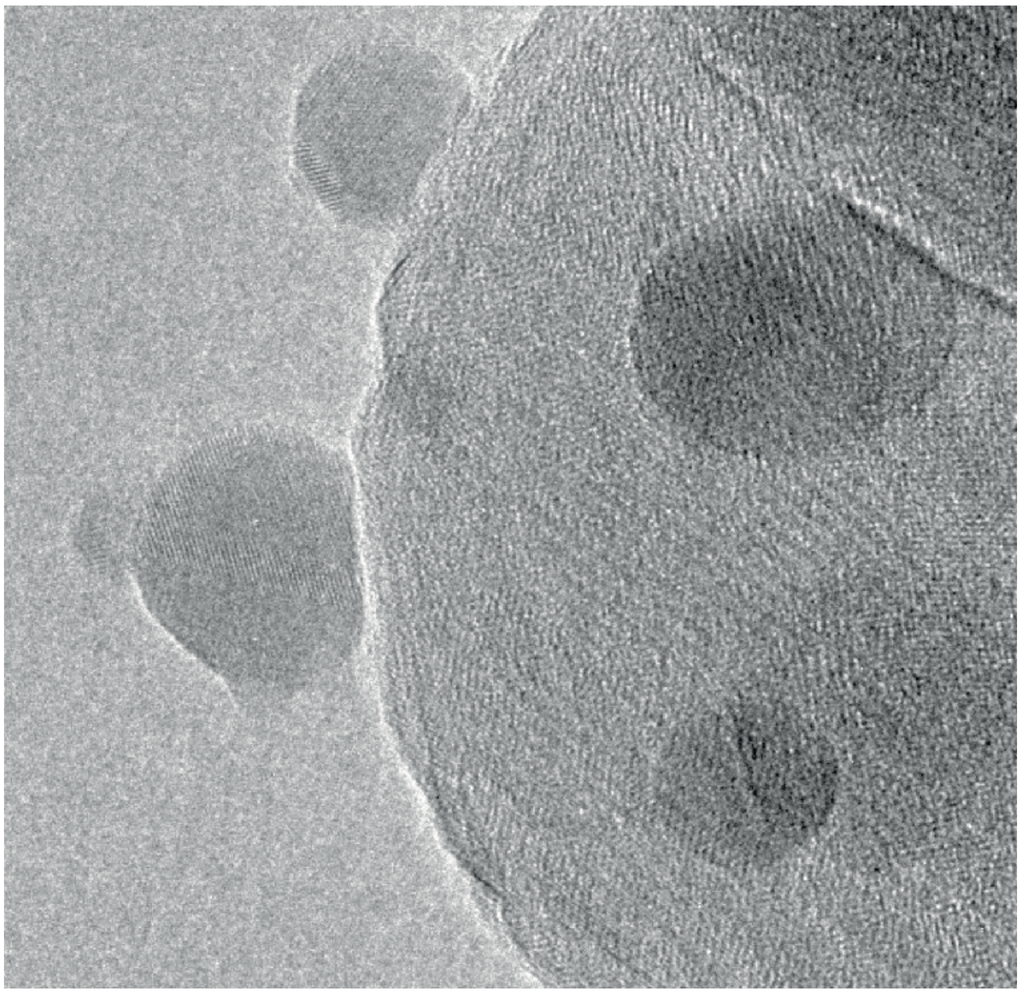

PHOTO: HALDOR TOPSOE

Fig. 1: Electron microscopy image of zinc oxide particles interacting with copper particles.

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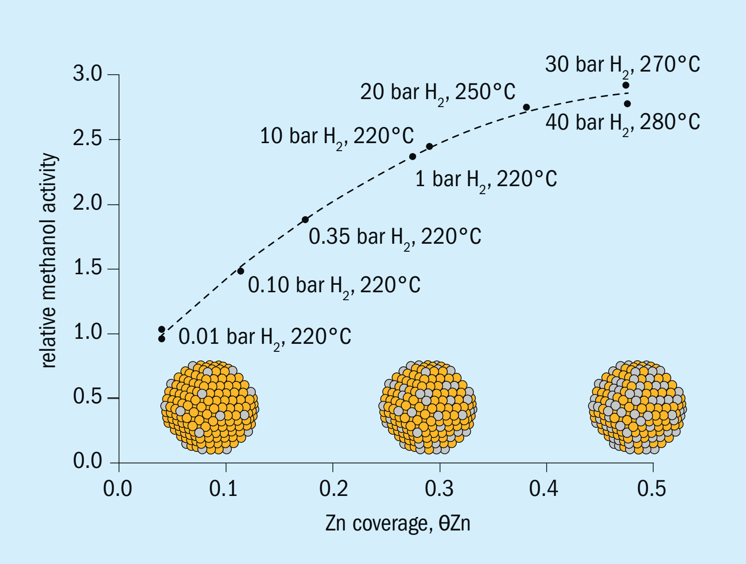
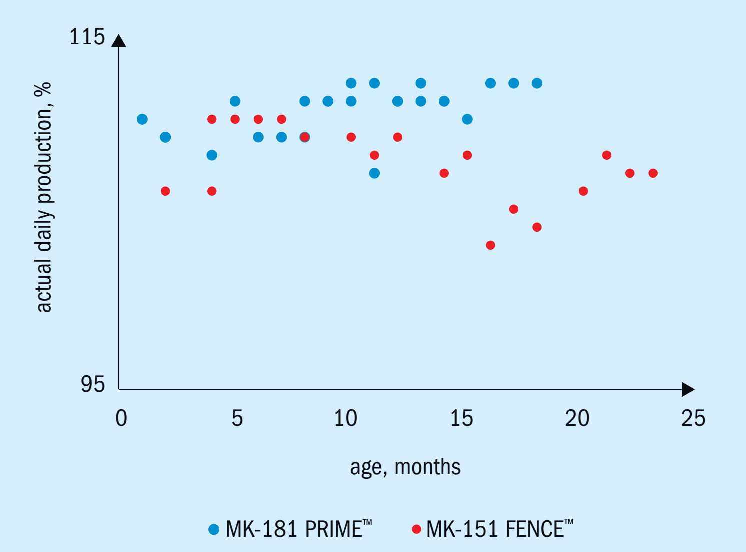
Fig. 2: **Methanol synthesis activity as a function of the Zn coverage of Cu nanoparticles in a copper catalyst**



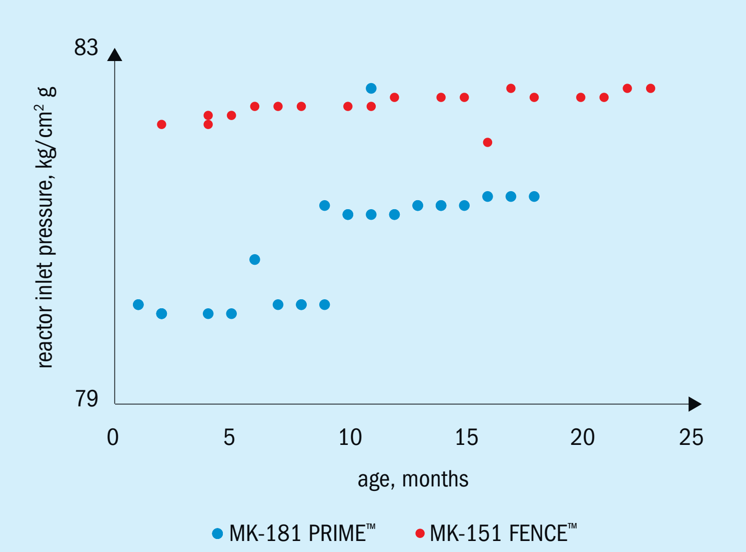
Source: Haldor Topsoe

Fig. 3(a): **Increase in production achieved, industrial experience**



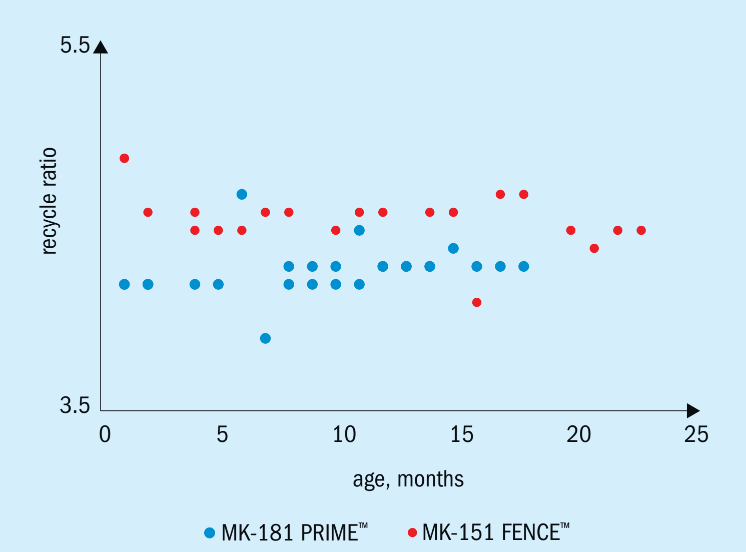
Source: Haldor Topsoe

Fig. 3(b): **Reduction in reactor inlet pressure, industrial experience**



Source: Haldor Topsoe

Fig. 3(c): **Reduction in recycle ratio, industrial experience**



Source: Haldor Topsoe

catalyst, *MK-151* uses zinc oxide (ZnO) and alumina (Al_2O_3) to create a barrier between active highly dispersed copper particles to help prevent sintering under the reducing conditions of methanol synthesis[1].

MK-181 PRIME

MK-181 is based on leading edge research to develop a methanol catalyst with the highest activity while retaining the high stability of the previous generations of MK catalysts. The aim has been to deliver higher reaction rates and hence efficiency, allowing producers to choose between achieving lower specific energy consumption or higher methanol production for a given charge of catalyst. As with previous generations it is supplied as 6mm x 4mm pellets and it is made from copper nanoparticles dispersed in alumina with a zinc oxide promoter. However, Topsoe's research, conducted in cooperation with the Center for Individual Nanoparticle Functionality (CINF) at the Department of Physics of the Technical University of Denmark[2], showed that the size of the zinc oxide nanoparticles was found to influence the coverage of the copper surface with nanoparticles of Zn, and a higher coverage was found to result in higher activity. Based upon this insight, Topsoe has developed a unique way of boosting the methanol synthesis activity via what it calls "PRomotion by Inter-Metallic Engineering" – or *PRIME*™ technology.

Mechanism

A typical methanol catalyst consists of copper (Cu) nanoparticles mixed with nanoparticles of ZnO and Al_2O_3. Although Cu can function alone as a methanol synthesis catalyst, its activity is substantially boosted by the interaction with ZnO, which on its own has only negligible catalytic activity. Using transmission electron microscopy (TEM), Topsoe's researchers studied reduced methanol catalyst and found that it consisted of an agglomeration of Cu, ZnO, and Al_2O_3 nanoparticles in intimate contact. Figure 1 shows an electron microscopy image of zinc oxide particles (the small spheres) interacting with copper particles (the larger spheres). The crystalline matrix of the particles can be observed as the pattern of parallel lines on the particles. The copper lattice fringes extend to the projected surfaces of the copper nanoparticles NPs without changes in their spacing and structure, indicating that the copper surfaces are in direct contact with the surrounding gas. The copper surfaces can thus only be covered with a sub-monolayer of zinc, confirmed with x-ray photoelectron spectroscopy (XPS) measurements.

It appears that in the reducing environment of the process, a copper-zinc surface alloy is formed by incorporation of zinc atoms into the copper nanoparticles, via equation 1.

$$ZnO(s) + CO = Zn + CO_2 \qquad (1)$$

High zinc coverage is observed within a few hours on exposure to synthesis gas at 220°C, eventually reaching a steady state equilibrium. Topsoe's work with the Technical University of Denmark attempted to quantify this via modelling at different gas pressures and temperatures, representative for methanol synthesis, for a series of copper surfaces, including steps, edges, and corners. It found that zinc coverage increases steeply for lower CO/CO_2 ratios and more slowly at higher CO/CO_2 ratios, as a result of Zn-Zn interactions. This was then confirmed for real samples via a variety of experimental techniques. Furthermore, synthesis activity appeared to be strongly related to the amount of zinc alloyed at the copper surface (Figure 2).

The model predicts that catalysts prepared with smaller ZnO particles will be very active because of an enhanced spillover of Zn to the Cu surfaces; hence, it is the thermodynamic activity of the promoter phase, ZnO, that determines promotion of the methanol synthesis activity. It also indicates that very small Cu nanoparticles (<100Å) will lead to lower Zn coverage and hence potentially lower methanol conversion. An alternative approach to optimising the performance of the methanol catalyst is to enhance Zn in the Cu surface by increasing the reduction potential of the synthesis gas via high $CO:CO_2$ ratios (around 10 seems to be optimal).

Benefits

Optimising the zinc coverage of the copper nanoparticles in this way allows *MK-181 PRIME* to have very high activity, which in turn leads to a high per pass conversion rate. This means that less unreacted gas needs to be recirculated, lowering energy consumption and improving the overall reaction efficiency. This not only lowers the cost of producing each tonne of methanol, but also reduces the CO_2 generated in doing so. In addition, *MK-181 PRIME* is designed for the highest possible selectivity for methanol synthesis, which means that fewer by-products are formed during the reaction. This improves feedstock utilisation on the one hand, and also reduces the energy required for downstream distillation, which again reduces CO_2 emissions per tonne of methanol through improved energy efficiency. Finally, the combination of *PRIME* and *FENCE* technologies in *MK-181 PRIME* leads to a high and stable conversion rate over the entire catalyst life cycle.

Industrial experience

Two charges of *MK-181 PRIME* are currently in service with major methanol producers, and have demonstrated significant improvements in plant performance. Being one of the worlds most experienced methanol producers and keen to continuously improve their production, the customer elected to assess *MK-181* PRIME at their plant, which has extensive R&D capabilities. Following an initial evaluation, the company installed a charge of *MK-181* in early 2018. Figures 3(a)-(c) show some of the results that have been obtained compared to the previous catalyst charge. The experienced operators have been able to optimize production to achieve an approximately 3% improvement in performance. As noted above, they found that as well as a higher production rate, the recycle ratio is also lower, providing energy savings in the recirculator. Higher per pass conversion also means that the loop pressure remains low for a longer period of time from the start of the run, and a lower reactor inlet pressure reduces the compression demand on the syngas compressor, meaning that the plant was able to simultaneously achieve higher production and lower energy consumption, boosting profits while reducing environmental impact. ■

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The growing importance of technical services

As existing facilities grow older, service requirements increase. Equipment needs to be low maintenance and back in operation quickly after service and repair. Technology licensors are expanding their technical services with new digital tools, using digitalised expertise with real time insights and data driven analytics to boost chemical production and ensure that equipment operates reliably and efficiently, while maintaining product quality.

CASALE

Casale's digitalised expertise at customer service

J. V. Goicochea, A. Guarino, L. Rugnone, F. Menghini and S. Ravasio

The operation of chemical plants is a highly complex task due to the intricate interaction between chemicals, reactions, flow dynamics, etc. and from the need to manipulate a large set of variables to reach production targets, while maintaining optimum efficiency. Plant performance and its associated operating costs are impacted by both external and internal factors, for example, changes in the composition of the raw materials, weather conditions, as well as the experience and expertise of the operators. Plant performance is measured in terms of key performance indicators, including the overall production, specific energy consumption, plant stability, emissions, etc.

The close relationship between process operation and mechanical reliability adds to the complex operation of chemical plants. Often, plants are highly stressed by the operating conditions, which are kept close to their limits to maintain profits. This is particularly true for old plants whose mechanical reliability and related performance must be carefully monitored. Therefore, it is of utmost importance to develop maintenance programs aimed at improving reliability. The operational data becomes a fundamental part of a more extensive analysis that not only supports the diagnostics of failures but also helps to understand the root causes during mechanical inspections.

Chemical plants generate a huge amount of data on a daily basis. The data is mostly used for DCS visualisation and archival purposes, and for helping field operations and control. Unfortunately, due to the lack of resources and time, prominent trends and data correlations are seldom analysed thoroughly, leading to suboptimal operation. Furthermore, in critical scenarios, expert advice is normally needed, if not mandatory.

To help plant operations, support maintenance and improve mechanical reliability, Casale has created a portfolio of digital products that takes full advantage of the existing plant data infrastructure:

- Casale Remote Engineering Service (CARES);
- Casale Operator Training System (OTS);
- Casale Model Predictive Control (MPC);
- Casale smart instrumentation.

Casale Remote Engineering Service (CARES)

CARES is a remote engineering service which provides assistance to plant operators and managers, supporting the achievement of their daily operational targets, improving process reliability and supporting mechanical inspections.

At the core of remote engineering services, Casale uses an automatic data reconciliation algorithm to convert measured data from the plant into physically-consistent values that respect global and local mass and energy conservation around units of operation, sections of the plant or the whole plant. An important feature to note is that the data reconciliation tool uses the same Casale proprietary models and thermodynamic packages regularly used for designing the plants: a critical feature that ensures the highest possible fidelity of the service.

The data reconciliation is much more than a process simulation, it is a tailor-made process model built up to reveal the real time performance of the plant, including full information of the critical process streams, which cannot be directly measured in the field, e.g. the full composition at the reactor outlet. Thus, calculated key performance indicators (KPIs) based on reconciled data offer great value to clients, providing an effective way to identify critical aspects of the plant operation and their temporal behaviour.

Data reconciliation also allows the identification of faulty readings and anomalies in the field instrumentation used to guide the process operation. Thanks to the power of the data reconciliation, abnormal deviations among reconciled quantities and field measurements are promptly detected and thus used to alert critical conditions into the plant. Essentially the identification of erratic readings of the instrumentation may suggest the underperformance of a plant section or the drift of parameters towards critical operating conditions and constraints.

For instance, in the case of urea plants, CARES provides value not only through the KPIs of the critical HP synthesis equipment, but also alerts the operator of critical conditions which can impair the reliability and equipment life. The example of the HP stripper is typical: specific KPIs monitor the equipment performance such as the NH_3 stripping efficiency providing guidance for process optimisation, while at the same time the stripper temperatures are kept under strict surveillance to alert the attainment of critical thresholds for corrosion or anomalies in the reading of the temperature transmitter which may represents a risk for equipment integrity.

Moreover, the operating conditions of such critical equipment, such as the temperature and inlet/oulet composition of the process solution, provide valuable information used by CARES to complement mechanical inspections and the diagnosis of findings by supporting pro-active maintenance programs.

How does CARES help clients?

Using a combination of advanced analytics and expert advice provided by the customer care team, plant behaviour is analysed, focusing on the aspects that are most relevant to the client:

- **Boost plant productivity:** CARES provides continuous support to utilise the plant capabilities at its best and to achieve maximum production.
- **Improve plant efficiency:** CARES provides guidance for reducing emissions, energy consumption and to achieve plant stability.
- **Troubleshooting:** CARES offers support in identifying the root cause of plant upsets and unexpected shutdowns, providing solutions to improve reliability and increase the on-stream factor.
- **Improve understanding and confidence in plant operation:** Take the right action at the right moment. Feel confident and conscious of the plant behaviour. This is not an easy task. CARES provides valuable advice which allows improved knowledge and confidence of the plant operation and production process.
- **Identify plant limitations:** Identify equipment bottlenecks and operating procedures that are hindering plant performance.
- **Supporting pro-active maintenance and inspection programs.**

Expert advice is communicated to clients via a web dashboard available anywhere, anytime via a secure web page. The aim of the web dashboard is to provide a clear view of the plant and equipment performance using simple visual indicators (widgets) for the key performance indicators. The dashboard is not limited to displaying current values of the indicators but can also be used for trending and performance analysis: the user can inspect the timeline of the operation by selecting any date in the main interface window.

The dashboard service is completely customised according to customer needs. It is provided with a chat interface to maintain a direct link with the Casale customer care team and is complemented by periodic conference calls and written reports. The customer care team is also ready to support clients when problems occur. It is like having a Casale expert on site every day. Fig. 1 shows screenshots (of a section) of the CARES dashboard and related KPIs.

Fig. 1: **Screenshot of the CARES dashboard showing examples of KPIs widgets**

Source: Casale

Benefits

Clients that use CARES have benefitted from the following:

- Direct operational advice and suggestions from the customer care team based on the behaviour of KPIs. Casale team experts comprise a broad spectrum of competences ranging from process to mechanical and instrumentation engineering.
- Critical insights of asset performance, leveraging Casale proprietary models that enable equipment parameters to be calculated that cannot be directly measured (e.g. catalyst health, catalyst activity, conversion efficiency, heat exchanger performance).
- Analysis of a full set of reconciled values for the different sections of the plant. Information that can be easily used to

tune or replace sensors that consistently exhibit large discrepancies between measured and reconciled values.

- Visualisation of performance and alert indicators of single units and plant sections by means of custom-made dashboards. Information that could be used by plant operators to reduce downtime and optimise equipment maintenance.
- Detailed reports summarising all the above and highlighting the limits of existing equipment.

How does CARES work?

Casale CARES can be visualised as a virtual cycle, where raw plant data is processed in the Casale data centre, where it is cleaned, corrected, structured and augmented to become a real source of information that can be used to improve plant operation. As shown in Fig. 2, Casale CARES is possible due to the interaction of different modules, including secure data transfer, analytics, monitoring, and reporting.

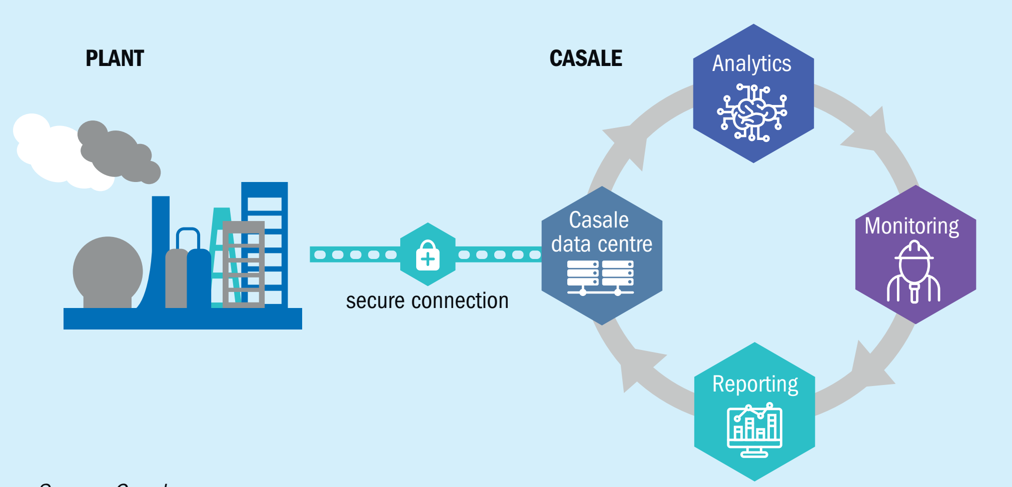
Secure data transfer

The first and essential step is to establish an automatic and secure plant data collection mechanism that transfers data from the client historian to the Casale data centre. Casale acknowledges that plant data is extremely precious, hence the established connection always satisfies the clients' security requirements. Casale often uses OSIsoft® PI cloud connect technology (see Fig. 3) to achieve secure data transfer and minimum infrastructure adjustments. This technology is based on a software-as-a-service platform that allows sharing data between the plant historian and Casale's data centre.

CARES analytics

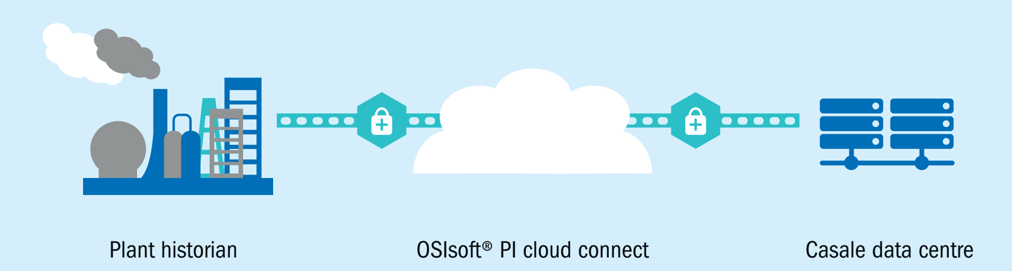
The CARES analytics module prepares data received from plant data. It detects and removes outliers and sets the variance of all measured quantities. Once the data is prepared, data reconciliation can take place of the streams and units of operation present in the section or plant being studied and with the determination of KPIs of critical and proprietary units. Fig. 4 shows an example of the reconciled values obtained for the synthesis loop of an ammonia plant. Lastly, plant behaviour is evaluated and a root-cause analysis of underperforming assets is carried out using machine learning techniques. All analytics can be triggered in batch or continuous mode.

Fig. 2: **CARES process cycle**



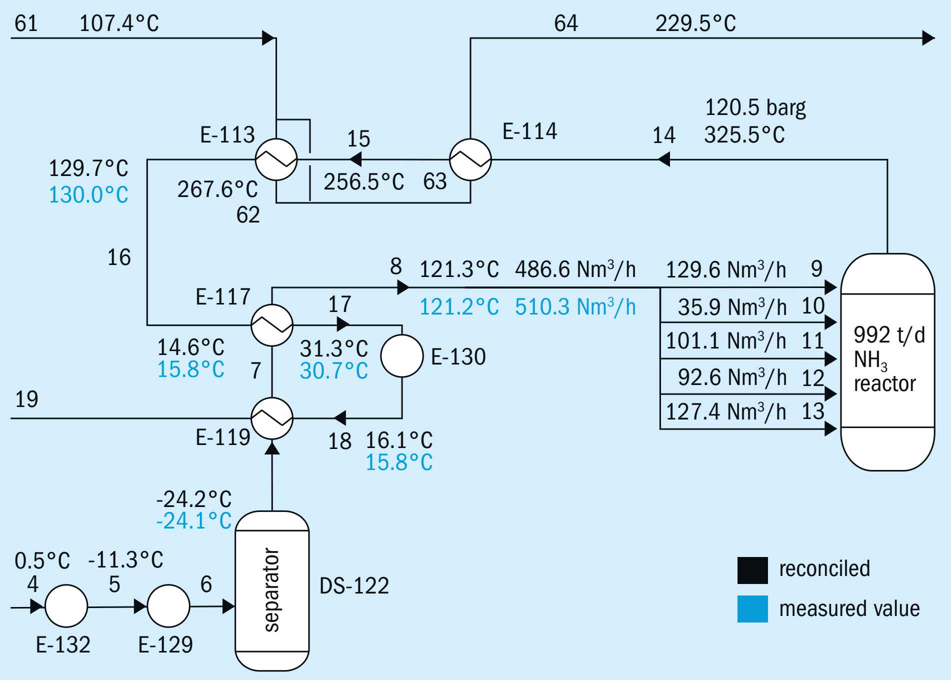
Source: Casale

Fig. 3: **Plant historian to Casale data centre connection**



Source: Casale

Fig. 4: **Data reconciliation of the synthesis loop in an ammonia plant**



Source: Casale

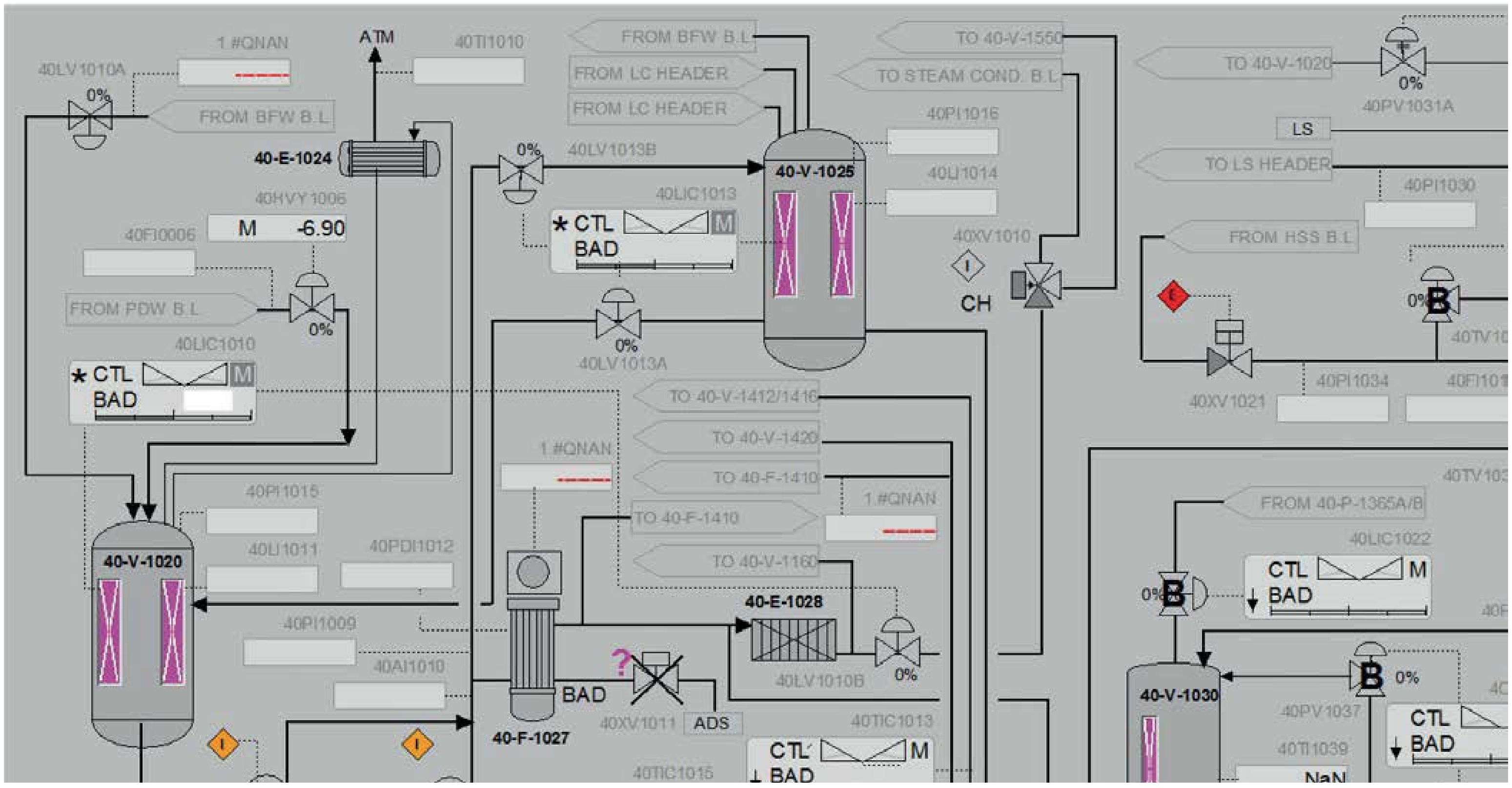


PHOTO: CASALE

Fig. 5: OTS screenshot of the melamine steam and condensate section. Casale and Honeywell have been working to deliver an OTS for the ammonia, urea and melamine plants for Metafrax complex in Gubakha, Perm region, Russia.

CARES monitoring

CARES is more than remote monitoring software, it is a true remote engineering service. Behind the scenes, a dedicated team of engineers will follow plant and asset performance. This is possible thanks to a specialised technical staff, that not only includes process engineers, who are a very important part of the structure, but also other subject experts dedicated to solving problems faced by clients, including instrumentation, machinery, reliability, and maintenance.

CARES reporting for valuable feedback

Providing effective feedback to the plant operational team is essential for a remote engineering service. CARES offers two types of reporting: a web dashboard, providing quick and effective plant performance visualisation, and periodic reports, presenting a detailed analysis of the performance of the assets and sections being studied during the last period. The reports also highlight identified states or bottlenecks that prevent optimal operation and stability of different sections of the plant.

Casale operator training system (OTS)

Training of operators is an essential requirement to improve plant performance, reliability, and safety. As a first step, operators learn how to operate the plant under normal conditions following design guidelines and field experience. However, to be prepared for unexpected or uncommon plant conditions, such as start-up, shutdown, incidents, safety procedures, etc. operators need special training to understand the behaviour of the plant under these conditions, as well as the associated risks. An OTS can help operators to quickly gain operational expertise on how their plant behaves under normal and special conditions, thereby improving the confidence and knowledge of operational teams. Casale's operator training system offers realistic high-fidelity plant simulations that cover many different scenarios and operating conditions. Moreover, the OTS allows operators to start learning how their plant works, even before the plant is running, improving the quality of operations from day one.

Existing commercial OTS providers offer excellent graphical user interfaces and dynamic simulation capabilities that perfectly mimic the operating experience of the control room. However, due to the inherent complexity of certain chemical technologies and operating conditions, standard thermodynamic packages and kinetic models used in these products, are not enough to accurately capture the physics of the associated chemical processes. To overcome this limitation, Casale can partner with any OTS provider to embed its know-how and proprietary models into the OTS, drastically increasing the accuracy of the response of the training simulator. As a result, clients receive high-fidelity plant models tested and validated by Casale. For example, Casale and Honeywell have been working in partnership to deliver an OTS for the ammonia, urea and melamine plants for the Metafrax complex in Russia (see Fig. 5).

Benefits include:

- reduced operational risks, downtime, failures, etc.;
- the best high-fidelity OTS can be obtained thanks to proprietary models to simulate the plants;
- operators can be trained even before start-up.

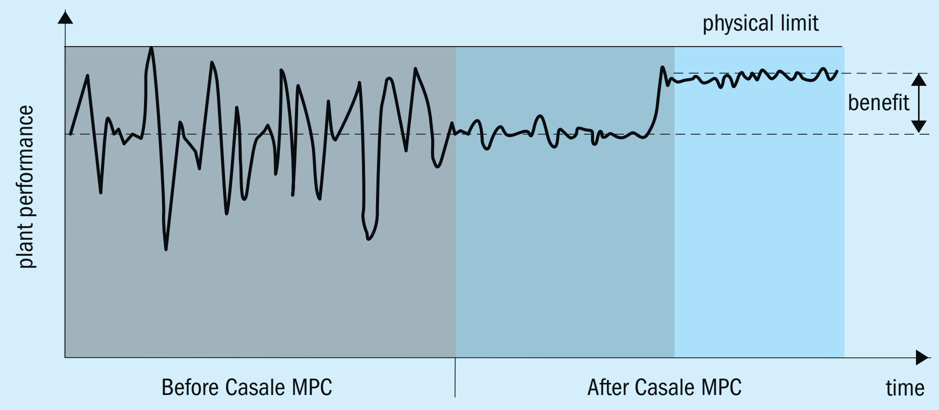
Casale model predictive control (MPC)

Plants are often operated in the "comfort zone" meaning that the key operating parameters controlling the performance are voluntarily kept below their optimum. This is mainly because even the most experienced operator is not able to adjust the parameters rapidly enough to respond to plant fluctuations or external changes and to avoid hitting physical constraints.

A model predictive control (MPC) system is an automation system that complements the DCS to overcome these problems by constantly tuning the set points of the different control loops to stabilise the operation and push the plant to the optimum. As shown in Fig. 6, once stabilisation is achieved, it is then possible, using the MPC, to safely increase performance and to achieve higher production, or to reduce energy consumption. Depending on the client's needs an MPC system can be implemented on the whole plant or on a section of it.

Casale has partnered with the most important providers of MPC software to offer a dedicated MPC product for all Casale technologies. The product has been developed by adding Casale process expertise to the most evolved industrial MPC software, such as Honeywell, Yokogawa, Rockwell Automation, etc. and have been successfully applied to several chemical industrial sectors.

Fig. 6: **Impact of a model predictive control over plant performance**



Source: Casale

How does Casale's MPC solution help clients?

Most available MPC systems are a simple automation system, which applies purely mathematical algorithms to optimise selected plant parameters, named controlled variables (CV). These are considered the key players in the achievement of the optimum performance of the entire plant, thus they are strictly "controlled" and maintained at the optimum. This is possible due to continuous and smooth actions on manipulated variables (MV), which change the set point of controllers to correct the observed plant drift produced by external disturbances.

While this approach may seem sufficient, in practice it can only be applied to correct small plant perturbations for simple linear systems. Complex plants, such as those found in the fertilizer industry, can only be properly stabilised and optimised using custom thermodynamic and kinetic process models. This is because only through reliable models is it possible to identify and target the actual optimum of the critical controlled variables, which is not a steady figure (see Fig. 6), but dynamically changes depending on the real time capabilities of the whole plant. By using best-in-class MPC software, which incorporates Casale proprietary models, Casale's MPC product achieves even greater MPC performance. The optimum process performance is achieved utilising efficient and robust process models, which constantly monitor the operation of the critical sections of the plant.

For its urea technology, Casale has made great efforts to develop MPC software for process optimisation, which is now available in the market. Among different functionalities, the software allows the efficiency of the urea synthesis to be maximised by dynamically targeting the optimum N/C, H/C and operating pressure in the urea reactor. This is possible thanks to the power of the physical process model which supports the MPC operation by suggesting the optimum value of the critical controlled variables depending on the real plant capabilities and constraints.

What is the optimum set of conditions for the urea reactor? Qualitatively one may know that by increasing the N/C ratio and reducing the H/C ratio the reactor performance is improved. However, optimisation of the process is not an easy task. For instance, increasing the ammonia may lead to a pressure increase in the HP synthesis, a decrease of HP stripper and HP scrubber efficiency, and to the increase of pressure in the downstream urea recovery stage, and a partial loss of vacuum in the evaporation unit. Ammonia that cannot be handled by the plant will make the process unstable, leading to an increase in the emissions and raw material consumption. Lastly, the excess of ammonia contributes to an increase in utilities consumption for recovering and recycling the extra ammonia.

The above considerations highlight that the optimum N/C is not a steady figure for a given process technology but may change plant by plant and for a given plant may depend on several other conditions. For example, the operating procedure of the process may suggest operating the reactor at N/C 3.1 but this should only be used as a guideline. The optimum figure will depend on plant, the actual condition of the equipment, the environmental conditions, etc. Only advanced MPC software that embeds the process knowledge can target such an optimum N/C ratio at all times and depending on the real capabilities of the plant and related constraints.

Similarly, the optimisation of the water loops in the entire process is complex, since they strongly affect the value of the H/C ratio in the urea reactor.

It is well known that water is needed to control emissions, pressure, and the composition of recycled solutions. Water is provided to avoid crystallisation and keep the process stable, but any excess impairs the synthesis efficiency. Water is efficiently controlled by the Casale MPC acting on critical parameters in the process condensate treatment, urea recovery and recycling sections. The MPC constantly tunes the plant downstream to stabilise the composition of the recycle streams, targeting minimum water content and fulfilling constraints e.g. for crystallisation, pressure control and emissions.

The Casale MPC drives the plant to achieve the highest N/C and minimum H/C in the reactor to maintain:

- plant stability;
- synthesis pressure;
- HP stripper and HP scrubber efficiency (CO_2 stripping plants);
- NH_3 venting in continuous and discontinuous streams;
- crystallisation of the recycle streams;
- stability and performance of vacuum evaporation section (vacuum pressure);
- product quality.

Casale smart instrumentation

All of the innovative digital products mentioned above work better when complemented by a robust instrumentation system. Casale offers a range of reliable tools and novel instruments that can support daily plant operations (Raman urea analyser, tunable diode laser, refractive index meter, HP urea service guided wave radar level, etc.).

Casale has developed several hardware solutions providing value-added quantities that cannot be directly or reliably measured via standard instrumentation.

For instance, Casale has developed innovative solutions for level, pressure, and composition, which are especially targeted at urea synthesis, monitoring the performance of the urea reactor and other critical HP synthesis units such as the HP stripper and the HP reactor.

Customers can now benefit from the newly-developed guided wave radar level transmitter and the improved HP diaphragm seals pressure transmitter for the urea synthesis. It is very important to ensure reliability in the level and pressure control in order to stabilise the plant.

The composition of any HP process stream is even more important and can be monitored in real time by Casale's Raman urea process analyser.

Tunable diode laser (TDL) techniques are used for monitoring emissions in process vents.

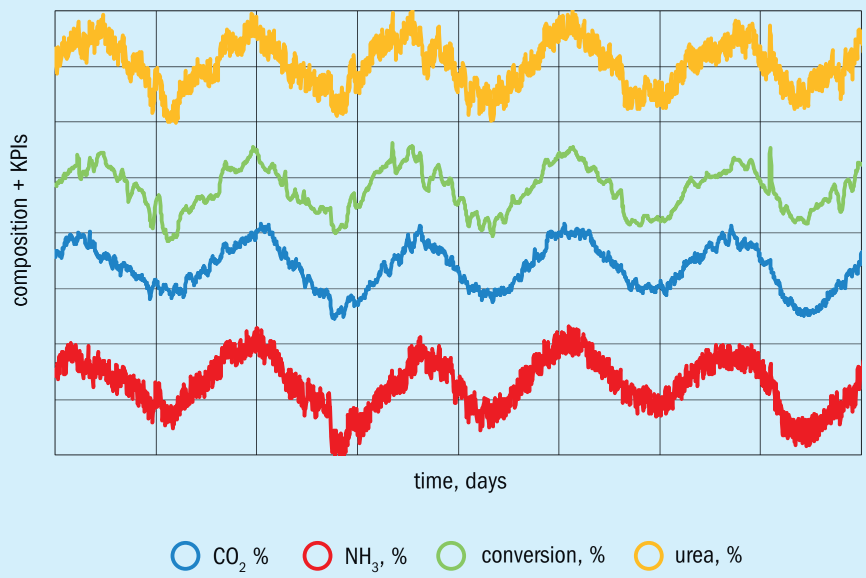
The availability of urea grade materials and tailor-made engineering for the urea process allows further techniques to be implemented, such as the on-line measurement of the refractive index in the recycle streams of the process to support the control of recycling water.

These are just some examples of smart instruments available today to support process operation. Casale offers tailor-made solution for any kind of need the process may have.

PHOTOS: CASALE

Fig. 7: Raman urea process analyser and special HP Raman probe.

Fig. 8: **Typical variation of composition and conversion during 9 days of production**



Source: Casale

Raman urea process analyser

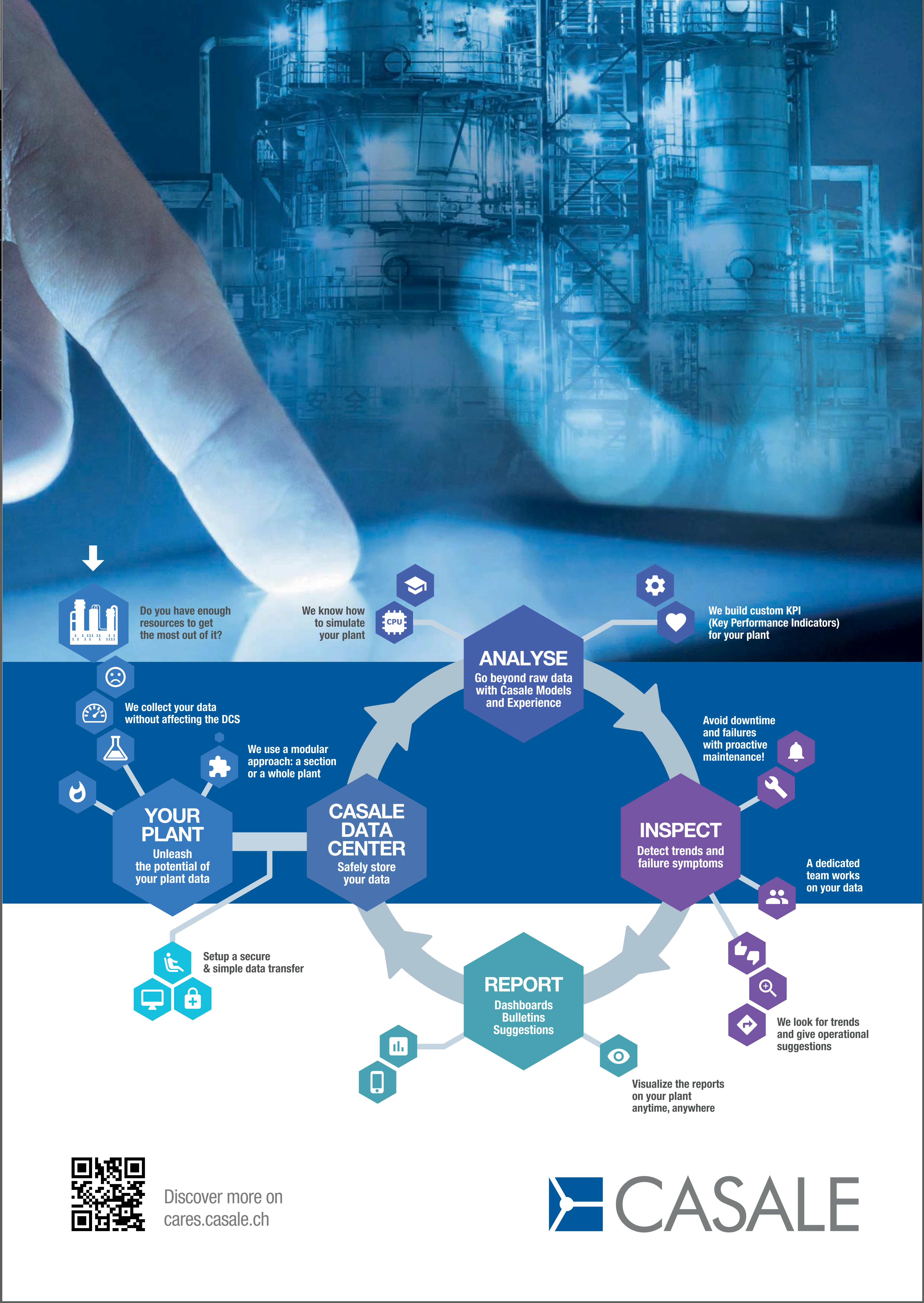
The Casale Raman urea process analyser, a new powerful tool for on-line process analysis and control of urea plants, is a striking example of a smart instrument that can provide added value to digital services. Based on Raman spectroscopy, the composition of a process stream is determined by analysing a light spectrum created from a laser light source injected into the process stream via a special probe (see Fig. 7) The spectrum represents a fingerprint of the different chemical components present in the stream.

The Raman urea process analyser accurately measures the full composition of any high-pressure stream of the urea process in terms of NH_3%, CO_2%, urea% and H_2O% and provides KPIs of the urea synthesis, such as the N/C and H/C molar ratios, conversion and stripping efficiency. In this way, the analyser supports the everyday operation providing alerts for deviations of the most important parameters of the urea synthesis which can then be promptly corrected by the plant operators.

The Raman urea process analyser overcomes the limitations of traditional instrumentation for on-line analysis of the urea process, e.g. N/C monitoring systems, in which the N/C ratio is inferred from density measurements at the exit of the urea reactor. The analyser also automatically samples different locations of the urea synthesis section, i.e. reactor, stripper, condenser, scrubber, downstream lines, etc. resulting in savings due to the elimination of manual sampling. Other important benefits are the reduction of safety concerns related to sampling operations (in particular, due to the volatility of the involved components), and improvement in the quality of the results.

More importantly, the analyser provides real-time data. Lab analyses are normally performed according to standard procedures and require some hours to complete. In contrast, the Raman urea process analyser delivers real-time measurements of the composition of synthesis streams and related KPIs, capturing in this way the dynamics of the urea synthesis section. Fig. 8 shows the variation of the composition of a urea stream and related reactor conversion during several days of production.

The main benefits of the analyser translate into a reduction in the steam demand of the HP stripper by up to 5%, reduced emissions by up to 5 kg/tonne of ammonia and up to 3% increase in plant production.


Do you have enough resources to get the most out of it?
We know how to simulate your plant
CPU
We build custom KPI (Key Performance Indicators) for your plant
ANALYSE
Go beyond raw data with Casale Models and Experience
We collect your data without affecting the DCS
We use a modular approach: a section or a whole plant
Avoid downtime and failures with proactive maintenance!
YOUR PLANT
Unleash the potential of your plant data
CASALE DATA CENTER
Safely store your data
INSPECT
Detect trends and failure symptoms
A dedicated team works on your data
Setup a secure & simple data transfer
REPORT
Dashboards
Bulletins
Suggestions
We look for trends and give operational suggestions
Visualize the reports on your plant anytime, anywhere
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SAIPEM

Saipem's digital transformation

Massimiliano Sala, Marco Scognamiglio and Giulio Paci

Over its history of more than 60 years, Saipem has always been at the forefront of technology, bringing innovative solutions to the industry and executing the most challenging projects. A roadmap for digitalisation is currently ongoing to embrace all aspects of Saipem's activities. When this roadmap meets the expertise of Saipem's proprietary Snamprogetti™ Urea Technology, new services can be offered to customers.

The main advantage that digital tools can provide is the management of huge data in a boosted way. Modern plants are equipped with a huge amount of analogue/digital signal which are useful for plant control and safeguard; however, every plant engineer has struggled to find in this jungle of data the key parameters that can solve an operational problem or explain why a plant trip has occurred. Today, machine learning techniques, enabled by IoT platform, can be applied in order to analyse huge quantities of data and find correlations and sensitive parameters. These data can then be used to optimise the behaviour of the plant, identify root causes and prevent failures.

Snamprogetti™ Urea Technology is well known for its flexibility and ease of operation, thanks to the ammonia stripping process and the use of the MP decomposition section. This flexibility can be further enhanced when combined with optimisation of operating parameters. In the process of optimisation, the licensor can offer extensive knowledge of the correlations existing among the different sections of the plant (thus avoiding the optimisation of one parameter from jeopardising the performance of other equipment), robust simulation capabilities and the expertise accrued in the design of more than 200 plants over the world, including more than 60 revamped units.

A good example of the combination of licensor know-how with state-of-the-art digital technologies is the so-called "digital twin", a perfect copy of the actual operating plant. The digital twin is based on plant process simulation and it is fed with live plant data; it can be designed in the engineering phase, connected and tested during plant commissioning, thus ensuring smooth hand-over to the production team, and kept continuously updated. Once online, the licensor can independently monitor the plant remotely, suggesting adjustments to the process parameters and evaluating possible optimisations. The remote monitoring enhances the collaboration and the decision making process between the licensor and owner, which is vital to maintain the optimum performance of the plant throughout its lifetime. It also fosters communication as it avoids the exchange of huge amounts of data and overcomes logistic constraints such as different time-zones.

Big data analysis is also helpful in the unlikely event of a plant or equipment failure. In this context, it is highly useful to exploit techniques such as data science visualisation tools and neural network prediction capabilities, which will analyse the data much faster than a human, reducing engineering man-hours by up to 80%. This allows process engineers to better use their valuable time to promptly recognise the root cause and identify potential preventive measures or design changes to avoid reoccurrence of the event. When involved in the root cause analysis, the licensor can offer independent judgement to detect potential deviation from design conditions and compare the behaviour of the plant/equipment with other units installed elsewhere to reduce the potential causes.

In addition, neural networks can be trained to predict with high accuracy the performance of equipment, reproducing also the physics characteristic time of the phenomena. This process, called predictive analysis, is able to anticipate the occurrence of a future event (such as an item malfunction causing plant shutdown) or an abnormal operating condition, such as high pressure or temperature, matching past trends with current plant data.

Another field of application made possible thanks to the digital revolution is the so-called additive manufacturing, which consists of the 3D printing of objects with a layer-by-layer material deposition starting from metal powders. Even though this is not applicable to all materials used in the fertiliser industry, it may be very useful for specific, non-pressure equipment or part thereof which can be engineered to the specific needs of each plant without being constrained by the requirements of standard manufacturing (which for example limit the possibilities in terms of geometry and shape). Saipem has recently developed a few cases which perfectly fit within Snamprogetti™ Urea Technology, for example the re-design of the high-pressure carbamate mixer.

Nowadays the austenitic stainless steels used in the high-pressure parts of Snamprogetti™ Urea technology offer good corrosion resistance if sufficiently passivated. By using an additive manufacturing technique, the mixer has now been redesigned using a more corrosion resistant alloy (CRA) starting from powder raw material.

The mixer was redesigned to be printed with a suitable alloy through 3D printing technology based on selective laser melting (SLM), that can accomplish geometry optimisation with the absence of welding, allowing weight saving as well as improving corrosion and erosion resistance.

Different samples were printed using the selected alloy under laboratory trials in order to verify the behaviour in terms of physical corrosion and mechanical properties. In case of satisfactory test results for the material tested with this additive manufacturing technique, the mixer prototype will be delivered for the final field testing.

In future, the application of additive manufacturing can guarantee a continuous improvement of Snamprogetti™ Urea technology to reduce plant downtime, costly maintenance and customer's spare parts.

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 57 58 59 60

STAMICARBON

Boost plant performance with real-time insights

Leo Rams

The use of first principles models to support process operations have been practiced in the chemical and petrochemical industry for over 40 years, but, their use in urea plants has been limited. Urea plant models, however, can encapsulate a large amount of process knowledge and companies have started to realise the significant value using these models in offline and online model-based applications. Such applications include real-time optimisation, predictive control, data reconciliation, virtual (soft) sensors, process performance monitoring and total plant monitoring systems, to name a few.

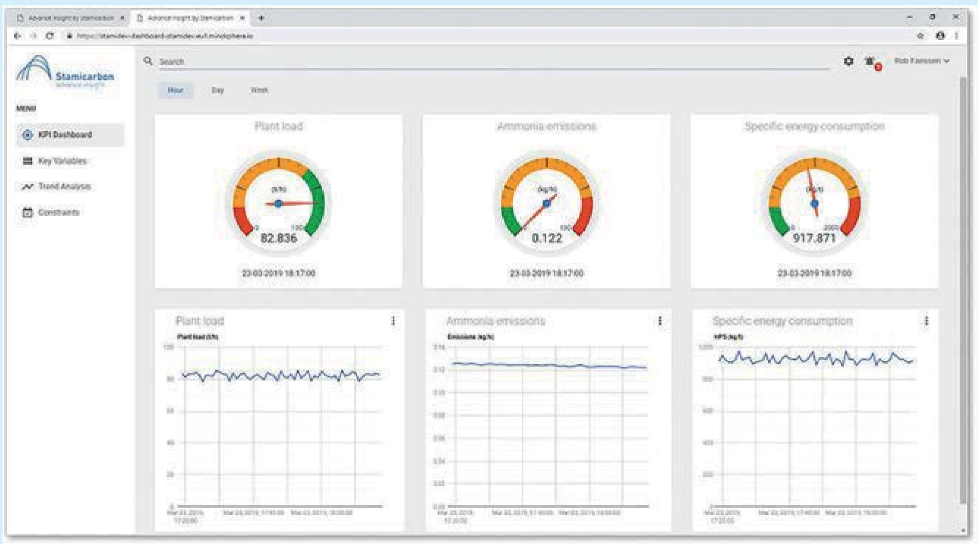
Stamicarbon, the innovation and licensing company of Maire Tecnimont Group, is committed to a sustainable fertilizer industry, by investing amongst others in innovative digital solutions.

The Stami Digital Process Monitor is one of the products that forms part of Stamicarbon's suite of digital products. By using a urea plant model as the engine of the Stami Digital Process Monitor, this monitor enables plant operators to optimise their plant operations, leading to an increase of the plant capacity, while reducing the plant energy consumption and plant emissions.

The Stami Digital Process Monitor feeds real-time data of a urea plant to a rigorous plant model which calculates key performance indicators (KPIs), such as plant load, energy consumption and emissions, as well as a variety of soft sensor key variables, such as equipment efficiency, equipment load and reactor load and shows them on a dashboard (Fig. 1).

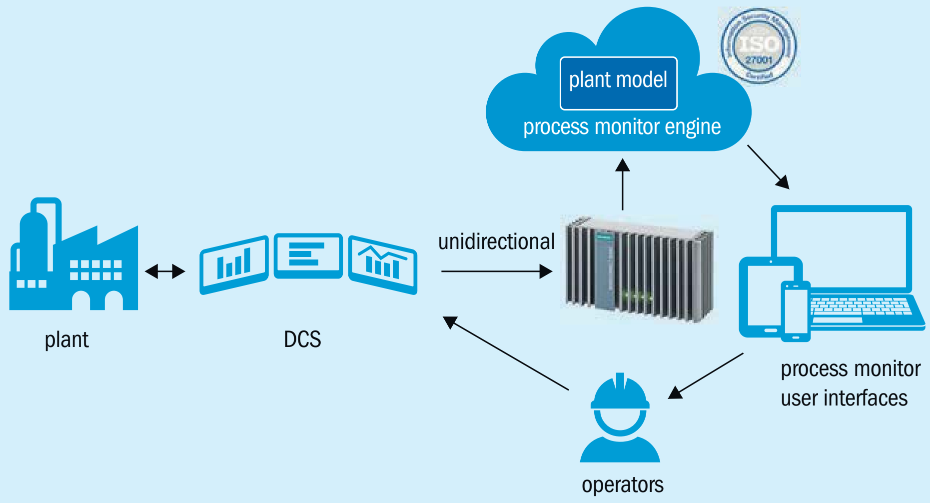
As illustrated in Fig. 2, the real-time plant data is unidirectional communicated to the process monitor engine, which runs in a secured Cloud environment. The plant data is processed by the plant model, which calculates the KPI and soft sensor key variables and are made available to the plant operators and all other stakeholders.

Fig. 1: Stami Digital Process Monitor dashboard



Source: Stamicarbon

Fig. 2: Stami Digital Process Monitor architecture



Source: Stamicarbon

An overview of plant modelling

Depending on the level of a-priori knowledge, three different classes of models can be developed:

- knowledge driven models;
- data driven models;
- gray box models.

Knowledge driven models, also called first principle models, are developed based on first principle analysis, and thus, require full phenomenological knowledge about the underlying mechanisms.

In contrast, data driven models, also called black box models, are proposed for situations in which physical understanding of the urea process is absent or not relevant (these models are based on experimental data which are fitted to typically simple equations).

In between the two extremes, there are many possible combinations of knowledge driven and data driven models. The prior knowledge offered by the simplified first principles analysis forms the core of a so-called gray box model, while data driven methods can compensate for fractions that cannot be modelled easily in terms of phenomenological models.

The Stamicarbon process model is purely knowledge driven, with superior prediction quality. The mathematical model developed includes mass and heat transfer equations, reaction kinetics, vapour-liquid equilibria, hydrodynamic aspects and covers the entire plant.

In total, the plant model consists of more than 5,000 linear and non-linear equations. An in-house developed equation-oriented flow sheeting program is used to ensure fast solutions of the large and complex problem.

Difficulties in urea plant modelling

Despite the simple chemistry in urea plants, the underlying physics of mixtures containing urea and carbamate is complex. First, the feedstock to the synthesis is in supercritical state. Above the critical points, distinct liquid and gas phases do not exist, which gives serious deviations in liquid/vapour-descriptions. Second, the presence of an azeotropic ratio for mixtures containing urea/carbamate/water creates solutions showing large negative deviations from Raoult's law and form a maximum boiling azeotrope at a specific composition. Inflection points caused by strong non-linearity are often the source of numerical instability, as the solver algorithm cannot distinguish from which side to climb the hill. For online application, the model must meet a set of performance requirements with respect to speed, robustness and flexibility; already a challenge by itself!

Plant model steps

The plant model of the Stami Digital Process Monitor is produced in two distinct steps: a consulting phase and a data reconciliation phase.

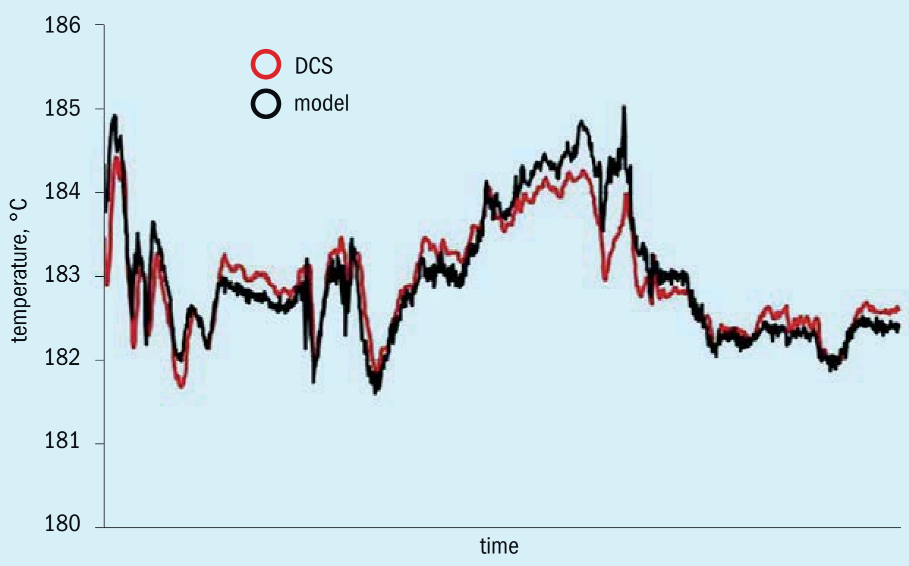
ADVANCE™ CONSULT is an offline model based service, offered by Stamicarbon. It starts off by conducting interviews with plant experts and operators as they play a key role in fully exploiting the wealth of historical data. The experiences and expertise of those involved in day-to-day operation provide valuable insight into relevant process changes and performance of measuring devices, etc.

With a validated plant model and historical plant data, an in-depth analysis can be made from the plant operation.

The report will typically indicate:

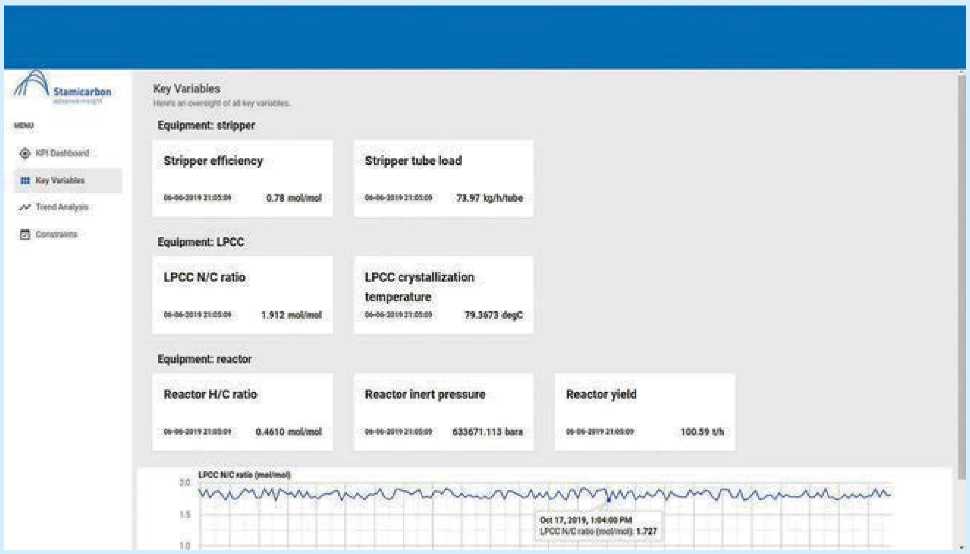
- evaluation of plant sensors;
- plant constraints and proposed solutions;
- achieved operation relative to key variables;
- low frequency oscillations and disturbance rejection (e.g. day and night rhythm);
- recommendations for improvements.

Fig. 3: Reactor temperature validation



Source: Stamicarbon

Fig. 4: Soft Sensor key variables



Source: Stamicarbon

Data reconciliation

To ensure that the model represents the process accurately, historical DCS data are collected from the operation and are subsequently used to validate the model. The measured data typically contain random errors, and less frequently, may also contain systematic errors.

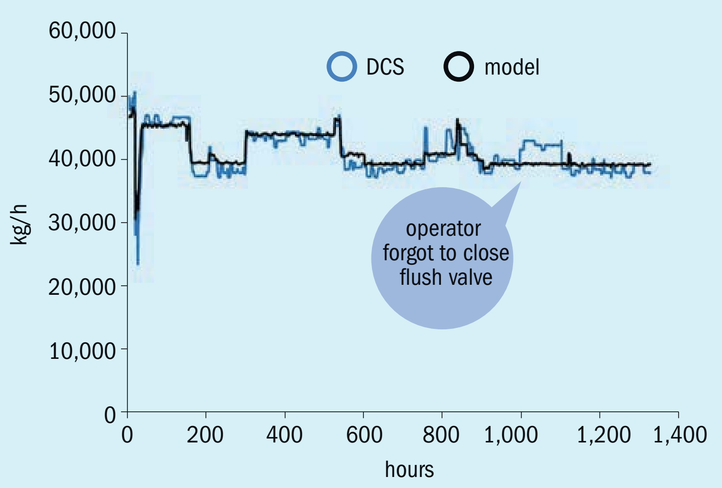
The role of the data reconciliation is to properly identify and correct deviations, and therefore provide reliable information for updating the parameters of the model, or to conclude on systematic sensor errors.

For process control engineers, offline validation can be viewed as a feedback process, aiming to bring the model predictions on target to the process measurements, similarly to the way feedback is used in a control application to bring measured values to requested target values or within ranges.

A validation example is illustrated in Fig. 3.

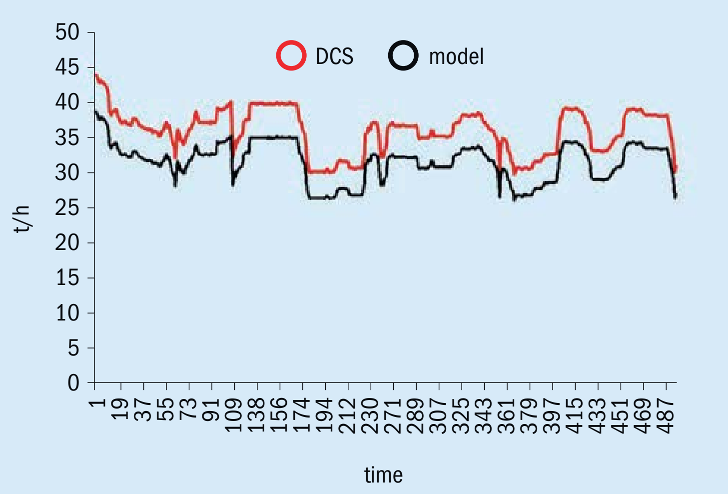
The urea reactor outlet temperature is typically a critical variable in urea synthesis. To some extent, it represents urea

Fig. 5: **Troubleshooting – feed stream**



Source: Stamicarbon

Fig. 6: **Troubleshooting – compressor load offset**



Source: Stamicarbon

conversion in the reactor, assuming other interacting variables being constant. The plot in Fig. 3 shows the model predicted temperature, compared with the DCS reading over a period of two weeks. Accuracy is the level of agreement between the predicted and DCS values, while reliability is the degree to which the prediction errors vary.

The accuracy of identification and reliability of validation procedures is sensitive to the size of the corresponding datasets. The required size of the historical data is typically one to two months; hourly averages will do for analysis.

Once the advanced consult and validation phases have been completed, the Stami Digital Process Monitor provides real-time KPI and soft sensor key variables information, real-time insights, that will help to maximise efficiency and increase production.

Soft sensor key variables

Key variables (KVs) characterise the technical and economic performance of the urea process. Once KVs are fixed, the operating points are fixed. KVs are normally determined by offline sample analysis in laboratory. One of the drivers of process modelling was to give operators and process engineers a reliable and accurate estimation of key variables. This would allow them to arrive at the optimum operational point and assist them in trouble shooting activities. For example, the urea yield in a reactor is fully characterised by its key variables N/C, H/C, retention time, and system pressure. Only N/C can be measured in real time, whereas H/C and system pressure are determined by offline sample analysis in laboratory. Calculation of retention time would require a total mass balance calculation over the reactor.

The Stami Digital Process Monitor produces these real-time soft sensor key variables (see Fig. 4), enabling advanced process monitoring and optimised control of urea plants.

Troubleshooting

The Stami Digital Process Monitor also provides means for troubleshooting of the plant operation by comparing the plant DCS values with the values calculated by the plant model, as per the example shown in Fig. 5.

In the trend graph the DCS data is shown in blue colour and the values calculated by the model are shown in black colour. It was found that a flush valve had been unintentionally left open, which explained the fairly large difference shown in the highlighted area. The Stami Digital Process Monitor will immediately show such a difference, which will trigger the plant operator for corrective actions and prevent unnecessary loss of production.

Another troubleshooting example is shown in Fig. 6. In this case the trend shows a constant offset between the compressor load as per the DCS value shown in red colour and the value calculated by the process model. The root cause of this particular offset was found in a wrongly configured density compensation of the orifice. As a result, the compressor can be pushed to a higher capacity which leads to a higher plant load.

Features

The Stami Digital Process Monitor supports the following features:

- **Key variables:** All plant key variables can be monitored on a real time basis.
- **Laboratory:** The number of offline analysis in the laboratory can be significantly reduced, as the Process Monitor can calculated all these analysis as well.
- **Emission monitoring:** The ever increasing stringent regulations on ammonia emissions require reliable real-time monitoring systems. Ammonia emissions from absorbers can continuously be measured with high accuracy.
- **Sensor duplication:** Every plant sensor, which is not a model input, will be duplicated by the model. Having such a soft equivalent is a powerful tool to identify sensor and process deviations.
- **Soft N/C meter addition:** For Stamicarbon plants with a high-pressure falling film condenser (HPCC), conventional plants and thermal stripping plants, the model can be configured with an accurate soft N/C-meter.
- **Flammability limits:** In the absence of a hydrogen converter, the purge gas from the synthesis might be within flammable limits. The flammability limits can be predicted, provided that the impurities in the feedstock are measured. This can be further supported with a graphical dynamic interface showing the operating point relative to the flammable area.

CLARIANT

ReforSafE™ for improved safety and performance in syngas operations

Ahmad Ghani

In today's cost competitive environment, syngas plants must perform at their full potential to survive and succeed. Cutting-edge thermal imaging services and catalyst solutions can help ensure ideal steam reformer conditions for optimum efficiency.

Importance of reformer tube temperature

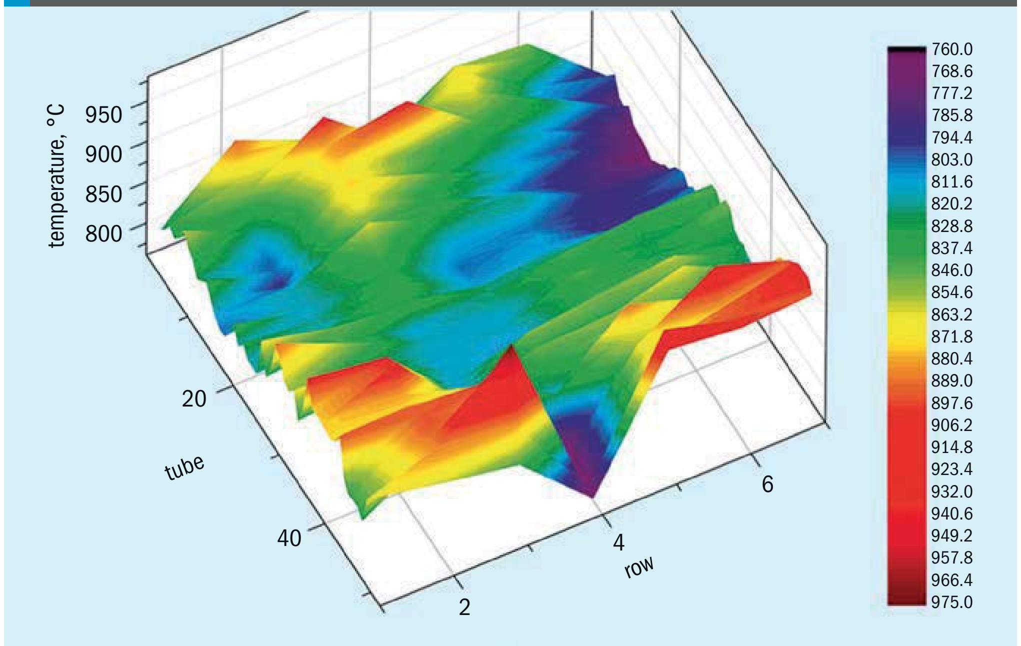
The steam reformer is the heart of any syngas plant and the unit that is the most costly and energy intensive. It is a complex unit that operates very close to metallurgical limits. Its improper operation can result in considerable hardware costs, production loss, and plant inefficiency. Therefore, optimising its performance is key to improving overall plant profitability, and even small improvements can amount to significant financial benefits from energy savings or production increase.

Ensuring well balanced and reliable operation of reformer tubes is essential for improving the overall efficiency of the plant. For maximum efficiency, a high performance catalyst should be used to boost the chemical reaction in the tubes, and the internal heat distribution amongst the tubes must be regularly examined, evaluated and optimised.

To evaluate and optimise reformer performance, the most valuable measurement required is the tube wall temperature (TWT). This should be uniform, and 20°C below the design temperature of the tubes to obtain maximum production while still operating at a safe condition within the integrity operating window of the tubes.

The thickness of the tubes is designed for a lifetime of 100,000 hours of operation at design conditions. Overly cautious firing may lead to lower production and/or higher energy consumption. Several syngas producers are reporting a 2% decrease in production when operating at low TWTs. Conversely, operating at higher TWTs can cut the lifetime of the tubes significantly. It should be mentioned that various factors, such as catalyst deactivation, incorrect burner settings, or uneven firing, can raise the TWTs above design limits, causing overheating of the tubes. Unless mitigated, the mechanical stress on the hot tubes will increase exponentially, causing a drastic decrease in tube lifetime. In the worst case, a tube may rupture, forcing the plant to shut down immediately, and resulting in costly hardware replacement and production loss.

Fig. 1: **Reformer tube wall temperature measurement**



Source: Clariant

ReforSafE™ technology

To prevent these adverse scenarios, Clariant offers an advanced and reliable service package for evaluating and optimising the steam reformer. Clariant's reformer survey allows plant operators to identify bottlenecks, increase tube lifetimes, maximise catalyst potential, and reduce energy consumption to boost plant productivity while minimising the consumption of energy and resources.

Clariant's reformer survey examines and optimises key indicators of steam reformer performance:

- tube wall temperature (TWT);
- steam-to-carbon ratio;
- excess combustion air;
- furnace draught;
- operating temperatures;
- burner performance;
- heat distribution;
- catalyst activity;
- methane slip.

Clariant's syngas partners can choose between three levels of reformer analysis, which differ in their degree of details concerning collection and examination of data.

ReforSafE™ Standard

The first level is a quick TWT check, performed with a Land Cyclops 100L pyrometer. Clariant experts will visit the plant to carry out visual inspection of the furnace, and to collect relevant information such as steam-to-carbon ratio, and methane slip to evaluate the performance of the catalyst. The service includes TWT evaluation through peepholes and temperature correction.

Scope of the first service level:

- ensuring safe reformer operation;
- evaluation of TWT;
- evaluation of catalyst performance.

ReforSafE™ Premium

Both burners and TWT are evaluated through the peepholes with a high resolution thermal imaging borescope that measures temperatures from 600 to 1,800°C at a short, accuracy-enhancing wavelength, and provides a thermal image of 656 x 494 px (+320,000 temperature points). This real-time, 3-D heat profile includes all tube rows of the furnace and can be easily examined for areas of inhomogeneous heat distribution and hot spots on the tubes. The equipment also provides live thermal images of reformer tubes, burners and refractory. The comprehensive temperature survey also includes recommendations for burner adjustments.

Scope of the thermal imaging service:

- same as pyrometer measurement, plus;
- evaluating the performance of burners and fuel headers pressure;
- providing recommendations for burner adjustment and optimisation.

ReforSafE™ Premium Plus

Readings are taken with a LAND gold cup reflector, which provides superior accuracy, as its near-perfect reflectance blocks background radiation, thus creating a black body for measurements. Using direct tube contact, the gold cup creates a seal between the tube surface and the instrument, shielding the thermocouple from additional radiation around the tube.

This is necessary since the tubes are typically cooler than their environment, especially the reactor wall. When measuring a cooler target in the hot surrounding, the radiation of the hotter surrounding reflects at the cooler target and causes a higher temperature measurement than the actual temperature of the target. The larger the temperature difference or the closer the tube is to the wall, the larger the error.

The gold cup measurements provide extremely accurate temperature data, as they are not affected by tube emissivity, hot background reflections, or side path emissions. The data gathered is used to calculate a formula for temperature corrections of future pyrometer measurements.

Scope of the thermal imaging plus gold cup service:

- same as thermal imaging service, plus;
- determination of thermal efficiency of the furnace;
- determination of tube emissivity;
- providing a correction formula for measuring true TWT;
- operator training on how to measure and correct true TWT.

Troubleshooting for reliable operation

The reformer survey indicates any problems with the burners and the refractory to ensure that all tubes are operated within their design temperature. This not only extends the lifetime of tubes but also that of the catalyst as thermal stress is minimised. Furthermore, catalyst performance can be evaluated based on the reformer data. Substandard performance, due to poisoning, coking or aging can be monitored, and corrective actions, such as catalyst steaming to remove coke formation, can be initiated to recover catalyst activity.

Optimising overall reformer performance

By fine-tuning different furnace parameters, plant operators can achieve higher methane conversion, and reduce their energy consumption. If pressure drop in the steam reformer is a limiting factor, upgrading to a catalyst with extremely low pressure drop, such as Clariant's ReforMax® LDP Plus series, can help remove this bottleneck, and increase the plant's production capacity. ■

NAVIGANCE

Data-driven chemical process optimisation

Lisa Krumpholz

Navigance is a tech startup recently created by Clariant: a cloud-based solution providing real-time recommendations to optimise control parameters in chemical processes. Its innovative approach, combining hybrid plant models and machine learning with process and catalyst expertise, can deliver continuous benefits within weeks, without tying up in-house resources.

Fine tuning a chemical process such as methanol production for optimum efficiency and reliability is an art. Keeping plant systems not only running, but running at their best, takes years of frontline experience and expertise to master. And, despite the many digital advances now within plants' reach, it still takes a considerable amount of educated guesswork in many cases, too.

One of the key challenges for chemical facilities seeking optimisation is their sheer complexity. Their many interlinked and overlaid processes and variables make it difficult to build realistic first principle plant models that describe real-time process behaviour. The control systems commonly in use are also insufficient to enable dynamic, non-linear process optimisation.

Unlocking hidden potential

The power to optimise effectively lies in the data many chemical plants already routinely gather. Successfully tapped, it can help improve operations in both the immediate and longer term.

However, the investment of time and resources needed to study, interpret and extract meaningful insights from immense data sets often precludes any real practical use beyond KPI development and day-to-day troubleshooting.

As a result, most process optimisation decisions are still taken using informed intuition and deep rooted experience of process behaviour. Even for the most experienced operators, making choices based on an incomplete picture of plant data can leave uncertainty as to whether the right decisions are made every time.

Machine learning, a subset of artificial intelligence (AI), offers a way to reduce these uncertainties. Deployed correctly and based on the right foundation, it can pinpoint and distil the data that matters most and identify the changes which need to be applied to process control variables to achieve operational goals.

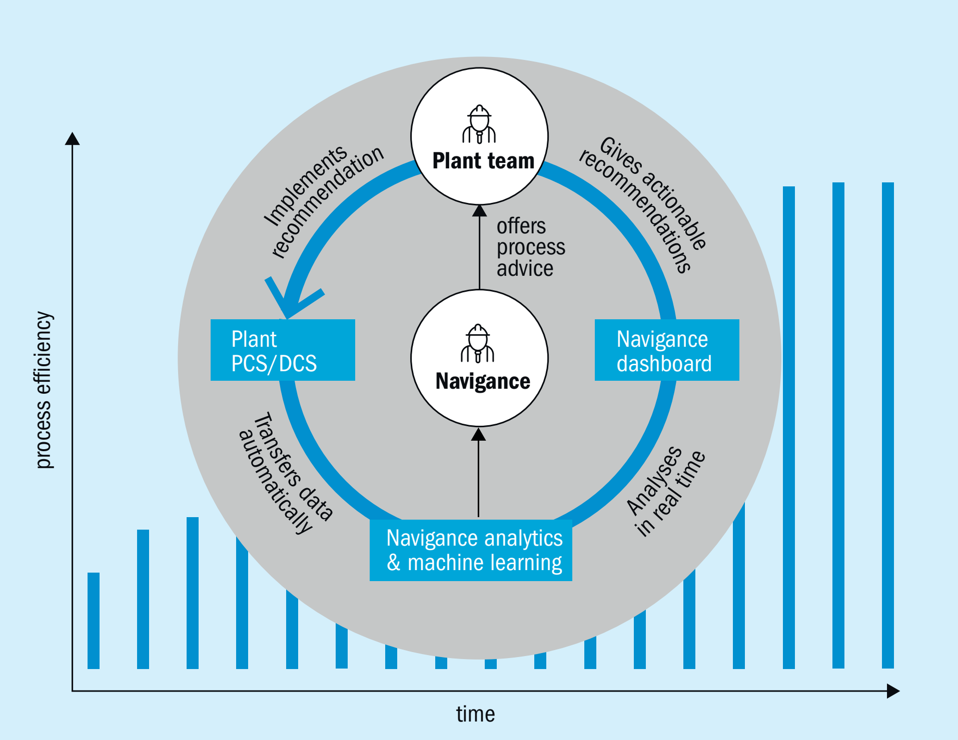
A fresh approach

Such capabilities require fresh thinking and a broad range of expertise, such as sufficient domain knowledge in the chemical process to develop models robust enough for AI-based optimisation and the mathematical and statistical know-how to develop and implement machine learning effectively.

Clariant took up the challenge, investing in Navigance: a new venture and innovative service for chemical producers that harnesses its rich catalyst and process expertise and decades of industry experience.

"What started as an internal initiative within Clariant Catalysts has developed into an entirely independent business and company using digital technologies to offer process optimisation services," says Stefan Heuser, Senior Vice President & General Manager at Clariant Catalysts. "It's a journey that underlines our commitment to delivering and generating value for different players in the chemical industry."

Fig. 1: **Navigance process optimisation cycle**



Navigance

Acting with intelligence

In a purely technological sense, Navigance is a service that enables producers to continuously optimise their chemical process using their own plant data. It provides this powerful support through a cloud-based platform.

Machine learning studies and identifies complex, non-linear patterns in historical and real-time plant data, predicts future performance and spots improvement potential to a high degree of accuracy. These insights are presented as recommendations in an online dashboard.

Operators can act on this advice immediately, adjusting control variable settings to continuously optimise and achieve their defined goals. These may be efficiency goals, such as yield, production output and other operational targets. Equally, the intelligent algorithms used can also identify any deviations and so help to maintain operational reliability too.

Partnering for success

Navigance is more than just a technology solution. Its team works closely with producers through their entire journey towards data-driven decision making – then beyond.

The approach of Navigance is not only to provide AI and data analytics tools to gather data and present findings, but also to deliver prescriptive recommendations and, crucially, provides ongoing expert support.

This starts with planning and deployment. Navigance process and data science experts take the pressure off chemical producers to find in-house resources to introduce real-time optimisation successfully themselves. This expertise remains available once the platform is up and running, providing insights and advice drawn from the data over time that help optimise further, even as conditions change.

The power to act on the recommendations always remains firmly in the operators' hands. Enabling them to optimise based on a clearer picture of plant performance, while freeing them to focus on the many other pressing aspects of running their operation.

Right from the start

While some AI projects fail before they really get started, Navigance helps plant teams identify upfront where digitalisation will deliver great value and the right usage cases. This starts with a check of their digital readiness and potential key areas for improvement.

A feasibility study conducted by Navigance helps to understand the plant, its process, logical connections, key variables and constraints. It also determines if there is sufficient quality and quantity of data to build a realistic digital process model, and what is needed to complete this picture if not.

Navigance builds hybrid plant models that enhance established first principle techniques with machine learning. By carefully integrating unknowns using arbitrary functions, these models can ensure a good fit for all observed data and that all relevant effects are captured, for recommendations of a high predictive quality.

This approach enables hybrid models to respond quickly and easily to real-time data, changing conditions and factors that could affect processes, such as varying load scenarios and deactivating catalysts.

Fig. 1 shows the process optimisation cycle with Navigance.

Ready to optimise with intelligence?

Navigance works with all technology licenses and catalyst types and can suit both older and newer plants, whatever their current level of automation.

Base models, tailored to a specific process, enable producers to optimise quickly to reach their individual goals, with little demand on their in-house teams. ■

PHOTO: JOHNSON MATTHEY

JOHNSON MATTHEY

Enhancing technical services with digital technologies

Paul Clark

Johnson Matthey (JM) provides an extensive range of on-site and remote technical services, based on deep process and catalyst knowledge and the expertise of its engineers across a range of chemical processes. The introduction of new digital technologies is enabling JM to enhance its existing services, from on-site surveys, reformer balancing and troubleshooting, to remote catalyst evaluations, sample analysis and benchmarking. It is also providing new ways for customers to interact with JM.

JM is in the process of developing and launching a range of new and improved technical service offers in three areas:

Specialist measurement and analytics

JM offers services in enhanced measurement and monitoring. An example is its ReformCMS offer, in which advanced steam reformer modelling capability, developed over many years as a catalyst supplier and designer/licensor of steam reformers, is used in conjunction with advanced measurement techniques to provide a much more accurate picture of reformer performance than is possible when using such tools independently. A remote monitoring interface allows JM to generate focussed recommendations for improving reformer performance as often as is necessary, thus allowing customers to increase throughput, reduce energy consumption, increase tube life and reduce NOx emissions.

Remote monitoring and dashboards

JM provides direct connections to plant historians and the potential for reports to be accessed remotely via a portal or dashboard. JM is able to deploy a range of secure connection options, suitable to each customer's particular environment and standards, including direct links or periodic file transfers. As well as allowing automated visualisation and generation of recommendations for plant and catalyst optimisation, the benefit of these solutions is to facilitate a richer exchange of information between the customer and JM. This means that JM engineers have easy access to a customer's latest data and can provide support and advice with a faster turnaround as less time is required for data collection and exchange.

Improved service for our customers

Finally, JM is working to introduce a range of new applications and tools to enable its engineers to have secure remote access to required customer information, historic knowledge and reports, links for reporting, as well as tools to aid safety on-site. These tools such as mobile applications, connectivity and communication tools are aimed at enabling engineers to provide better services on-site and help achieve JM's commitment to the safety of all its staff. JM is also launching tools to ensure more effective risk and safety assessments, simplified data reporting and to streamline communications between staff and with customers. Furthermore, JM has a range of webinar capabilities to ensure that training services can be provided from anywhere in the world.

The pace of digital innovation means that JM is continuing development across all the markets that it serves – new solutions are in development with customers and partners that aim to improve the experience of customers, reduce effort and time, and improve connectivity between JM and its customers. JM is actively engaging in partnerships with customers to develop customised solutions that leverage the best of JM's experience and technical expertise to meet specific customer challenges. ■

KBR TECHNOLOGY SOLUTIONS

Technical services and digitalisation solutions increase operational reliability in ammonia plants

Satish Baliga, Katerina Yamalidou, Sandro Mazzini and Alex Romero

You license a unit, commission it and start it up. The air is full of hope and expectations of performance and value delivered by the unit. Production targets are established and suddenly the start-up turns into daily management and routine.

As the routine sets in, things often appear to work smoothly and can quickly lead to a position of comfort where most results are delivered, but also where we normalise small issues and stop challenging our companies, our teams and even ourselves to perform better. This can open the value breach between the maximum value a team and its assets can generate vs the actual value realised. The worst part is that this gap becomes invisible and, over time, it grows.

Adopting technical services and digitalisation solutions can make a dramatic difference. By effectively planning and managing the lifetime of the unit and recognising the various events that take place, value adding services and solutions, especially those provided by the licensor, can help plant owners and operators to quickly benchmark their performance in operation and maintenance of their unit, and to define the optimum way for achieving top performance and the way to close the value breach, in order to maximise returns.

KBR envisions the following four general areas where technical services and digitalisation solutions can add value:

- Fit for operation
- Operational reliability
- Profitable operation
- End of lifetime services

Fit for operation solutions and services help the unit become ready to be operated at top performance. They may include commissioning and start-up services, but also training services, operator training simulator (OTS) solutions, operation readiness reviews, safety, health and environment services, maintenance team readiness and even procedure reviews.

Operational reliability solutions and services make sure the unit performs at design conditions consistently and at target operating and maintenance costs. They include asset integrity and reliability reviews, asset management, reliability management solutions, maintenance management systems, equipment inspections and repairs, maintenance execution and turnaround planning and execution.

Profitable operation solutions and services help maximise the yields that the unit can deliver. Many units can operate at higher-than-design capacities. Hence, these services include studies to define how to do so in a safe and reliable way, studies to lower operation/maintenance and energy costs, increase quality, yields, production outputs, but also technologies that lead to reduced costs, such as remote process monitoring, preventive operating issue resolution, preventive maintenance, advanced process control and advanced simulations.

End of lifetime services help extend the lifetime of the asset, for instance revamps and retrofits and eventually services related to the decommissioning of the asset.

Discover, diagnose, design and deliver

KBR uses a unique methodology that is proven to deliver measurable valued solutions, which are designed to address complex problems related to plant operational issues.

The methodology has four major sections: discover, diagnose, design and deliver.

In the first step, KBR works together with clients to understand their business and operations strategy, profitability targets and possible improvement scenarios. After agreeing on the priority of the identified improvement scenarios, KBR selects the one to work with and move into the second step.

In the second step, KBR collectively elaborates on how the selected scenario will address the desired improvements and generate the potential value.

In the third step, KBR evaluates all possible solutions to the problem and provides guidance to identify the parameters of the solution. The third step concludes with the selection of the solution, which will deliver the expected value.

The fourth and final step is the implementation, ensuring the promised value is delivered, is adaptable and can be sustained by operations. This includes solution adoption, adjustment to the corresponding business processes and the required training and change management programs, which will enable the organisation to work according to the implemented scenario.

Digitalisation solutions for operational reliability

Operational reliability is one of the key areas which impact the plant's productivity and is directly linked to the plant's uptime. This, in turn, is determined by the health of both the equipment and the process.

Operational reliability is the crucial factor in maintaining high profitability. High level of operational reliability implies reduced maintenance costs and less capital tied up as high spare parts inventory, both of which directly affect the plant's bottom line.

In order to achieve high level of reliability in terms of asset and process performance, and to ensure that the plant operates safely and efficiently, the maintenance practices must be driven by sound reliability-based business processes and accompanying solutions.

The advances of technology offer the opportunity to plant owners and operators to apply different approaches to the management of the plant, the process and the operations, which can have significant benefits in terms of safety, efficiency, plant uptime and eventually increased profits.

Digitalisation is the adoption of new business practices and technologies and their incorporation into the operations and plant decision making, with the purpose of increasing the value generated by the assets, by pushing the operating points to new areas and maintaining them safely there.

The digitalisation solutions for operations monitoring and management are currently in a mature state due to:

- advances in data acquisition and data processing;
- availability of advanced modelling and simulation techniques;
- availability of complex and robust process models;
- commercial software using artificial intelligence (AI) and machine learning (ML) techniques;
- availability of cloud-based solutions and the industrial internet of things (IIoT);
- mobile devices;
- 3D visualisation tools;
- virtual reality equipment and software.

A comprehensive digitalisation solution uses business and process data to learn from the past process and equipment behaviour, to analyse the current indicators and understand why the plant and process behave as they do, to prognose what will happen in the future and to support the operations and business management teams to make the best decision proactively (Fig. 1).

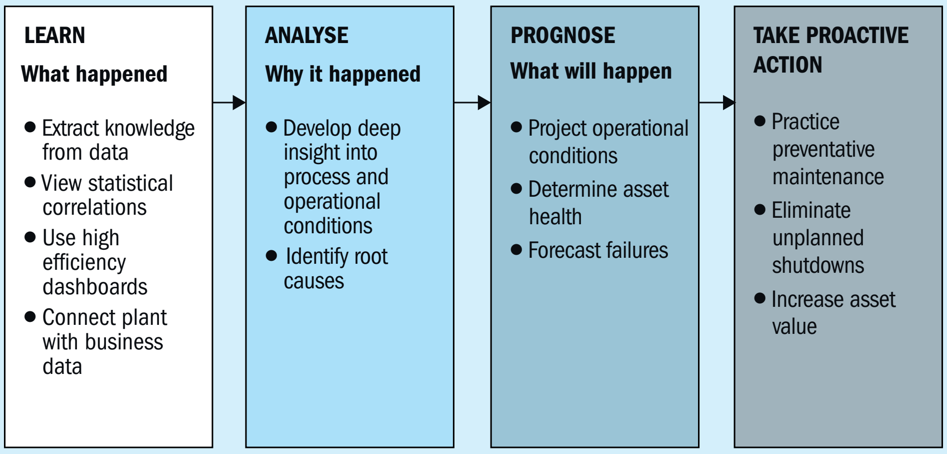
It should be noted that the digitalisation solutions offer additional value when they combine seamlessly process knowledge with cutting edge technology and sound accompanying business processes, adapted to the business and plant environments.

Configuration of a software alone does not guarantee value.

KBR discusses below two digitalisation solutions, which ensure increased operational reliability and help clients reap maximum value from their existing assets. These are the reliability-based maintenance (RBM) solution and the performance monitoring and advisory solution, KBR InSite℠, which together form the basis for condition-based practices.

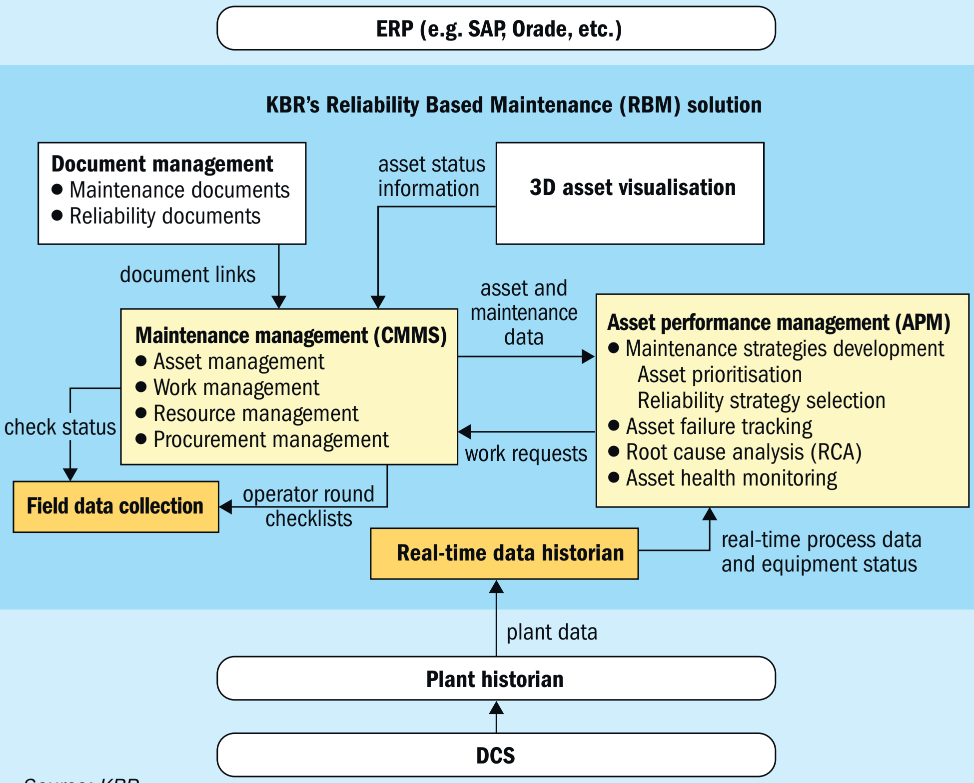
By embedding an artificial intelligence/ machine learning (AI/ML) module the condition-based practices can be progressed to more predictive and prescriptive operational strategies.

Fig. 1: **Digitalisation solutions**



Source: KBR

Fig. 2: **KBR's Reliability Based Maintenance (RBM) solution**



Source: KBR

KBR's RBM solution

Among the digitalisation solutions available in the market today, reliability-based maintenance solutions, such as the one KBR has designed and developed specifically for ammonia plants, accompanied by best in class relevant business processes, offer great value to customers and have high return on investment, because they address the core issues of operational reliability and help clients increase the value generated by their assets.

Reliability-based maintenance minimises and even eventually eliminates reactive maintenance, resulting in significantly lower maintenance costs and lower inventories of spare parts. When the plant experiences less reactive maintenance, both unplanned maintenance-related downtime and labour costs decline.

The KBR RBM solution has modular functionality and optimised business processes that enable best practices. It helps clients improve the performance of their reliability and maintenance practices and maximise their asset's return on investment (ROI), by transforming the maintenance operations from reactive to proactive.

KBR's RBM solution is fully integrated with the plant distributed control system (DCS) and the client's business system and provides scalability for growth in terms of users, facilities, and assets.

KBR's RBM solution is offered with the following modules:

- Maintenance management

- Document management
- Asset performance management
- 3D asset visualisation
- Field data collection
- Real time historian

Fig. 2 shows the functional block diagram of KBR's RBM solution.

The RBM solution enables proactive monitoring of assets and automatic notification of performance issues, so that the plant's operations and maintenance management teams can take corrective actions. Benefits are generated due to the direct reduction of the overall plant maintenance requirements and associated costs, reduction of unplanned shutdowns, increase of plant uptime, reduction of overall production costs and improvement in energy consumption. Continuous performance management will ultimately yield improved safety, higher product quality, increased reliability and availability of the company's assets, which have a direct effect on profitability, while at the same time will help manage risks and compliance to regulatory requirements.

KBR InSite℠

KBR InSite℠ is a cloud-based technology licensor service for remotely monitoring plant process performance and the health of associated critical equipment. KBR InSite℠ uses a combination of state-of-the-art web-enabled visualisation dashboards and advanced mathematical algorithms to observe, track, and analyse operational parameters and key performance indicators (KPIs) that impact the overall efficiency and productivity of the plant.

At the core of this service is the availability of a pool of KBR process and operations experts who leverage their in-depth technical know-how of the process to provide timely guidance to plant personnel to support improvements in plant operations and equipment reliability. The process experts use the KBR InSite℠ dashboards as an enabling platform to visualise and diagnose operational problems, determine probable root cause, and recommend corrective actions that can either prevent abnormal operations or enable quick resolution of current problems. Drill-down features allow the rapid visual identification and exploration of potential problem sources.

Proprietary calculation methods and first principle-based simulation models unlock the value of near real-time plant data to create a visual "digital fingerprint" of the plant and provide the necessary framework to estimate the performance and health of process and rotating equipment. Inherent or derived parameters such as exchanger heat transfer coefficients, compressor efficiencies, specific-energy consumption, approach to equilibrium, etc. are examples of parameters calculated periodically by these first principle models. Moreover, these models can be used to periodically reconcile the overall heat and material balance of the plant so that inaccurate or faulty sensors can be flagged for recalibration or replacement. Offline, what-if analyses can also be conducted using these models, to identify opportunities for production increase or energy reduction by driving the plant operations towards the upper limits of thermodynamic efficiency (subject to process or equipment constraints).

Smart, proactive, escalating alerts to flag deviations of KPIs from as-designed or targeted performance are setup to trigger advisory service and the proactive engagement between plant personnel and KBR's experts. These alerts act as early warning notifications of impending abnormal or sub-optimal process deviations, they can be visual (displayed on the dashboards) and can be propagated as text messages via e-mail or to a mobile device. Any data analysis related to these alerts as well the recommended follow-up actions are summarised in Event Reports that are sent to the customer.

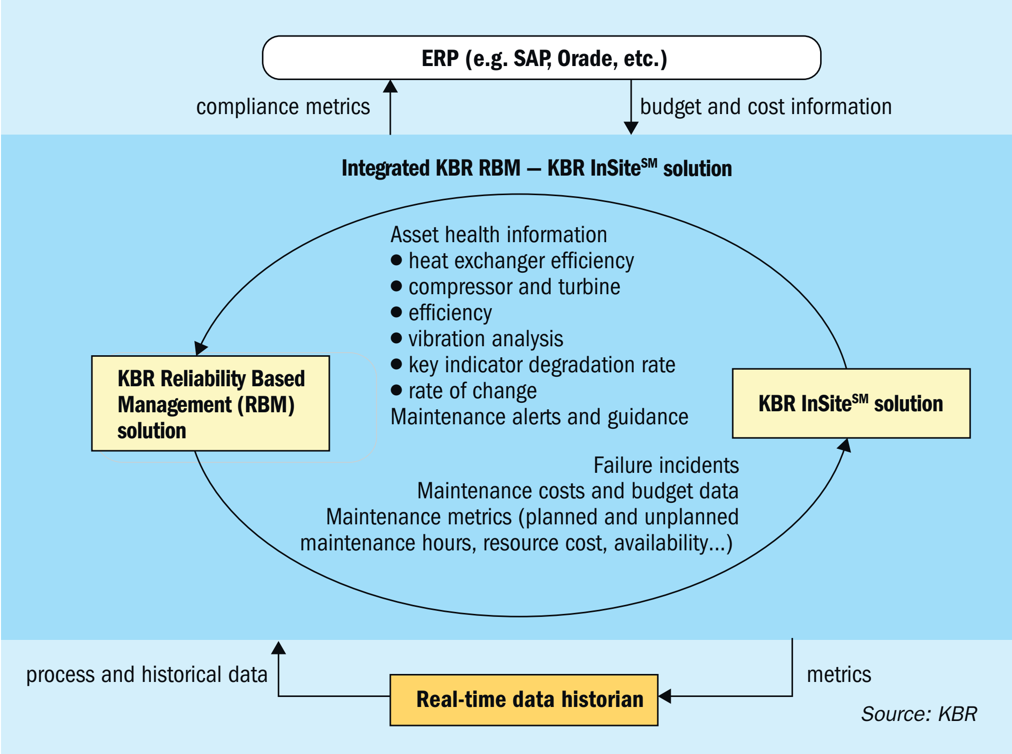
This mode of alert propagation and expert analysis based on early event detection clearly reflects a paradigm shift from a conventional, reactive form of service to a more proactive form. This prevents incipient issues from progressing into serious operational problems that could negatively impact plant uptime.

In essence, the KBR InSite℠ service embeds the key functionality required to estimate the current health of an asset, to detect early events that can impact this health, and the expert guidance to prevent or mitigate abnormal events from leading to unplanned plant shutdowns.

Integrating KBR InSite℠ and RBM

KBR's experience with process plants is that the type of root cause of unplanned shutdowns varies depending on the age of these plants. For instance, in brownfield plants most unplanned shutdowns are directly caused by equipment failure, usually as a consequence of gradual wear and tear associated with the operation of such equipment. On the other hand, at grass root plants many of the unplanned shutdowns are attributed to uncontrolled process upsets, failed sensors, abnormal weather conditions, errors in trip-logic, and in some situations due to operational oversight of inexperienced operators. To address both these diverse situations, KBR has designed the integrated InSite℠ and RBM solutions, as part of our integrated

Fig. 3: **Integration of KBR InSite℠ and RBM**



Source: KBR

operations management and performance monitoring offering.

A schematic of the functional integration of the two solutions is shown in Fig. 3.

The combined solution enriches RBM with predictions and alerts regarding the health of the process equipment based on derived parameters (i.e. not available directly from sensor values in the control system), such as heat exchanger fouling, compressor efficiencies, and catalyst activity all of which can impact plant uptime. Moreover, it provides the flexibility to consolidate all the reliability management and maintenance management KPIs into the interactive dashboards of KBR InSite℠, thereby offering KBR clients a centralised mechanism to track and review overall health of the asset.

Furthermore, the integration of RBM with the maintenance management module of RBM provides the ability to use the current health of the process equipment to support condition-based maintenance practices, enhancing further the ability of the combined solution to improve plant uptime.

Together, the integration of KBR InSite℠ with RBM and the maintenance system forms the basic building block for the deployment of a wider digitalisation program, which includes the use of AI/ML modules (described below) as well as the development, alignment, and optimisation of business processes and organisational capabilities needed to effectively implement and utilise the various technologies that comprise the overall digital solution.

Artificial intelligence and machine learning

An emerging global mega-trend in the process industry today is the use of artificial intelligence and machine learning for analysing plant operations data and predicting process anomalies and equipment failure. These applications typically use data from disparate sources (such as process historians, and laboratory and maintenance systems) to provide early detection and identification of incipient issues that can potentially lead to undesirable process excursions or equipment failure in an operating plant.

Moreover, the ability of such data-driven models to predict ahead of time when these process excursions or equipment failures will occur, allows a plant operator to take proactive remedial action to prevent an uncontrolled process excursion that can result in an unplanned plant shutdown. Similarly, the prediction and analysis of time-to-failure of equipment can help the operations and maintenance teams to plan and schedule maintenance activities ahead of time as well as initiate actions for on-time delivery of spare parts to reduce production downtime.

Therefore, for KBR the embedding of AI/ML functionality within the InSite℠ and RBM applications represented a perfect opportunity to create a high-value solution that helps customers adopt prediction-based preventive maintenance practices that can reduce unplanned shutdowns and improve the uptime of operating plants. To meet these requirements, KBR designed an AI/ML module that would as a minimum provide the ability to:

- detect anomalies or events that indicate that a process or an equipment is behaving abnormally;
- quantify the contribution of different variables or parameters to these anomalies;
- predict ahead of time the value of a critical process variable that if uncontrolled can lead to a plant upset;
- forecast the time to failure of an equipment;
- provide prescriptive analysis or recommendations to resolve a process anomaly or to prevent an equipment failure.

From an end-user perspective it is critical that the diagnostics provided by the AI/ML module in response to an anomaly are very visual and facilitate easy review of the main contribution factors. To further extend the functionality, KBR is developing a smart rule-based system that combines the AI/ML diagnostics with the domain knowledge of their experts to help identify not only the root cause of the anomaly but also the remedial actions required to prevent these operational anomalies from progressing into unplanned plant shutdowns.

Digitalisation and expertise

Reducing unplanned downtime and increasing asset utilisation represent the largest opportunities for reducing operational expenditure (opex) of a plant. Hence the ability to quickly diagnose and remedy operational issues which impact equipment performance is a prerequisite for achieving operational excellence in most plants. Based on KBR's experience, the ability to combine digitalisation solution with domain knowledge of their process experts has provided them the opportunity to assume the role of a "Trusted Advisor" to plant personnel and achieve significant benefits for them in the various stages of plant life:

During commissioning and start-up: As a detailed engineering contractor, KBR has provided commissioning and start-up teams for onsite service while being supported by technology advisors from the home office. To a large extent, the deployment of the KBR InSite℠ service has increasingly contributed to the safe and successful start-up of these plants. Specifically, the ability to remotely monitor plant operations in near real-time through the visualisation dashboards has allowed KBR experts located at different engineering offices to collaboratively shadow commissioning and start-up activities and alert the onsite team of any deviations from best practice guidelines. Moreover, it allows the validation of any operating guidelines that are recommended to plant personnel from the home office through the use of dynamic simulation programs which are developed to closely mimic transient conditions normally observed during start-up of the various process units.

Normal steady state plant operations: Continuously improving normal steady state operations of a plant through timely expert advice based on proactive monitoring and data analysis is a primary benefit derived from the KBR InSite℠ service. The use of proprietary mathematical and optimisation tools combined with subject matter expertise helps identify how the plant can transition from a current steady state operation to a more optimal one.

Unscheduled plant shutdowns: The use of AI/ML tools provides early detection and identification of anomalies and helps prevent incipient issues from progressing to process excursions or equipment failure. These tools can also be used against historical data to identify the root cause of plant shutdowns that occurred in the past. However, a well-tuned dynamic simulator could also be used to mimic the sequence of events that precede an unplanned shutdown, allowing the root cause of the trip to be analysed, controllers to be retuned, and the interlock logic to be modified and thoroughly tested to account for relevant process dynamics as well as operator action. Without the KBR InSite℠ service, the plant operators would have had to learn from each event after the fact and plan proper anticipatory response to address similar events in the future. ■

Reducing industrial carbon footprint

Imagine an industry that only uses carbon-free fuels and does not have any carbon footprint. Assume this is feasible within a decade. Now wouldn't that be an ambition worth pursuing? Duiker believes this is achievable. **A. Lanser** provides Duiker's view on how its SCO technology can act as an enhancer for reducing industrial carbon footprint.

New application of SCO technology

Today the call for renewable forms of clean energy is increasing in order to reduce emissions of greenhouse gases (GHG) and to achieve the goals of the 2015 Paris Agreement. Many companies are striving to lower their carbon footprint during production. This creates the potential for a new application for Duiker's patented Stoichiometry Controlled Oxidation (SCO) technology.

Duiker's SCO technology was developed and commercialised in the early 2000s and is typically integrated in sulphur recovery units (SRUs) for processing ammonia (NH_3) produced as a waste product in the refinery. Today, SCO technology is employed in several units in operation under various process conditions which have proven its ability to completely decompose NH_3. In stark contrast to uncontrolled ammonia combustion which can easily generate thousands of ppm of NOx emissions, the NOx emissions from the SCO unit can easily meet environmental regulations without further treatment. The SCO unit can realise NOx emissions in the range of 50-70 ppm @ 3% O_2 dry.

Companies active in energy intensive and/or high temperature industries could benefit from SCO technology, because "green" or "sustainable" ammonia will be used as a carbon-free fuel, provided ammonia is produced from renewable sources.

This new application for Duiker's SCO technology aims to replace fossil fuels (coal, oil, natural or refinery gas) by green ammonia, in so-called direct fired equipment applications and endeavours to contribute to a significant reduction of CO_2 emissions.

Electrification and energy storage

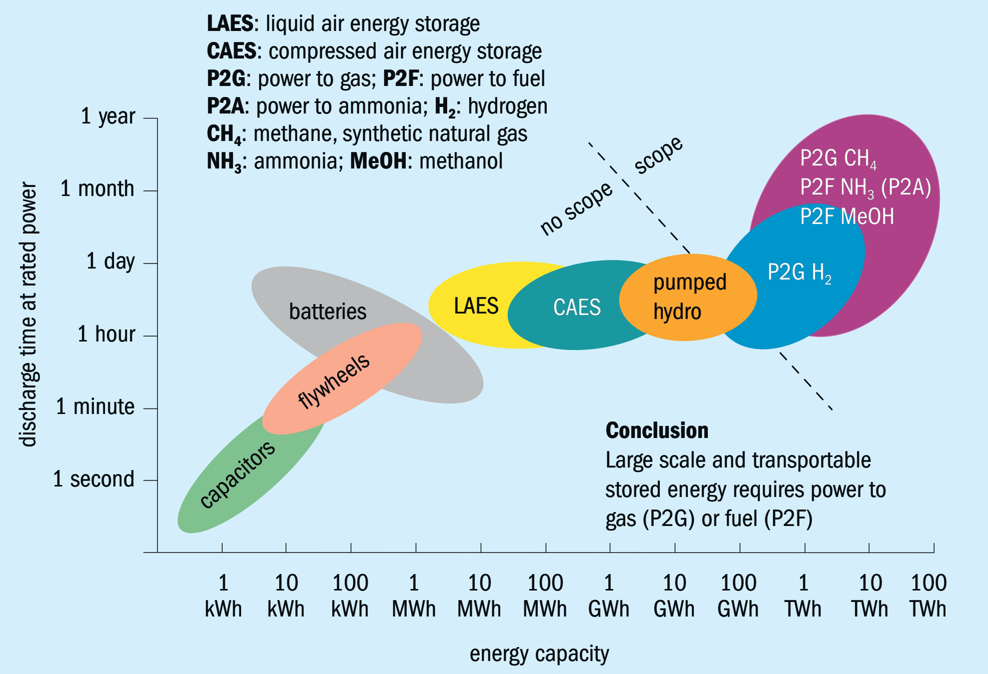
One of the major efforts to reduce climate affecting gaseous emissions is the ongoing "electrification" of society and industry. This requires energy to be produced from renewable sources like wind, solar and hydro, or other methods. As the supply of renewable energy increases it is hoped this will reduce fossil fuel consumption.

The lack of long term storage options for electricity generated from renewable methods is a major disadvantage compared to traditional energy production. Special batteries, for example, could be a solution for short time storage in the magnitude of hours but are not optimum for seasonal storage (see Fig. 1).

Between the storage challenges of renewable energy and the daily or seasonal fluctuations in potential generation levels, the electrification of industry faces unique challenges. To meet the demands of certain industries, electrification will need to take a different approach, not using electricity directly from renewable sources. The use of "energy carriers" can provide long term storage and easier transportation options without creating economical barriers.

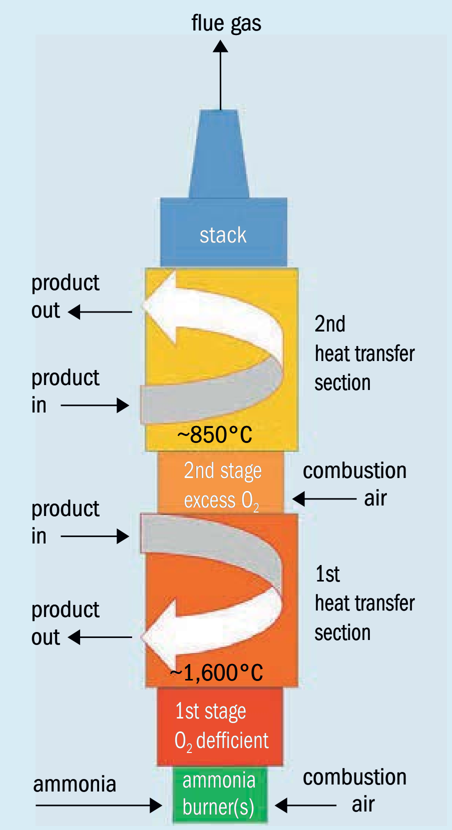
The chemicals in the blue and purple ellipses in Fig. 1 are currently labelled as potential "energy carriers". Amongst other chemicals, ammonia has been identified as a highly suitable medium for the storage and long distance transport of hydrogen.

Fig 1: **Potential energy storage solutions**[1]



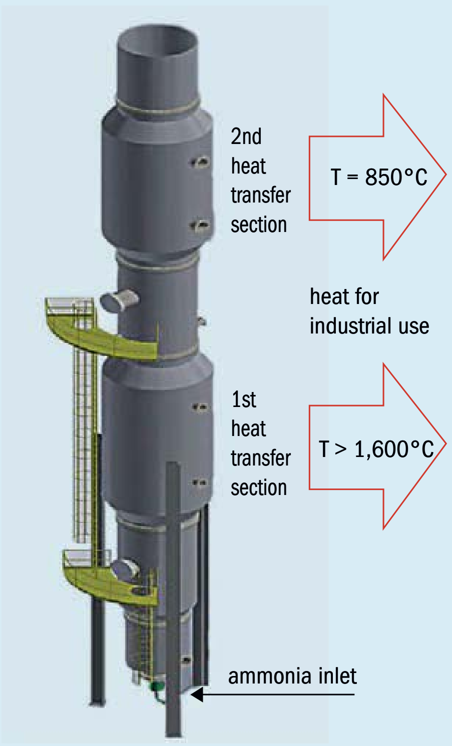
Source: ISPT

Fig 2: **Possible industrial application of ammonia as a fuel**



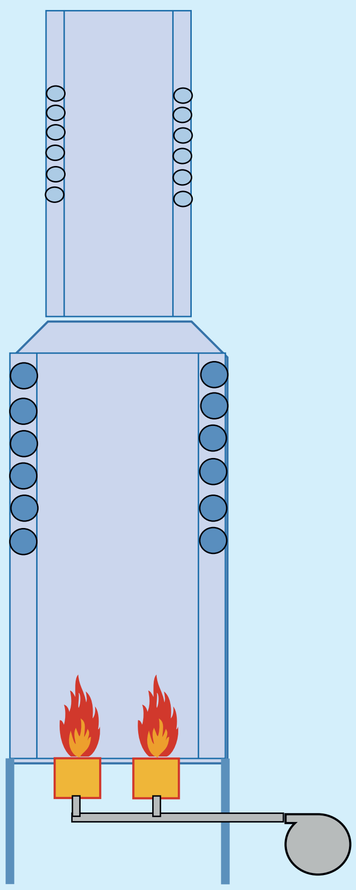
Source: Duiker

Fig 3: **Imagined direct fired equipment with sustainable ammonia**



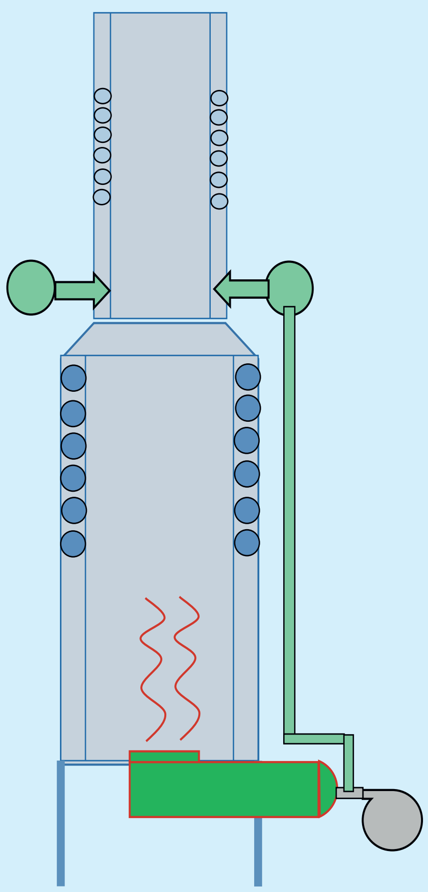
Source: Duiker

Fig 4: **Forced draft heater firing on fossil fuels**



Source: Duiker

Fig 5: **Revamped heater firing on green ammonia**



Source: Duiker

An important advantage of using ammonia as opposed to unbound hydrogen is that it can be stored and transported at room temperature at a pressure of 8.5 bar. Hydrogen on the other hand has to be stored and transported at a very low temperature and very high pressure. This not only makes it impractical but severely reduces the overall efficiency of the hydrogen-energy chain.

Ammonia as a sustainable green and carbon-free fuel

The ISPT report "Power to Ammonia"[1] mentioned: "NH_3 if produced from renewable electricity can be used as a high caloric energy carrier to store CO_2-free electricity. NH_3 has a potential to be used as a chemical storage medium due to a relatively high round trip efficiency, energy density and low cost of nitrogen sourcing. Converting NH_3 back into electricity can be done without CO_2 emissions. The technology is scalable and not limited by scarcity of materials or storage space."

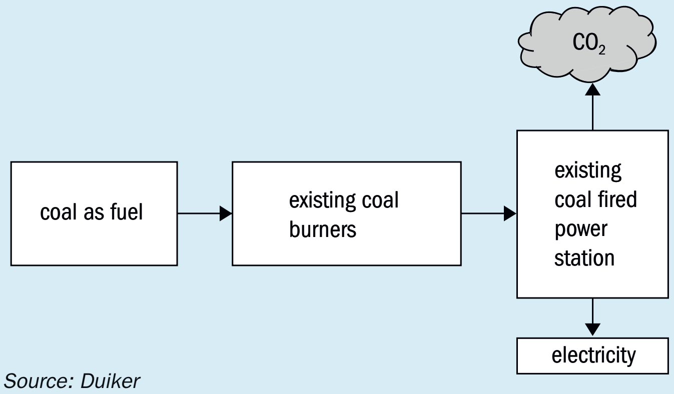
Aside from the conversion of ammonia back into electricity it is feasible to use ammonia directly as a fuel. This might be an even more interesting option for certain industries. The maritime industry is already considering the use of ammonia as a fuel. A quote: "The decarbonisation by 2050 scenario shows a drastic switch to ammonia from 2040 onwards, with almost 100% of the fleet using ammonia by 2050", published in a recent article[2] from the Global Maritime Forum, shows serious consideration of green ammonia as a fuel.

From a technological point of view, sustainable or green ammonia as a fuel is a feasible solution for the electrification of industry. This can be realised with Duiker's SCO technology that converts ammonia into flue gases of high temperature (>1,600°C). This will be further referred to as "high temperature heat".

Energy release benefit of SCO technology

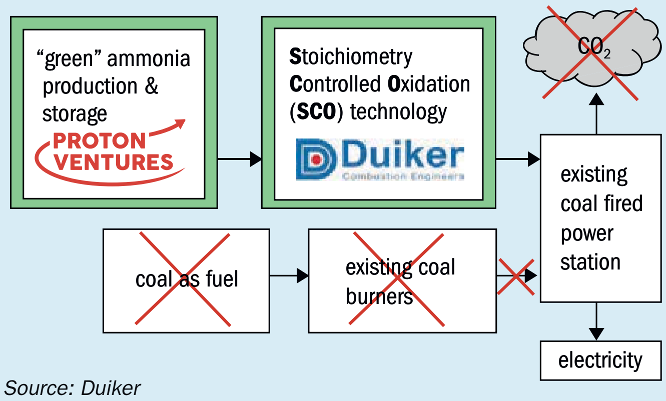
Fig. 2 illustrates how the heat released by the combustion of green ammonia could possibly be transferred to a potential production process by means of heat transfer equipment. After the first combustion stage the flue gas temperature may rise to a level above 1,600°C and these flue gases can be used as input for a high level temperature heat transfer section (1st heat transfer section).

Fig 6: **Conversion of existing coal fired power station**



Source: Duiker

Fig 7: **Renewable multi-fuel power station**



Source: Duiker

After the flue gases have passed through the 1st heat transfer section, another combustion process takes place in the second stage. Thereafter, the flue gases still contain enough energy to make energy recovery worthwhile. In the second stage the flue gases have a temperature of approximately 850°C so another heat transfer section can be used to harvest this energy (this takes place in the "2nd heat transfer section" in Fig. 2).

Fig. 3 shows a piece of imaginary equipment. This visualisation has been derived from the block scheme in Fig. 2. This is how Duiker envisages an example of direct fired equipment with "green or sustainable ammonia".

The dimensions and configuration of the equipment may vary to a large extent, depending on the application. The exact heater configuration and dimensions will be determined in consultation with Duiker's customers. Efforts will be made to minimise modifications to an existing (fossil fuel) fired heater/furnace.

Refer to Figs 4 and 5 for a brown field example. Fig. 4 shows a typical forced draft heater firing on fossil fuels and Fig. 5 shows the same heater after a typical revamp based on SCO technology, enabling green ammonia as a fuel.

From a combustion viewpoint, Duiker's SCO technology is suitable for a variety of future applications in high temperature and energy intensive industries (i.e. steel, cement and power generation). The following equipment, amongst others, can be redesigned for ammonia as a green fuel:

- fired heaters / ovens;
- industrial gas fired furnaces;
- naphtha crackers;
- gas fired turbines;
- steam boilers;
- steam methane reformers (SMRs);
- (coal-fired) power plants.

Sustainable multifuel coal-fired power station

In general, CO_2 emission reductions are a political and environmental topic. For example, in The Netherlands, the Dutch government decided that, in 2030, all coal-fired power stations for generation of electricity have to be either out of operation or rebuilt for carbon-free electricity generation.

This is not only a challenge from a viewpoint of CO_2 emission reduction, but also from a power grid balancing perspective. The current Dutch coal-fired electrical power stations are also operating as a buffer for the preservation of the fine balance between supply and demand of electrical energy. Eliminating coal-fired power stations, which are relatively flexible, operating within a wide load range, stabilising the power grid, will be challenging, because generating electricity from renewables is less predictable and hardly determined by demand. Green ammonia as a fuel substitute for coal in a power station can take over this grid balancing role. This is another argument for considering ammonia as a flexible energy storage system.

Duiker Combustion Engineers, together with its partner Proton Ventures[6], are jointly working on a plan to convert existing coal-fired power plants into renewable multi fuel-fired power plants. The objective is to substitute coal by green ammonia combustion. The fuel conversion from coal to green ammonia will take place step by step and will, eventually, eliminate coal firing completely. The firing of green ammonia will be based upon Duiker's SCO technology. The achievable reduction in CO_2 emissions by this fuel change would be obvious and significant. Figs 6 and 7 visualise this process.

Economics vs environment

Let's start with a couple of quotes about the perceived value or costs of ammonia: "Green ammonia is increasingly acknowledged as a valuable chemical for transportation and storage of hydrogen produced from renewable electricity."[1]

Or: "The current price of green ammonia produced by renewable electricity, is about 18% more expensive than ammonia produced from fossil fuels".

"So if brown ammonia goes to market at a price of, say, $450 per tonne (~15% mark-up over cost), and green ammonia could be available at a price of $530 per tonne, what effect might this have on national policy calculus? It's one thing if the price of a green commodity is twice that of a brown one. But just 18% more? This could be a bargain policymakers may be willing to strike.", according to a news item on the AEA website[3].

And: "Ammonia fits well in a hydrogen based economy."[4]

It is noteworthy that ammonia, in the current market, is predominantly used as a feedstock in the fertilizer industry and not as a fuel. If ammonia produced from renewable sources becomes cheaper than from fossil fuels, this will also reduce the cost of producing fertilizers. The largest cost driver for green ammonia is the electricity price to produce sustainable ammonia from green hydrogen. Thus, the lower the electricity price, the lower the price for green ammonia.

The Hydrogen Council expects that the cost of hydrogen: "is projected to decrease by up to 50% by 2030 for a wide range of applications."[5]

The current economic feasibility of green ammonia versus fossil fuels, such as coal, is a challenge. However, the actual situation is most likely to change over time in favour of green hydrogen and ammonia. The price for CO_2 emission rights is likely to increase in the next decade and the economies of scale will have a positive impact in bringing down the production costs for green hydrogen and ammonia. Today's economics still rule over environment.

Duiker anticipates that it is only a matter of time before the business case for large-scale renewable energy production will favour renewable energy over fossil fuels.

The timing for economic breakeven for renewables will be greatly influenced by a higher price for CO_2 emission rights, as a "penalty" for carbon emissions. Breakeven as soon as possible will be most beneficial for the environment.

Next steps

Coming back to the original ambition and question at the beginning of the article, Duiker's conclusion is that the ambition is indeed worth pursuing and the answer to the question is a convincing "yes". SCO technology has been proven and is scalable in SRUs and thus offers a feasible route to convert green ammonia into high temperature heat and to phase out industrial CO_2 emissions.

The economic competiveness for this path forward is only a matter of time. Large-scale green ammonia production in the near future, as well as extra carbon emission costs for using fossil fuels, will change the economic outlook for green ammonia in the coming decade.

The time taken for renewables to become an economic choice could be shortened significantly once a major industrial player or a consortium of different industrial players has the courage to invest considerably in green fuel production. This will prove that a large green fuel production plant is scalable and possible and it will have a very positive impact on the acceleration of the necessary infrastructure of green fuels.

Duiker Combustion Engineers is ready to act as an innovative partner for long-term solutions and is eager to explore the possibilities of its SCO technology with any potential customer who is interested in reduction of CO_2 emissions and in applying green ammonia as a green solution for its (production) process. ■

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Sustainable production of nitrates from renewable energy

Paving the way for commercially attractive, sustainable, decarbonised fertilizer production, **J. Dobrée** of Stamicarbon BV discusses the latest developments for nitrate fertilizer production based on renewable feedstocks sourced from solar and wind energy. Stamicarbon has upgraded plant designs used in the past to create a new type of small-scale fertilizer plant capable of producing a product mix that can be adjusted to meet specific local requirements with maximised output value, thereby maintaining a competitive position towards imported products and large-scale producers.

The chemical industry is showing an increased interest in using renewable or carbon recycled chemicals to reduce its environmental and carbon footprint.

The availability of renewable energy sources creates new opportunities for the use and geographical location of nitrate fertilizer production, while providing a clear path for sustainable and decarbonised fertilizer production.

Power-to-fertilizers

The energy section is facing a huge transition from fossil fuels to renewable feedstock sources, such as wind and solar energy. The increasing capacity of renewables has created economy of scale, which today results in competitive electricity pricing that can match and, in some regions, even beat electricity produced from fossil fuels.

However, the large quantities of renewable energy create pressure on the grid, especially in Europe, and create an issue in relation to the stability of supply. In addition, interesting solar and/or wind locations lack grid connection or a market and are therefore not utilised.

The interest in renewable, carbon free or carbon recycled fertilizers is increasing slowly, considering the substantial environmental footprint of the agriculture, while industrial partners face the pressure of stake and shareholder to improve the sustainability of their operations.

> **...providing a clear path for sustainable and decarbonised fertilizer production.**

Another driver for reducing the environmental footprint of fertilizer production lies in the governmental pressure that can be seen in various regions on fertilizer producers to push for sustainable solutions, facing location regulation and possibly carbon taxation.

This article introduces Stamicarbon's approach for the sustainable production of nitrates from renewable energy sources. It covers the background of current developments in the field and shows the commercial viability of carbon free nitrate production today. The article follows the strategic direction of Stamicarbon set out during its Future Day in April 2019, which announced Stamicarbon's engagement to develop projects covering the production of ammonium nitrate or urea-based fertilizers from renewable energy sources.

Project approach

For projects in the field of renewable energy and carbon free or carbon recycled feedstock, a dedicated approach is considered via project development. The approach needs to ensure that the hurdle of new technologies can be overcome and that the commercial benefits can be realised. Stamicarbon, as part of the Maire Tecnimont Group, can rely for such involvement on its Project Development and Venturing Group, which coordinates the whole process as well as the various financial, institutional and technical actors involved, while leveraging advanced technical and financial skills to promote sustainable fertilizer projects. The set-up is shown in Fig. 1.

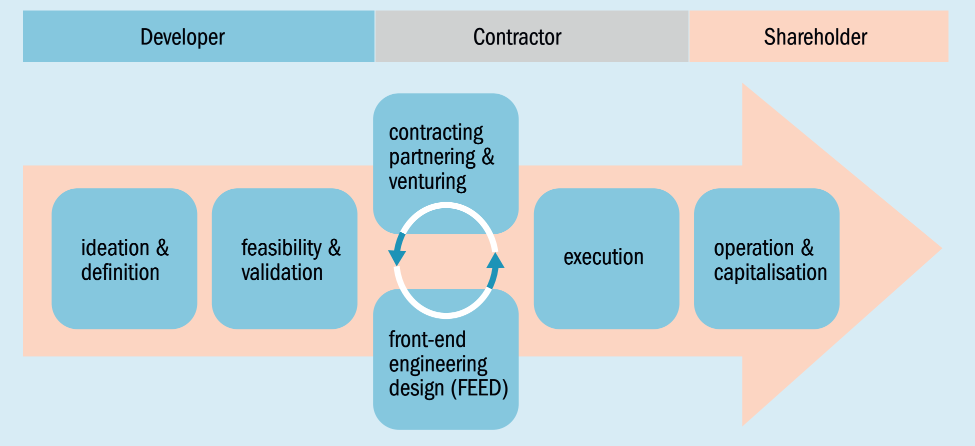
Full process co-ordination is required with a dedicated consortium, as the development of projects driven by renewable feedstock utilise state-of-the-art technology in all of its building blocks.

Having the right consortium in place is considered critical to secure a successful result, as the targeted projects consider technical challenges that are partially under development and require customisation dedicated for the purpose and anticipated site location.

Conceptual plant configuration

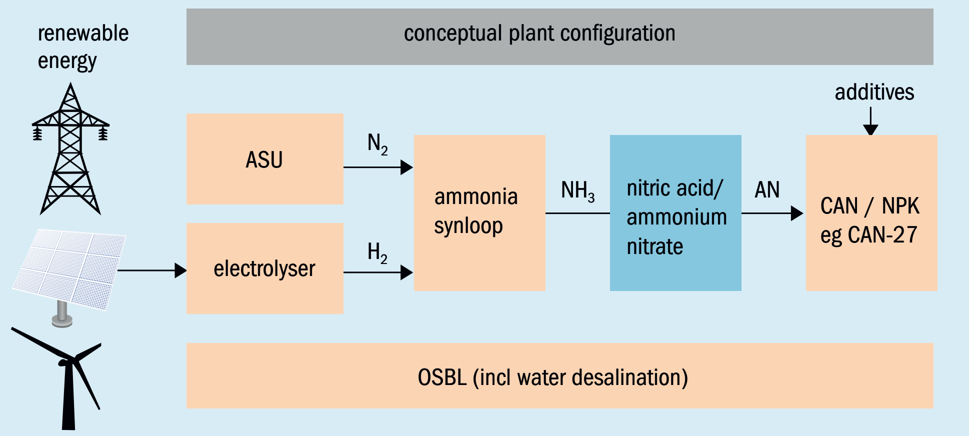
In order to serve an increasing market demand for small-scale facilities, Stamicarbon has developed a niche technology referred to as LAUNCH MELT™ Small Scale Design for urea and the LAUNCH Nitric Acid Mono Pressure Design for nitrate production.

Fig. 1: **Project development approach**



Source: Stamicarbon

Fig. 2: **Conceptual plant design for sustainable nitrate production**



Source: Stamicarbon

Stamicarbon's design for sustainable nitrate production (Fig. 2) is focused on the merger of various available technologies. The core technology is Stamicarbon's mono pressure nitric acid technology, which results in ammonium nitrate production for a capacity of 100 or 200 kt per year CAN. The final product can be various nitrate types, but for the conceptual design calcium ammonium nitrate (CAN) with 27% Nitrogen (CAN-27) is used as the reference point.

The design follows the same principle of the small-scale fertilizer production available for urea technology and is focused on supplying local nitrogen demand, extended with the production of specialty fertilizers for specific local soil and crop requirements. For example, Stamicarbon's state-of-the-art LAUNCH MELT™ Small Scale Design is capable of producing AdBlue®/DEF, urea for melamine, enriched urea, UAS, UAN, as well as direct application coated urea with e.g. controlled release coating.

Stamicarbon nitric acid technology

The unit design for nitric acid production originates from Stamicarbon's heritage and has been upgraded to state-of-the-art technology, which allows nitric acid production of up to 1,600 t/d and more. Stamicarbon mono pressure technology is derived for the application of small-scale fertilizer plants capable to produce a product mix that can be adjusted to meet specific local nitrogen requirements and demand. It can also be considered for the production of explosives if necessary. The origin of the Stamicarbon mono pressure technology dates back decades, to a time when it was being used in Egypt, based on hydro power.

The core of the value proposition brought by the mono pressure technology overcomes logistic deficiencies, while minimising capex. In order to provide a competitive solution for producers that have interest to produce locally on a small-scale or to tap into a niche product market, key elements have been considered to provide a successful technological solution:

- minimise capex with minimum equipment to optimise the financial model;
- highest energy efficiency;
- robust and reliable plant design with possibility for remote support, as relative limited plant staff and operational competences will be available at site;
- modularised construction approach possible by using prefab skids to reduce local construction;
- compliant to most stringent environmental standards for NOx and N_2O;
- highest quality and safety as per Stamicarbon standards;
- flexibility to process renewable or bio-based feedstock, which may be variable in supply and/or entail logistic deficiencies;
- based on a long track record of historical references.

The mono pressure technology is standardised for small-scale plant sizes with a minimum capacity of around 100 t/d, following a reputable track record with over 40 references worldwide.

The main technological feature of the mono pressure technology, besides the compact and low capex design lies in the use of an innovative ammonia burner design and smart heat exchanger network. This results in core advantages:

- highest energy efficiency/team export;
- lowest NOx and N_2O emissions;
- corrosion prevention by design without the need for exotic construction materials;
- plant design suitable for digital automation.

As is the case for all Stamicarbon plants, the nitric acid plant has a characteristic compact design. The lay-out is focused on reduced capex by utilising modularisation and the optimum design has been engineered without compromising Stamicarbon's performance, reliability and safety requirements.

For nitrate finishing, Stamicarbon has a partnership with INCRO, which provides a wide array of nitrate finishing technology for CAN and NPK production. For UAN production, Stamicarbon relies on its own reliable UAN technology, which has stood the test of time in various plants across the world over the last decades.

1 47 2 48 3 49 4 50 5 51 6 52 7 53 8 54 9 55 10 56 11 57 12 58 13 59 14 60 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

New geographical reality

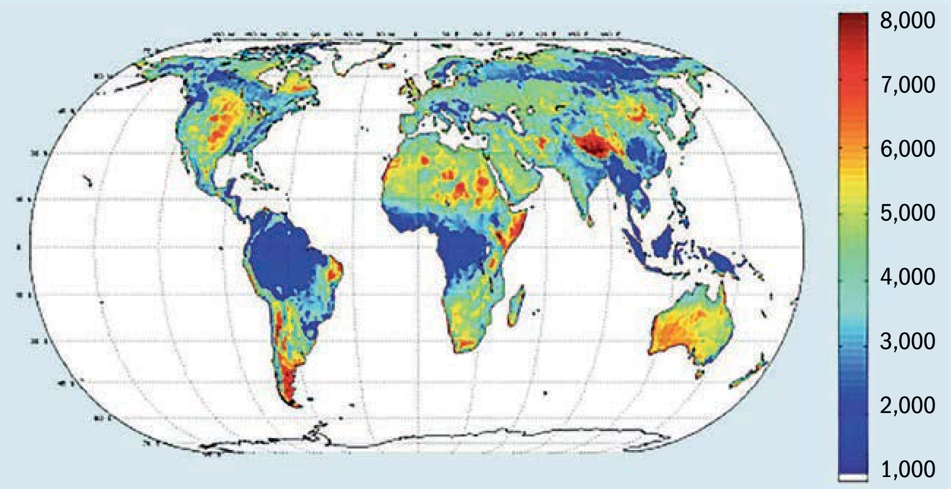
The fertilizer technology portfolio of Stamicarbon has the capability to facilitate renewable or carbon recycled feedstock, depending on the desired fertilizer. Examples considered are the use of feedstock originating from refuse derived fuel (RDF) gasification units, which produces syngas based on municipal waste or feedstock derived from furnace off-gas from the steel industry. Another example could be the combination of green ammonia production from renewable electricity derived from wind, solar, thermal or hydro, while using the carbon dioxide from carbon capture units from conventional power plants or industry. In the case of nitrate production, the focus is primarily on the use of carbon free feedstock sources, such as wind, solar, thermal and/or hydro.

In light of current developments related to the reduction of carbon footprint and the ambition to produce chemicals in a more sustainable way, the interest of project developers is slowly shifting from power production to the production of chemical and fertilizers instead. By doing so, nitrate production from renewable energy can be considered as a green CAN-27 in this case.

The change of approach, the use of renewable sources as feedstock for fertilizer production, creates a new geographical reality for the nitrate market. Renewable sources are mainly available in areas with high load factors, which can be suitable for chemical or fertilizer production. However, areas with high load factors are not by definition typical for present day production locations of nitrate fertilizer from fossil fuel.

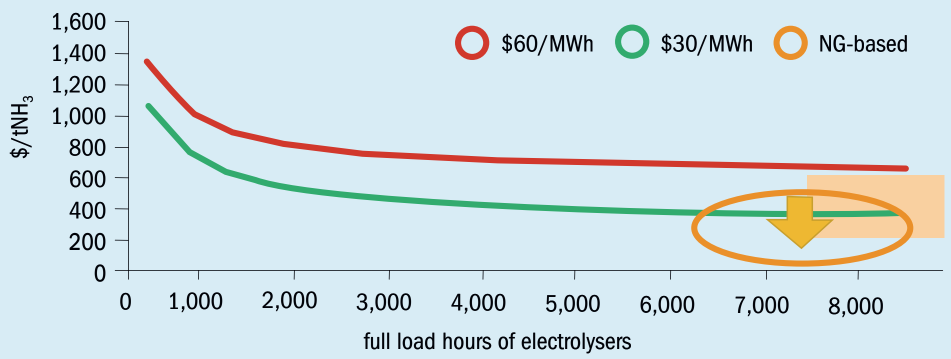
This creates new opportunities for the industry to service markets that were difficult to access in the past by local supply. On the other hand, fertilizers are easily transported over the globe, which makes the location of production less relevant to the end market, whereas in the past, location of production always tended to be dictated by the availability of attractive fossil fuel-based feedstock. This paradigm might shift in the future, considering the high load areas for renewable energy, indicated in Fig. 3, which provides a new view on the ideal production locations, especially in the light of reducing costs as a result of economy of scale of renewable wind and solar energy, which in some areas has outperformed fossil alternatives. In addition, any possible carbon taxation can act as game changer.

Fig. 3: **Ideal production locations for utilising renewable energy resources**



Source: Modified from Fasihi and Breyer, 2018

Fig. 4: **Cost of ammonia at various electricity prices and electrolyser load factors**



Source: Modified from OECD and IEA "Renewable energy for Industry: from green energy to green materials and fuels", 2017. Plant capacity: 500 kt per year.

The consideration of renewable production of nitrate fertilizers will follow a new approach driven by various (new) types of reasoning:

- competitiveness and availability of feedstock with distinction between renewables or fossil fuel;
- needs of local production, special types of fertilizer (blends) for special applications or explosives;
- carbon taxation, which can be applied upstream or downstream;
- incentives for sustainable fertilizers, e.g. by taxation or the application of premiums;
- governmental pressure to greening the brown;
- corporate vision and/or shareholder pressure;
- economic feasibility.

Despite slow moving regulations in the direction of carbon taxation, the economic feasibility is always the main driver. However, the modern-day view of investors, such as, for example, pension funds, are more and more focused on sustainable investments. This pressure on shareholders is becoming more relevant, making companies look at how they will operate in the future, which is a great driver for the development of sustainable fertilizer production. The critical question remains: Is nitrate fertilizer production based on renewable energy commercial attractive?

Economic feasibility

When developing a renewable project, the project size is typically small-scale. For these types of projects full understanding of the economics is critical, since small sized plants are only attractive in specific market conditions. Clear focus on the high value product mix, the ideal location and the right technology selection are key success factors.

One of the drivers of the cost price is the feedstock source, which is indicated by the cost of electricity. The International Energy Agency (IEA) studied the potential

Contents
ISSUE 365 NITROGEN+SYNGAS MAY-JUNE 2020
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production cost of renewable ammonia for a plant with a theoretical production capacity of 500 kt per year, which is illustrated in Fig. 4. At an electricity cost of $30/MWh, the cost of production should be feasible below $400 per tonne at high load hours compared to natural gas feedstock.

However, the interesting development since the publication of the graph in 2017 is that in some tenders the cost of renewable energy has already achieved electricity prices below $20/MWh for solar and wind, e.g. in areas of Brazil, Mexico and Saudi Arabia.

Considering the improved economy of scale towards reduced cost of electricity below $20/MWh and high load areas, able to support electrolyser production above 6,500 hours per year, it can be concluded that in specific locations renewables are already proven as a competitive alternative to natural gas, as indicated in Fig. 4 with the orange circle and indicative orange arrow.

Specific business case for inland Africa

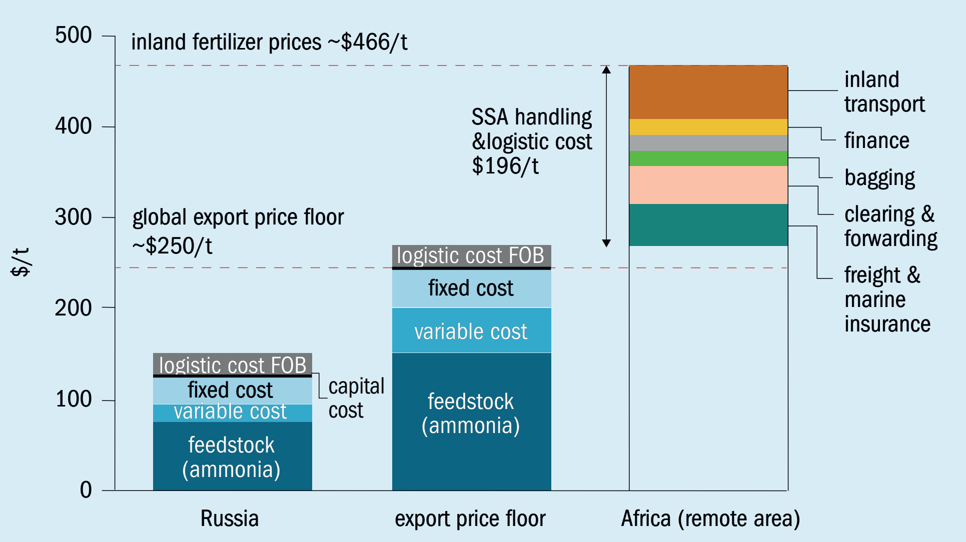
The economic feasibility can be illustrated with a feasible business case for inland Africa. Today all fertilizers used in inland Africa are imported from overseas. This results in two complicating factors, as a result of the long supply chain:

- affordability of fertilizers;
- availability of fertilizers on time.

In the current day situation the import of a tonne of CAN results in an estimated inland pricing in the range of $450-$500 per tonne minimum, while more than 20% of the cost originates from the logistics specifically for the domestic location inland Africa. The case is illustrated in Fig. 5. The cost can also increase in case of scarcity during peak season or supply chain issues, as was the case, for example, during the cyclone Idai in March 2019, which is unfortunately not an exception. The cyclone hit the port of Beira in Mozambique and thus the main gateway for fertilizers towards inland Africa.

In this case supply to a domestic location in inland Africa is subject to availability, due to the dependency on imports and high pricing as a result of the logistics and the inefficiency thereof. The alternative to produce fertilizers from natural gas is not an option, as the availability of natural gas in these areas is typically restricted or not available.

Fig. 5: **Example case: CAN prices inland Africa (2019)**



Source: Stamicarbon, analysis derived from data of AFAP/Ferticon/IFDC/Stamicarbon (2019)

However, renewable energy sources are available, which can be found in solar, wind, hydro and geothermal sources. This can therefore create the basis to justify local small-scale fertilizer production with the focus on high value fertilizers, dedicated to the local market. Market availability is not an issue as current imports are sufficient to sustain a small- to medium-sized plant, and application rates are currently very low. The latter might be solved by improving the availability and affordability of fertilizers, which could boost local fertilizer consumption and improve the application rate. This effect was observed after the recent commissioning of a urea plant in Nigeria.

The key question for the economics remains the competitiveness of the small-scale plant. Being aware of the relevant variables and parameters for the financial model, key characteristics of a typical 100 kt per year CAN plant have been optimised for this specific purpose. The measures taken allow for a very interesting business case. For the financial modelling the entire complex of the process plant is taken into consideration, which has resulted in an IRR of 10-15% for this specific example for the combined facility including full EPC.

These validated figures indicate that a sustainable future based on a renewable nitrate grade fertilizer can be realised with surprisingly good economics for carbon free fertilizer, and it is feasible today.

Especially in the light of anticipated economy of scale for power generation, electrolysers and the scale of production, we are at the beginning of a new way to produce nitrates. The main issue today seems to be the availability of renewable energy.

Conclusion

Nitrate production from a renewable source can technically be achieved and is already competitive with nitrate production from natural gas in specific regions today. At the moment the logistics, inefficiencies and investment costs are the major differentiators compensating the economy of scale effect to justify the small-scale plant.

Improving the economy of scale within power generation based on wind and solar and the electrolysers will further improve the proposition and will allow larger scale production utilising economy of scale in production as well. Stamicarbon's nitric acid technology allows for competitive small-scale nitrate plants in geographical locations where they overcome logistic deficiencies or access niche market.

In the light of the full plant design based on a renewable source, hydride solutions can also be considered as an intermediate step to replace brown hydrogen with a green version to improve the environmental footprint or to facilitate capacity debottlenecking. This is especially relevant during the transition phase as the availability of renewable energy will prove to be the main issue now.

Renewable nitrates will eventually make the fertilizer industry sustainable and positions nitrates as a potential substitute for other fossil fuel-based fertilizers in the future. The technology is already available and can be implemented with an acceptable business case today. The path towards sustainable fertilizer will be long and challenging, but it is the future and the future is now. ■

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