Number 354

July | August 2018

nitrogen+syngas

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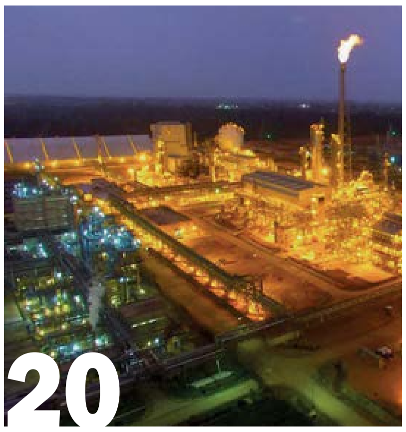

Africa's new plants

A mixed picture for new capacity developments.

Innovation and partnerships

Clariant's strategy for China and beyond.

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Published by:
BCInsight

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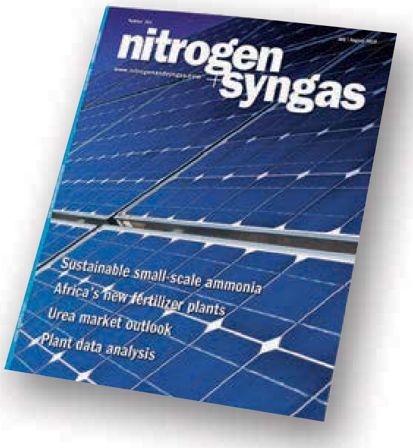
Lacking fizz



As the weather finally turns warm here in the UK, and with the World Cup and Wimbledon running or about to start, the ammonia industry has managed to deliver something of a blow to the British summer. The reason has been a shortage of carbon dioxide for the food and beverage industry, potentially affecting the output of some animal products, soft drinks and, even more crucially, beer. The situation has been described by industry magazine *gasworld*, which broke the story, as “worst supply situation to hit the European carbon dioxide business in decades”.

“The UK has been hardest hit by the shortage.

The cause seems to have been shutdowns and turnarounds in ammonia plants in the UK and northern Europe. Ammonia plants, we learn, are the largest source of industrial food grade CO_2 in Europe, and remains so in spite of some other producers like bio-ethanol plants and some other industrial facilities also being able to capture and sell CO_2. Indeed, the situation has been exacerbated because several of these alternative sources have also shut down at the same time.

Ammonia plant turnarounds in Europe tend to happen from April to June, as the peak season for fertilizer production tends to run from August to March so that farmers can stock up for the winter/spring application season. Of course, April-June is also the peak production period for soft drinks and beer, ready for the peak summer demand season. The European ammonia industry has however been hit by lower product prices and higher natural gas prices this year – on average $2.00/MMBtu higher than last year, squeezing margins and encouraging several producers to take extended turnarounds this year. It has coincided with a spike in demand for drinks due to the current heatwave in Europe and, probably a bit of ‘World Cup factor’ as well.

The UK has been hardest hit by the shortage, with only one major CO_2 plant still reported to be operating in early June. Imports from Scandinavia and the Netherlands simultaneously dried up because of ammonia shutdowns in France and the Netherlands which have meant there is limited availability from there. The result has been considerable issues for the UK drinks sector; UK food wholesaler Bookers’ is rationing beer and cider, many pubs have begun to run short of some types of beer, and Coca-Cola said it had “temporarily paused” some of its production lines. Some frozen food manufacturers which use ‘dry ice’ for freezing and storage have also seen issues. The problems have also spread to Norway, where the city of Oslo has introduced water supply restrictions because of a lack of CO_2 for water treatment, and even Mexico, which has also seen ammonia plant shutdowns.

There is apparently light at the end of the tunnel – the Billingham ammonia plant at Teesside, which is one of the largest sources of CO_2 production in the UK, has reportedly now re-started production, as has another major source in the country. However, in the interim, abattoirs (which use CO_2 to stun animals before slaughter), bottling plants and breweries have seen considerable disruption to production. It has been an illustration, if illustration were needed, of the interconnected nature of modern economies, and how events in one industry, in this case our own, can have a major knock-on effect on other industries which might not at first sight seem to be related. There is probably a veiled warning about the potential effects of Brexit in there somewhere, too, but perhaps for now it’s best to simply enjoy the sunshine and the beer – provided it lasts. ■

Richard Hands, Editor

Price trends

MARKET INSIGHT

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

NITROGEN

Nitrogen industry sentiment was increasingly bullish at the annual IFA gathering in Berlin last week, where urea prices at the major f.o.b. ports seemed to be gaining around $10/t every day of the conference. Discussions with participants yielded initial confusion as to the drivers of the rapid price rally, but weak Chinese exports in H1 appeared to be combining with strong demand from rice applications at the close of the US season and emerging Latin American demand as pre-buying kicked off for the southern hemisphere season. Ever-present was the spectre of US sanctions on the Iranian economy – the elephant in the room – and no one was sure of the severity with which they would restrict financial transactions and urea exports. However, reports of cancelled cargos to Europe quickly created an arbitrage between f.o.b. Iran and offers from the other Gulf countries.

Integer currently estimates Chinese urea operating rates to be at just over 70% based on a total installed, nameplate capacity of 81 million t/a. However, given the current level of idled plants (idled for environmental and economic reasons), this nameplate capacity number is unrealistic in the short-term and the effective operating rate is likely much higher, with little room for increase. As we are currently in the Chinese corn application season (peak demand) there is little room for more than around 150,000 tonnes of urea exports per month. This is unlikely to change until the season comes to an end in mid-July. When it does, we should see an increase in exported material, especially if f.o.b. business in the Arab Gulf is still at the $270-280/t level (excluding Iran). Total Chinese exports for the year-to-May 2018 are around 550,000 tonnes, a reduction of almost 75% on the same period in 2017.

Another contributor to the bullishness of urea markets was the now complete collapse of Ukrainian urea production. European gas markets remain tight and spot volumes on West Europe's major gas hubs were still trading above $7.50/MMBtu in June. Gas pricing at this level is squeezing the profitability of European producers, and nowhere is feeling the pinch more keenly than the Ukrainians. Odessa Port Plant, DniproAzot and Cherkassy have all now ceased urea production and without lower gas pricing it is hard to see them being restarted this year.

Most of the new capacity planned to begin commercial operations in 2018 falls in the second half of the year, and, so far, only Dakota Gasification has produced at commercial volumes. Pupuk's Gresik II (Amurea II) had begun the commissioning phase at the writing, and may have produced some urea. However, we are not expecting to see stable, commercial output from the new Indonesian plant until at least July. When commissioning is complete, the new ammonia-urea train at Gresik will add around 570,000 t/a of new urea production in Indonesia.

The SOCAR project in Azerbaijan looks a little delayed and the company has confirmed that production is unlikely to begin before November 2018, and we are unlikely to see more than 50,000 tonnes of production in calendar 2018. Elsewhere in the CIS, Russia's Acron has reported that it is close to completing work on the revamp of its fifth urea train (Urea V) at its Novgorod plant, as well as its small new urea plant, Urea VI (also at Novgorod). In total, the upgrades at Novgorod should add around 225,000 t/a to Acron's urea production.

The major wild card on the supply side this year will be the Garabogaz plant being developed on the Caspian coast of Turkmenistan. There has been very little news of progress filtering out of Turkmenistan, and while the plant was scheduled for a July 2018 start, we are not assuming it will be producing urea at commercial rates before Q4 2018.

The ammonia market is pivoting at Suez, with markets west of Suez relatively oversupplied despite Europe's struggles with high gas prices. Ammonia prices for spot business in North Africa are currently at the $270-280/t level, while ammonia markets in Asia are tighter, pricing at around $320/t. Chinese imports have increased dramatically over the last 12 months, and look like they have reach an annualised level of over 1.0 million t/a (up from 450,000 tonnes in 2016). Poor production economics and environmental restrictions are limiting Chinese ammonia production in much the same way they have limited urea production.

The ammonia market has been relatively quiet over the last month. However, OCI is currently operating its Geleen nitrates plant on imported ammonia rather than restarting its ammonia plant (taken down for maintenance a few weeks earlier). And with gas at $7.80/MMBtu at TTF (the main Dutch gas trading hub), ammonia production will remain a low margin business. If we assume 32-34 MMBtu per tonne of ammonia and around $45/t of other cash cost and overhead, then ammonia production costs will be around $295-310/t. If prices remain at these levels, we should expect to see further reductions in European ammonia production. ■

Table 1: **Price indications**

Cash equivalent	**mid-May**	**mid-Mar**	**mid-Jan**	**mid-Nov**
Ammonia ($/t)				
f.o.b. Caribbean	220	270	320	270
f.o.b. Arab Gulf	263	265-275	330-340	280-330
c.fr N.W. Europe	280-305	290-300	350-385	305-340
c.fr India	260	290-300	350-380	310-360
Urea ($/t)				
f.o.b. bulk Black Sea	215-220	232-238	215-225	240-250
f.o.b. bulk Arab Gulf*	215-223	253-263	242-250	259-264
f.o.b. bulk Caribbean (granular)	233-235	233-235	233-235	250-260
f.o.b. bagged China	257-262	305-315	285-295	268-272
DAP ($/t)				
f.o.b. bulk US Gulf	408-410	413-415	395	375
UAN (€/tonne)				
f.o.t. ex-tank Rouen, 30%N	153-158	158-161	160-165	159-164

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

Source: Fertilizer Week

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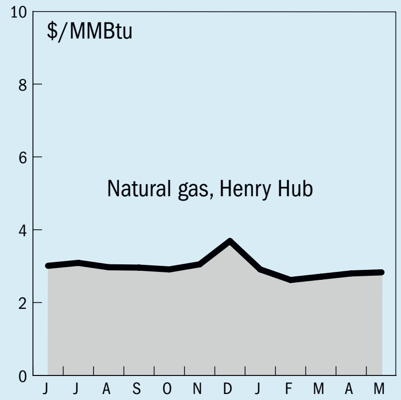
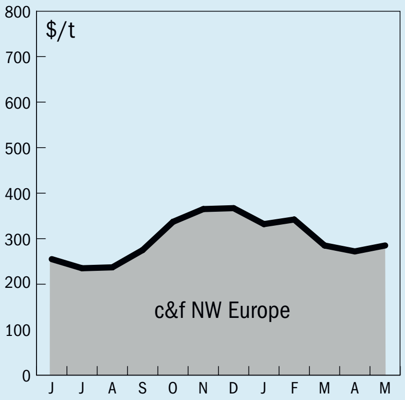
END OF MONTH SPOT PRICES

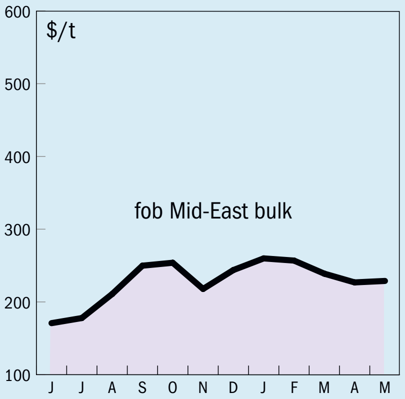
natural gas



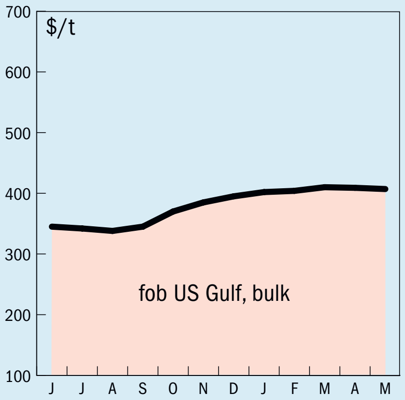
ammonia



urea



diammonium phosphate



MARKET INSIGHT

Mike Nash, Global Business Director, IHS Chemical, assesses the market for methanol.

METHANOL

Spot methanol prices rose in Asia and Europe and were stable in the US during May. In the US, the official posted reference-prices from major producers for June are $1.49/gal for Methanex (a rollover from May) and the same for Southern Chemical (also a rollover from May). Month-on-month weighted average spot prices in the US Gulf for May (finalised) increased by just 0.01 cent per gallon from April to $1.1852/gal (nominal $394/t). IHS Markit Chemical's contract net transaction price for June is officially posted at $1.49/gal (nominal $495/t), flat to the previous month.

North American units operated at 93% on average in May, down 3% from April, following a minor operational issue and the start-up of new capacity last month. In Trinidad the overall operating rate was up in May, averaging around 95%. The methanol units in Venezuela are estimated to have operated at a rate of around 48% of nameplate capacity during the first week of May, due to ongoing operational issues at one unit while another was in turnaround. North American demand for formaldehyde and MMA was strong in May, supported by a strong construction market and healthy overseas demand.

European spot prices (T2 f.o.b. Rotterdam) for May were up €12/t from their April level at €328/t. Methanex posted its 2Q 2018 West European Contract Price at €380/t f.o.b. Rotterdam T2, a rollover from the previous quarter. The ongoing suspension of duty on methanol arriving into the EU implemented by the European Commission is due to expire at the end of 2018. As yet, there is no guidance on whether the allowance will be extended or revert to previous levels. In May a European producer issued an objection to the duty-free allowance being extended. European demand into formaldehyde was strong in May, with this segment showing consistently healthy demand. The acetic acid market remained tight, as a major producer was offline for a planned maintenance outage which will last to mid-June.

In Iran, Fanavaran and Zagros restarted following planned maintenance. In Oman, one unit operated at normal rates and the other restarted early in the month and ramped up operating rates. The EMethanex unit in Egypt has run at rates of around 85% over 2018; the unit is expected to continue running at high rates given the improved natural gas supply situation. The one line at Libya's Sirte Oil that has been operating ran at reduced rates during March and then shut down following an explosion at the plant. Viromet in Romania is idled due to high gas prices.

In India, port prices averaged $407/t in May, down $17/t from their level of $424/t in April. India c.fr port prices rose sharply during April, driven by tight supply and lower domestic coastal inventories but then eased towards the end of May, as Iranian units which had shut down for planned maintenance restarted.

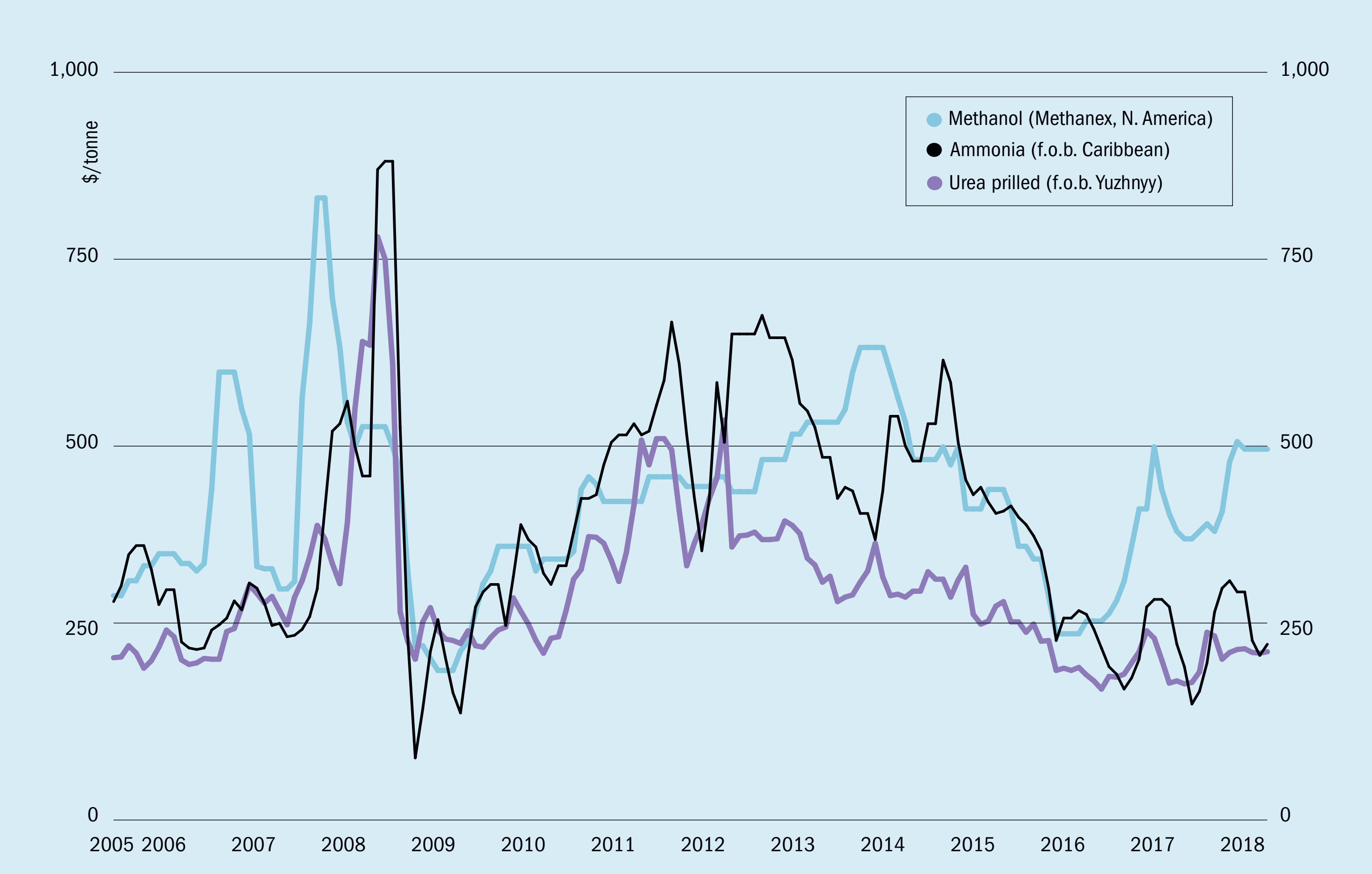
Asian prices in May traded up by $17.5/t, in an average range of $380-420/t c.fr. Chinese average c.fr prices were up $23.75/t in the range of $380-410/t. Methanex's posted Asia-Pacific contract price for June is $490/t, up $30/t from for May. In China, overall capacity utilisation increased in May compared to April, averaging around 57% of nameplate capacity, or around 73% of effective capacity during the month. Coking gas-based methanol producers in North China ran at 41% utilisation in May on average and coal-based methanol plants in Northwest China at rates of 64%.

Methanol consumption into the MTO sector decreased in May, especially towards the end of the month, as the sector entered an intensive turnaround schedule. All MTO producers were honouring term methanol contracts. MTO producers' methanol inventories were at a low level, it is understood. Formaldehyde demand in China was strong, with good demand into derivative products. There were healthy consumption rates into man-made boards and the housing sector. Demand will be impacted negatively by the upcoming rainy season in South China. China acetic acid average operating rates were assessed up at 80% of total capacity in May. By the end of the month, the acetic acid unit in Nanjing began its turnaround and average operating rates declined to 77%.

In Southeast Asia, production improved with higher operating rates and fewer outages. Petronas's number two unit will undergo a planned maintenance outage during the second half of 2018. ■

Market outlook

Historical price trends $/tonne



Source: BCInsight

AMMONIA

- Ammonia markets remain oversupplied and prices are discounting their normal relationship with urea.
- European, North African and Middle Eastern upgrade margins heavily favour urea production over ammonia: based on \$280/t urea and \$280/t ammonia the urea margin over ammonia is \$120/t.
- This \$120/t upgrading margin should see a shift away from merchant ammonia production into higher-value nitrogen output (more urea & nitrates), tightening ammonia supply.
- High gas prices are squeezing European urea production – with its lower value-add, ammonia markets are under the most pressure. If gas prices hold their ground or rise further expect to see a few more shutdowns.
- China is still buying ammonia at an increasing rate to offset lost domestic production. However, when the Chinese urea season ends, we could see an increase of domestic merchant ammonia production.

UREA

- Iranian export business is already under downwards pressure from US sanctions. We do not yet know the full extent, but we are already seeing Iranian f.o.b. prices significantly discounting the rest of the Middle East.
- A strong end to the US and Chinese application seasons is linking up well with strong Latin American pre-buying, at least from Argentina and Chile.
- Chinese exports should increase in July and August as domestic agricultural consumption decreases. We are expecting monthly exports to increase from an estimated 150,000 tonnes in May, to around 250,000-350,000 over the summer months. Expect environmental controls in Q4 will reduce this back to 100,000 tonnes a month.
- Truck strikes in Brazil, and lower corn acres are a concern for the start of the Brazilian urea season next month. However, urea markets remain bullish. Should business be slower than expected, the current bull run could be checked.
- July should also see an additional urea tender from India. However, slow sales and high international prices may put this in doubt.
- Plants in Kuwait and Brazil are still scheduled to shut: Kuwait by the end of June and the Brazilian plants by October.
- While there are some concerns around demand, the balance of supply/demand fundamentals remains bullish for the second half of 2018.

METHANOL

- Global operating rates also rose slightly in May, as units which were down for planned maintenance gradually restarted and ramped up operating rates. Overall, global utilisation rates in May increased to 70% of nameplate capacity, or around 80% of effective capacity. This was due primarily to the restart of plants in the Middle East and Southeast Asia, following numerous planned and unplanned outages in April and early May.
- Chinese MTO affordability declined slightly and remained under pressure, leading to decreased consumption in China.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Nitrogen Industry News

ITALY

Agreement to produce biodegradable urea

Maire Tecnimont, via its subsidiary Maire Green Chemicals srl, has signed an investment agreement with Italian bioplastic development company Bio-on to form a 50-50 joint venture partnership, U-Coat, which will market a new, 100% biologically-based and biodegradable coating for urea-based fertilizers. The coating degrades harmlessly in the soil without leaving any residue, using a technology based on polyhydroxyalkanoate (PHA) 'bio-plastics' designed by Bio-on. PHA bioplastics are made from agricultural waste from the production of molasses, sugar cane and sugar beet syrups, and as waste material have are not only renewable but also have no competition with the food supply chain. It is used to coat the urea pellet, leading to controlled release in the ground while protecting the fertilizer from rain and maximising its effect.

According to the investment agreement, Maire Tecnimont will act globally as turn-key contractor on an exclusive basis to implement plants based on this innovative technology. Tecnimont says that the global urea market is growing at around 4% per year, and represents a large market to commercialise the technology.

Marco Astorri, President and CEO of Bio-on SpA said: "I am extremely proud to share with Maire Tecnimont this new and important market opportunity. Being able to study and develop new fertilizers for the agricultural world through the technology setup by Bio-on together with Maire Tecnimont, worldwide leader in the technologies related to the urea production, allows us to build a more sustainable future, full of new bio products".

Chile's Sociedad Química y Minera (SQM) has entered into a joint venture with Italian speciality fertilizer company Pavoni. The aim, according to SQM, is to combine its global expertise in the production and marketing of potassium nitrate with Pavoni's local know-how, to focus on plant nutrition programs in precision farming sector in Italy.

"Pavoni is a solid, reliable local player with a thorough understanding of the Italian market. I am very excited about this JV, which provides us with tremendous opportunities. It should enable both companies to meet specific local needs and to address new challenges in the specialty plant nutrition market in Italy. Our substantial investment program means that our production capacity is constantly growing and we are prepared to meet increasing market demands in Italy and worldwide", said Frank Biot, vice president of Potassium and Nitrate Sales at SQM.

"The key driver behind this partnership is the development of innovative products and practices for the national irrigation market", said Cristoforo Pavoni, founder of Pavoni srl. "SQM is a global company and a leader in the production of potassium nitrate. We are very happy to work with them in this JV, which will allow us to grow and to become a pivotal player in improving the Italian agricultural practices". ■

RUSSIA

EuroChem signs agreement with environmental protection foundation

EuroChem Group AG has signed a further agreement with the John Nurminen Foundation, a Finnish private foundation working for the protection of the Baltic Sea. The agreement will see both parties continue to work together on measures to further improve the environment in the Luga River basin. The agreement will cover EuroChem's installation of a closed water cycle system in its new ammonia plant at the site of the Group's Phosphorit plant in Kingisepp, close to the Estonian border and on the banks of the Luga River, which flows into the Baltic Sea in the Gulf of Finland.

"We have already achieved much with the John Nurminen Foundation and look forward to our continued collaboration," said Igor Nechayev, General Director of MCC EuroChem. "The proposed closed water cycle system is a state-of-the-art development and a key part of our effort to minimise our impact on the Baltic Sea."

The two parties first began working together in 2012 to reduce phosphorus discharges from the Phosphorit fertiliser factory into the Luga River. A system of dams and other measures to prevent water runoff from Phosphorit led to a significant decrease between 2011 and 2017 in the phosphorus load carried by the Luga into the Baltic. The system was later tested by independent experts who concluded that its treatment capacity was sufficient for all conditions and that the used water purification technology used was functioning well. To mark the signing, representatives of the John Nurminen Foundation are visiting Phosphorit this week to see the purification system in operation for themselves, six years after it first started operations.

"The effect of the measures at the Phosphorit plant on the water quality of the Gulf of Finland, especially in the eastern parts, has been remarkable," said Marjukka Porvari, Director of the Baltic Sea projects of the John Nurminen Foundation. "Research organisations, including the Finnish Environment Institute SYKE, confirm that symptoms of eutrophication, such as excessive growth of harmful algae, have been reduced while, at the same time, water clarity in the Luga River and the Gulf of Finland has increased significantly. In terms of its positive impact on the environment, it can be said that this is the largest environmental project ever implemented in the Gulf of Finland in the Baltic Sea."

UNITED STATES

Another carbon free ammonia process

A team led by materials chemist Adam Rondinone at the Oak Ridge National Laboratory in Tennessee has developed an electrochemical method to produce carbon-free ammonia in a more efficient way than previous methods, not by water electrolysis to make hydrogen but by direct conversion of dissolved nitrogen in water. If an aqueous electrolyte is used, the solvent water itself can directly supply the hydrogen needed for the reaction. But previous attempts to engineer this have suffered from low efficiencies, with the majority of efforts requiring metal-based electrodes that are often better at promoting the competing hydrogen evolution reaction than they are at reducing nitrogen. Key to the new technique is an electrode made of a heavily textured form of graphene that has been doped with nitrogen atoms. The material's surface features an array of barbs around 50-80 nm in length that the team calls 'carbon nanospikes'. When used in an electrochemical cell, the carbon nanospike electrode drives the conversion of nitrogen gas dissolved within the electrolyte into ammonia.

The team found that electrolytes containing smaller counter-ions increased


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the electric field at the tips of the carbon nanospikes, improving the efficiency of the ammonia synthesis – the reaction worked best when they used lithium perchlorate rather than sodium or potassium salts. The efficiency of the system is almost nine times greater than any previous example of ammonia reduction performed under similar conditions. However, Rondinone noted that much work is still required before electrochemistry can challenge the Haber-Bosch process as a realistic means of producing ammonia commercially.

Fine for ammonia release

Dyno Nobel has been fined $250,000 for failing to report an ammonia discharge from its plant outside St. Helens, Oregon. In February, Dyno Nobel admitted the release of six tonnes of anhydrous ammonia vapour from the company's urea plant over three days from July 30th 2015, and acknowledged that it did not notify the National Response Center, required under the federal Comprehensive Environmental Response, Compensation and Liability Act, known as CERCLA. Dyno Nobel has taken several actions to address air emission issues over the past few years to avoid similar accidents, according to the company's senior vice president, Jeffrey Droubay. "The health and safety of our employees and communities in which we operate is our first priority," Droubay said. "For this reason, we will continue to invest and take steps to assure that releases like the one we experienced in 2015 are much less likely to recur.

Pursell opens controlled release fertilizer facility

On June 5th Pursell Agri-Tech officially opened a new fertilizer coating facility in Sylacauga, Alabama, producing next-generation controlled-release fertilizers. Pursell says that the new product range from this facility will enhance nutrient-use efficiency and increase agricultural output and productivity, while reducing the impact that traditional fertilizers can have on the environment. The coating plant has been developed in partnership with Stamicarbon, and features a combination of unique coating materials applied through proprietary processing techniques in a modular facility design that allows plants to be placed close to the markets they serve, removing additional cost from production and distribution. Pursell Agri-Tech is partnering with Stamicarbon to license this technology to fertilizer producers, traders, blenders and distributors worldwide.

Pursell Agri-Tech's new coating facility.

"We are proud to have Pursell Agri-Tech as our partner and want to congratulate them with the launch of their first controlled-release fertilizer plant. It is a wonderful feeling for a company to work alongside a strong partner sharing the same vision and values," said Pejman Djavdan, Managing director of Stamicarbon.

"The Pursell name has been synonymous with innovation in the fertilizer industry," added Nick Adamchak, Chief Executive Officer of Pursell Agri-Tech. "We're focused and committed to developing and delivering new sustainable, yield-enhancing technologies that can have a significant, lasting impact on global food security and the environment." The Pursell family has been active in the agricultural sector for over 100 years, and has pioneered the use of polymer coatings for controlling fertilizer release rates and enhancing nutrient-use efficiency.

WORLD

Continuing rise in urea for vehicle exhausts

Integer Research says that use of urea solutions for selective catalytic reduction (SCR) of vehicle exhausts – so-called 'automotive grade urea' (AGU) is continuing to rise. In its latest report on the market for SCR and AGU, it highlights the rise of SCR-equipped light-duty vehicles, which will ultimately become the driving force for AGU consumption in India, although less so in China, which has virtually no diesel passenger car sales. The European Union SCR market remains the largest, but on a country level analysis, the top three markets are the USA, Germany and China. While previously Asia-Pacific countries have been mainly importing AGU from China, import sources are now diversifying due to the increased price of Chinese prills in Q1 2018. Meanwhile, Petrobras has announced the closure of its last AGU production facility from October 2018, and intends to rely on imports.

AUSTRALIA

Yara Pilbara makes A$58 million loss

Yara Pilbara made an A$58 million loss in 2017, as compared to a A$94 million profit for the previous year. Speaking at a results presentation, parent company Yara International said that the A$140 million turnaround was due to "general market conditions" – in particular depressed product prices for ammonia; ammonia prices are currently 25% below 2014 levels due to overcapacity in the market. "Global pricing and pressures on operating costs created a challenging year for us in the market place," Yara said. Yara's Burrup ammonia plant produces 850,000 t/a of ammonia.

NORWAY

Norway abandons CCS project at Yara Porsgrun

Although the Norwegian government agreed in May to commit a further 80 million krone ($10 million) of funding towards engineering and design studies of carbon capture, transport and storage projects, taking the total amount so far committed to 280 million krone ($35 million), it has decided against pursuing carbon capture and storage (CCS) at Yara's Porsgrun ammonia plant. Instead the government is proceeding with design studies at Norcem's cement works at Brevik, and the Fortum Oslo Varme waste-to-energy facility, with the aim of bringing Europe's first full CCS value chain – covering capture, transport and storage – into operation by 2022.

In its statement accompanying the announcement, the Norwegian government said that Yara's ammonia facility had "smaller learning potential compared to the two others, and some uncertainties concerning the plant", adding that it "does not make sense industrially to continue the planning of their plant". In theory CCS should be easier at Porsgrun as the CO_2 is already separated out of the process stream. However, press reports indicate that Yara has lost interest in the project. The company already sells some of the CO_2 it generates for industrial use, and said that any additional capture would be "complicated" and may not provide any returns on investment. The government likewise cautioned that bringing the full CSS project into operation would be a costly exercise without support from the companies involved and cooperation with the EU.

INDIA

Project approval for new fertilizer handling facility

The Standing Finance Committee of the Ministry of Shipping has cleared a project for setting up a fully mechanised handling facility for fertilizer cargoes at Deendayal Port in Kandla. The facility will be developed at berth number 14 of the port, and is being constructed at an approximate cost of $20.5 million. The port will invest a further $50 million for the project from its internal resources. Initially, the proposed facility will handle 2.6 million t/a and subsequently this will be raised to 4.5 million t/a.

All activities, from unloading of bulk fertilizer cargoes from ships to loading of bagged fertilizer onto rail wagons will be fully mechanised. The fertilizer cargo will be unloaded using mobile harbour cranes onto mobile hoppers. The conveyor system, along with the tipper system, will transfer the cargo to a 38,500 m² storage shed, equipped with 40 sets of bagging and stitching units which will feed the bagged cargo directly into wagons to reduce labour, optimise time and reduce logistics costs. A tender for the work is in progress, and the facility is expected to be commissioned by October 2020.

Contracts awarded for two fertilizer plants

TechnipFMC has been awarded two EPC contracts for gas-based fertilizer complexes in eastern India by Hindustan Urvarak and Rasayan Ltd (HURL) – a joint venture between three large Indian public sector companies; IOCL, NTPC and CIL. Technip, in conjunction with Larsen & Toubro Hydrocarbon Engineering (LTHE), will build the two complexes, at Barauni in the state of Bihar and in Sindri in Jharkhand, each with a capacity of 2,200 t/d of ammonia and 3,850 t/d of ammonia, on a lump sum turnkey (LSTK) basis over the next 36 months.

Nello Uccelletti, president of Onshore/Offshore business at TechnipFMC, said: "We are honoured to be entrusted with the execution of these prestigious projects in consortium with LTHE, which demonstrates our long-term commitment to India and strengthens our leadership in executing challenging projects in fertilizers, refinery and petrochemical sectors. The project is of great national importance to India to address the demand for urea in domestic market and thereby, boosting the economic growth of the country".

NIGERIA

African Development Bank approves loan for fertilizer expansion

The African Development Bank has approved a $100 million senior loan to Indorama Eleme Fertiliser & Chemicals Ltd, to support the company's plans to double its fertiliser production from 1.4 million t/a of urea to 2.8 million t/a. The estimated $1.1 billion cost of the project will be financed with equity of $100 million and debt finance of $1 billion. AfDB's intervention follows a previous loan extended to Indorama Fertiliser in 2013 for the commissioning of the company's previous $1.5 billion urea plant, which helped turn Nigeria from a net fertiliser importer to a self-sufficient producer in 2016, and now a net exporter of fertilizer. In 2017, 700,000 tons of urea were exported to West Africa and North and South American markets. Production from the new plant will predominantly target export markets.

Indorama Eleme was privatised in 2006 after the sale of the Nigerian government's 75% stake.

Abdu Mukhtar, Director for Industrial and Trade Development at the African Development Bank said: "This project will build upon the success of Train-I in increasing the domestic supply of urea fertiliser in Nigeria, making it easily available and leading to cheaper prices for the Nigerian farmer."

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

RUSSIA

Haldor Topsoe to deliver large-scale methanol plant for Baltic Gas Chemical

The Baltic Gas Chemical Company, Mitsubishi Heavy Industries and Haldor Topsoe have signed a tripartite license agreement for a methanol plant project at Ust-Luga in northwest Russia. Under the contract, Topsoe will deliver its new *SynCOR Methanol*™ process license, basic engineering, proprietary technology, and catalysts. The planned capacity of the plant is a world-scale 1.7 million t/a. The license agreement was signed on May 25th at the St. Petersburg International Economic Forum.

SynCOR integrates catalysts, proprietary technology and equipment as part of the technology license. The technology has recently been chosen as the core of the world's largest methanol facility constructed by IGP Methanol in Louisiana. Topsoe says that it offers more than 99% availability and exceptional economies of scale.

"We have chosen Haldor Topsoe's *SynCOR Methanol*™ process technologies due to its superiority in efficiency, costs, as well as conformity with the highest environmental and safety standards. We are planning that Mitsubishi Heavy Industries (MHI) will be responsible for front end engineering design and engineering, procurement and construction for our project, while Haldor Topsoe will support MHI with process basic engineering, catalysts, and proprietary equipment deliveries. Both MHI and Topsoe have successful references of work under Russian chemical projects, and they have a long cooperation history globally. We think that signing of such tripartite agreement is an important milestone in the project development," emphasized Grigory Omelchenko, General Director, BGCC.

Financing for the project will be provided by the Russian Direct Investment Fund (RDIF), Invasta Capital and Japanese financial institutions, via the Marubeni Corporation and linked to the EPC contract with Mitsubishi.

Kirill Dmitriev, CEO of the Russian Direct Investment Fund, said: "Russia has large reserves of natural resources which creates a sustainable competitive advantage in terms of raw materials. However, if compared to other oil and gas exporting countries, we produce substantially less chemical products, including methanol. The volumes of gas utilisation in methanol in Russia are the lowest among the leaders in gas production, and the potential of this sector is still not realised. Due to the joint project of RDIF and partners in this field, we will be able to increase methanol production capacities in Russia and generally contribute to the development of the gas chemical industry". ■

Kawasaki to build a hydrogen plant in Magadan

In another Japanese investment in Russia's syngas industry, Kawasaki Heavy Industries says that it intends to build a hydrogen plant in the Russian city of Magadan and is currently looking for a suitable construction site, according to local press reports.

GERMANY

Clariant forms hydrogen alliance

Speciality chemicals company Clariant says that its Catalysts business has formed an alliance with clean energy company Hydrogenious Technologies, "to provide reliable, scalable and safe hydrogen supply solutions for a wide variety of applications". Hydrogen's suitability as an alternative fuel, driven by electrolysis of water powered by renewable electricity, faces a variety of hurdles, including the fluctuating nature of electricity supply, and low energy density and volatility which present significant challenges to both storage and transportation. Conventional storage methods typically involve either compression to 200-700 bar or extreme cooling (to -253°C), both of which are energy intensive and carry significant safety risks. Hydrogenious Technologies, has developed a means of transporting hydrogen by chemically binding the molecules to Liquid Organic Hydrogen Carriers (LOHCs). Hydrogenation of the liquid organic hydrocarbon dibenzyltoluene via Clariant's *EleMax H* catalyst allows hydrogen to be 'stored', while its dehydrogenation with *EleMax D* 'releases' hydrogen on demand. The highly active Clariant catalysts are designed to offer exceptional selectivity for loading and unbinding hydrogen in order to optimise the life-cycle and efficiency of the LOHC.

Commercial scale units in operation at United Hydrogen Group (Tennessee) have confirmed the process' technical and economic attractiveness, according to Clariant. The company says it will "continue to further broaden the applicability and efficiency" of the technology via catalyst research and expertise.

Marvin Estenfelder, Head of R&D at Clariant's Business Unit Catalysts, welcomed the alliance, stating, "We are delighted to partner with Hydrogenious Technologies in the evolution of renewable energy and global efforts for sectoral integration. The successful development of dedicated catalysts for LOHC technology is not only testament to Clariant's pioneering capabilities, but also reflects the importance of sustainability to our culture, operations, and as a driver for growth and innovation."

DENMARK

Haldor Topsoe looks for investment partner

The Topsøe family, the long-term 100% shareholder of Haldor Topsoe A/S, says that in conjunction with the company, they have begun a process to find "a potential investor in order to accelerate growth". Further down the line, they say that they intend to seek a listing for Topsoe's shares: "it is the intention that a future financial minority partner can own a significant share of the company with an option of an initial public offering (IPO) after five to seven years." Haldor Topsoe Holding A/S, owned by the Topsøe family, will continue as the long-term majority shareholder. SEB (Skandinaviska Enskilda Banken) and Citi (Citigroup Inc.) have been appointed as advisors for the search process.

"Haldor Topsoe is extremely precious to the family and we want to make sure the company is in the best possible position to grow and develop. We believe that inviting one or more investors on board, on terms acceptable to us, will enable Haldor Topsoe to accelerate the development of solutions that can further strengthen the business and make a positive difference in the world," said Jakob Haldor Topsøe, chairman of Haldor Topsoe Holding A/S.

Jeppe Christiansen, chairman of the board of directors of Haldor Topsoe A/S, said: "We wish to strengthen our capital base by inviting one or more financial partners to invest in Haldor Topsoe with a long-term intention to list the company. We believe, that long-term majority shareholders combined with minority shareholders on the stock exchange is proven to be a very strong ownership structure for resilient and profitable development. Our ambition is to grow organically and potentially also drive growth through acquisitions."

SWEDEN

Andritz to supply bio-methanol plant for pulp mill

Finnish wood processing and technology group Andritz says that it has received an order from Södra to supply a bio-methanol cleaning and purification plant for Södra's pulp mill in Mönsterås, Sweden. Start-up of the plant is scheduled for 3Q 2019. The plant is designed to produce 5,000 t/a of methanol as a key part of a new process producing sustainable methanol from renewable raw materials. Andritz's process takes stripper off-gases from the kraft mill in pulp and paper manufacture and cleans and condenses it to extract methanol. The company notes that the current target of the European Union is to have 10% of the transport fuel of every EU country coming from renewable sources, such as biofuels, by 2020. The new EU Renewable Energy Directive 2 currently in preparation will significantly increase the share of advanced biofuels by 2030.

"If Sweden is to achieve the fossil-free climate targets, there must be viable alternatives to the fossil-fuel products that are currently available. The investment in the new bio-methanol cleaning and purification plant contributes towards reaching this target. It is also a major part of Södra's own strategy to be totally fossil-free by 2030," said Henrik Brodin, Business Development Manager Energy of Södra.

EQUATORIAL GUINEA

Equatorial Guinea to construct a gas 'mega-hub'

Equatorial Guinea plans to build a natural gas hub linking production and offshore processing to existing onshore demand. The project is led by the Ministry of Mines and Hydrocarbons in collaboration with oil and gas companies operating locally. The first phase of the project will implement a new gas supply agreement with Noble Energy, operator of the Aseng and Alen fields. Gas will be supplied to the Punta Europa gas complex, which includes the Malabo power station, Atlantic Methanol's methanol plant and the Equatorial Guinea LNG plant. The agreement, combined with new subsea pipelines linking the Aseng, Alen and Alba fields, will replace some of the gas production lost as the Alba field declines. Building on the new Punta Europa-Alba-Alen link, the gas 'mega-hub', expected to be completed in 2020, will link into other existing and future gas projects, reducing dependency on single upstream developments for industrial development, and will allow gas to be directed to where the value is greatest. The hub will also play an important role in leveraging stranded gas and developing the LNG sector in Equatorial Guinea, as part of a wider LNG to Africa initiative, involving Burkina Faso, Nigeria, Togo, Ghana. Cameroon, South Sudan, Mozambique and Uganda. The development is likely to keep the AMPCO methanol plant operating for the foreseeable future, after concerns had been expressed about potential shortfalls in gas supply.

IRAN

Return of sanctions may hit methanol developments

Reintroduction of US sanctions against Iran could delay implementation of Iran's ambitious methanol projects on the back of technology and capital bans, and hinder the country's methanol exports amid banking and currency restrictions, according to Platts. Iran is hoping to bring over 4 million t/a of new methanol capacity onstream during 2018, including some major projects delayed from 2017 such as Kaveh Methanol's 2.3 million t/a plant at Dayer Bushehr and Marjan Methanol's 1.65 million t/a unit in Pars. At present the detail of the sanctions remains patchy with no clear timescale for their implementation. The reaction of European nations such as the UK, Germany and France, which have started they are still keen to preserve the nuclear deal with Iran, remains to be seen in the light of US moves. Europe imported nearly 130,000 tonnes of methanol in 2017, 45% more than 2016, although still only a fraction of the 900,000 tonnes imported in 2008. US financial sanctions may also affect shipments to China – China imported 2.5 million t/a of Iranian methanol in 2017.

UNITED KINGDOM

New hydrogen plant for Merseyside

Natural gas distributor Cadent says that it plans to build a massive hydrogen network in the Liverpool area as part of a £900 million ($1.2 billion) investment plan to cut greenhouse gases. The gas-based facility would for part of a local hydrogen distribution system called HyNet which would take hydrogen from the production facility to various industrial companies around the region, where it could be burned as fuel instead of natural gas. The carbon dioxide waste from the hydrogen plant would then be pumped into offshore gas fields under the Irish Sea so that it can be stored. Cadent says the Liverpool Bay fields will soon be decommissioned but the existing rigs and pipelines could be reused for storing carbon. Longer term, it is hoped that the network could make the north-west of England into a centre of hydrogen technology, as companies develop ways to use hydrogen as a fuel for buses, lorries and trains. Cadent says 5,000 jobs could be created by 2025 under the first phase of the plan, including the hydrogen plant and the offshore storage. A location has not yet been chosen for the production site, but Cadent say it is likely to be in an existing industrial area around Ellesmere Port or Runcorn. In total, Cadent says HyNet could save 1 million tonnes of carbon dioxide emissions every year – "the equivalent of taking 600,000 cars off the road".

UNITED STATES

Fulcrum Bioenergy breaks ground on waste-to-fuels project

Fulcrum BioEnergy says that it has started site construction on Phase 2 of its first waste-to-fuels project, the Sierra BioFuels Plant. Sierra will be the first commercial-scale waste gasification plant in the US, converting a municipal solid waste feedstock, i.e., household garbage that would otherwise be landfilled, into a low-carbon, renewable transportation fuel product via a Fischer-Tropsch synthesis section. The gasification section uses a ThermoChem Recovery International gasification system, which rapidly heats the prepared waste feedstock upon entry into the steam-reforming gasifier and converts it to syngas. A venturi scrubber captures and

PHOTO: NATGASOLIINE

The Natgasoline methanol plant at Beaumont, Texas.

removes any entrained particulate, and the syngas is further cooled in a packed gas cooler scrubber. The cleaned syngas is then processed through an amine system to capture and remove sulphur and carbon dioxide, and passes through a secondary gas clean-up and compression section before being fed to the Fischer-Tropsch (FT) process. Here, the purified syngas is processed in a fixed-bed tubular reactor with a proprietary catalyst to form three intermediate products: heavy, medium and light liquids. The latter – naphtha – is recycled to the partial oxidation unit with remaining tail gas to be reformed to hydrogen and carbon monoxide. In the last step, hydrotreating, hydrocracking and hydroisomerisation upgrading steps are used to upgrade the combined heavy and medium products into jet fuel.

When the plant begins commercial operations in the first quarter of 2020, Sierra will convert approximately 175,000 t/a of household garbage into more than 10.5 million gallons of fuel each year. As construction proceeds on Sierra, engineering, siting and permitting activities are underway for the company's next several projects to be sited near large US metropolitan areas where Fulcrum has already secured long-term supplies of feedstock, fuel logistics and fuel offtake agreements. Collectively, these future plants are expected to have the capacity to produce more than 300 million gallons of jet fuel annually.

Commercial operations begin for Natgasoline

The OCI Natgasoline methanol plant has begun commercial operations at its Beaumont, Texas site, according to the company. The 1.8 million t/a greenfield project has been a joint venture with Egypt-based fertilizer manufacturer OCI and Consolidated Energy Limited/G2X, each with a 50% stake. The start-up of the plant puts the US just short of self-sufficiency in methanol production, after ramping up rapidly from 2.5 million t/a of domestic production in 2014 to 6 million t/a of capacity in 2016 as plants have re-started or, as in the case of Methanex, been relocated from Chile. No additional new methanol capacity is expected this year, according to Natgasoline, but next year Yuhuang Chemical's new 1.8 million t/a unit is scheduled to start up in St James parish, Louisiana, turning the US into a net methanol exporter.

US Methanol plant delayed by compressor

US Methanol, which is in the process of relocating a methanol plant from Brazil to West Virginia, says that the project is likely to be delayed by more than a year, from late 2018 to late 2019. The reason given for the delay is the requirement to order a new compressor for the plant. US Methanol CEO Frank Bakker has said that the company will provide methanol for the chemical industry in the mid-Atlantic and northeastern states of the US.

Air Products completes acquisition of Shell gasification technology

Air Products has successfully completed the acquisition of the Coal Gasification Technology licensing business from Shell Global Solutions International BV, and formed a strategic alliance with Shell for residue gasification technology to refinery complexes. The acquisition includes Shell's associated patent portfolios for solids (coal and biomass) gasification and sharing of patent rights for residue and biomass gasification. Financial terms are not being disclosed for the agreement, initially announced in January. These moves extend Air Products' offerings in synthesis gas to provide turn-key sale-of-gas gasification facilities for solids (coal and biomass) and liquids (refinery residues).

"Air Products now has immediate access to Shell's proven technology and a successful business, with that technology already in place at nearly 200 gasification systems delivering syngas around the world," said Air Products' Chairman, President and CEO, Seifi Ghasemi. "Beyond a strong operating base, we now have a robust technological foundation that builds on our core focus supplying the full range of industrial gases to our customers," he continued.

Shell has been at the forefront of gasification research and innovation over the past 50 years, with 170 Shell gasification process (SGP) and 34 coal gasifiers built, and 96 SGP and 24 Shell coal gasification process gasifiers in operation worldwide.

People

Garrett Lofto, who has served as the president of J.R. Simplot agribusiness since 2009, has been named the company's new president and CEO, taking over from September 1st this year. Lofto, who has been with the company for 26 years, has led the company's agribusiness group since 2009. He replaces **Bill Whitacre**, who retired in April after 18 years with Simplot, including nine years as president and CEO. As president of Simplot agribusiness, Lofto oversaw a $2.5 billion operating division. During his tenure, the company charted significant growth in its retail arms, Simplot Grower Solutions and Simplot Partners, and opened a new state-of-the-art ammonia plant.

"I'm honoured and humbled that the board and the Simplot family have entrusted me to lead this great organization as part of the senior leadership team," Lofto said in a statement Tuesday. "The company is filled with tremendous talent and leaders, and I'm committed to ensuring they have the support they need to make the J.R. Simplot Company the best we can be."

Scott Simplot, chairman of the Simplot board of directors, praised Lofto for his vision and leadership.

"We're well-positioned for success across our organization, and the Simplot family and board of directors are confident we've got the right leader to help us achieve great things," Simplot said.

Lofto was raised on a farm in southern Manitoba, Canada, and has lived in Idaho since 2001. He earned a bachelor's degree in agriculture from the University of Manitoba and a master's degree in business administration from the University of Phoenix. He joined Simplot in 1992 as a crop adviser for the Morris, Manitoba area. He also serves on the board of directors for the Ronald McDonald House Charities of Idaho, the Fertilizer Institute, Nutrients for Life Foundation and the International Plant Nutrition Institute.

Whitacre, who steps down as president and CEO, played a key role in growing company revenues from approximately $4.5 billion to $6 billion, according to the company. Scott Simplot described Whitacre as a "highly successful and visionary leader" who helped the company reach new heights and expand its global presence. "The company, the board and the extended Simplot family thank him for his leadership and commitment," Simplot said.

Mosaic said in May that **Gregory Ebel** has become the company's new chairman of the board of directors following their annual meeting of shareholders. Ebel succeeds **Robert Lumpkins**, who had served as Mosaic's Chairman from the company's inception in 2004. Mr. Lumpkins will continue as a director to ensure a smooth transition. Mr. Ebel has served on the Board since 2012. He currently chairs the Corporate Governance and Nominating committee and also serves as a member of the Audit committee. Previously, he served as chairman, president and chief executive officer of Spectra Energy Corp and as chairman, president and chief executive officer of Spectra Energy Partners until his retirement in February 2017. He also serves as a director and chairman of Enbridge, Inc.

"Mosaic and its board of directors have benefitted immensely from Bob's dedication, leadership and insight in his role as chairman," said Mr. Ebel. "Bob was instrumental in the transactions that formed Mosaic, and his deep knowledge of the fertilizer and agriculture industries helped build Mosaic into the thriving company it is today. I'm thankful that Bob will remain on the Board, and I welcome his experience and guidance in the year ahead."

Two additional changes to the board of directors occurred at the annual meeting: **James Popowich** retired as a director, and **Oscar Bernardes** was elected to the board.

Mr. Bernardes currently serves as managing partner, Yguaporã Consultoria e Empreendimentos Ltd., a consulting and investment firm in São Paulo, Brazil. Previously, Mr. Bernardes was a managing partner at Integra Associados – Reestruturacao Empresarial Ltda., a consulting firm specializing in financial restructuring, governance and interim management in turnaround situations, also in São Paulo; chairman of TIW do Brasil, a Canadian telecommunications company; and CEO of Bunge International, a leading global agribusiness and food company. Mr. Bernardes brings important knowledge of Brazil and its agriculture industry to Mosaic and its Board of Directors, along with expertise in international operations and risk management. ■

Calendar 2018/19

SEPTEMBER

16-20

63rd AIChE Annual Safety in Ammonia Plants and Related Facilities Symposium, TORONTO, Canada
Contact: AIChE Customer Service
Tel: +1 800 242 4363/+1 212 591 8100
Fax: +1 212 591 8888
Email: xpress@aiche.org

16-21

Ammonium Nitrate/Nitric Acid Conference, CALGARY, Canada
Contact: Hans Reuvers, BASF; Karl Hohenwarter, Borealis.
Email: johannes.reuvers@basf.com, karl.hohenwarter@borealisgroup.com
Web: www.an-na.org/2018-conference/

OCTOBER

5-6

36th Annual World Methanol Conference, VIENNA, Austria
Contact: Lynn Urban, IHS Markit
Tel: +1 303 397 2801
Email: Lynn.urban@ihsmarkit.com

28-30

Gasification and Syngas Technologies Meeting, COLORADO SPRINGS, USA
Contact: Gasification and Syngas Technologies Council, 3030 Clarendon Blvd., Suite 330, Arlington, VA 22201 USA.
Tel: +1 703 276 0110
Fax: +1 703 276 0141
Email: info@gasification-syngas.org
Web: www.gasification-syngas.org

23-25

IFA Crossroads Asia-Pacific Conference, SINGAPORE
Contact: IFA Conference Service, 28 rue Marbeuf, 75008 Paris, France.
Tel: +33 1 53 93 05 00
Email: ifa@fertilizer.org

MARCH 2019

4-7

Ntrogen+Syngas 2018, BERLIN, Germany
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

Plant Manager+

Problem No. 49 Reverse rotation of CO_2 compressor

The CO_2 compressor of the urea plant is an expensive piece of critical rotating equipment installed without any spare position. Its reliability is therefore of prime importance. Sometimes reverse rotation occurs which can damage the internals of the compressor. What are the causes and what are the remedies to avoid reverse rotation of the CO_2 compressor? There is a lot of misunderstanding around this subject. Here we share the experiences of various end users.

Bhawna Dangi of NFL Vijaipur in India starts the round table discussion: What harm can reverse rotation of the CO_2 compressor do and how can it be prevented?

Niranjana Murthy of Mangalore Chemicals and Fertilizers in India first asks for some further information: Which type of compressor are you referring to and why is it rotating in reverse direction?

Bhawna replies: When a centrifugal compressor trips, the higher pressure still existing at the discharge side of the centrifugal compressor will equalise with the lower pressure that is always present at the suction side of the compressor. This situation can cause reverse flow. Some plants have reported reverse rotation phenomena in the CO_2 centrifugal compressor.

Gholamali Soroush of Shiraz Petrochemical Complex in Iran shares his valuable experience: In the CO_2 compressor outlet, there are three valves (check valve, shutdown valve and bleed valve) which should avoid reverse flow. By depressurising the compressor outlet line, one prevents reverse rotation. The shutdown valve and bleed valve are automatic valves, which are actuated by trip signals and are in the discharge outlet upstream of the non-return valve (NRV).

Ajay Singh of Chambal Fertilizers in India contributes to the discussion: Reverse rotation of the compressor may damage internals, such as bearings, seals etc.

CSK provides some valuable input: In general CO_2 compressors have four reverse flow protections in the discharge line: 1) trip shutoff valve, 2) vertical NRV, 3) horizontal NRV and 4) pressure release valve. However, reverse gas flow through the compressor is possible, by passing of the level control valve of the third separator or by passing of the NRV at the suction side of the third stage. These may cause the reverse rotation of the compressor. The compressor is not designed for reverse rotation, and it can cause bearing damage and misalignment. To overcome this problem, the pressure release can be linked (open) with the trip logic of the compressor.

Pawan Verma of IFFCO in India shares his valuable experience: Reverse gas flow through the CO_2 compressor is only possible when NRVs provided in compressor are passing and the vent control valve size provided in the final discharge line and at the third discharge line size are insufficient to discharge the volume trapped. This problem of reversal flow may be overcome by regular servicing of the NRVs and by increasing the size of the vent valve in the compressor.

Prem Baboo of National Fertilizers Ltd, in India contributes to the discussion: We also experienced reverse rotation in our urea line-II in 1997. Reverse rotation is an unwanted phenomenon in a centrifugal machine as it is always associated with severe radial vibration and axial displacement which may lead to damage of the bearings and rubbing of seals with the stationary components. Bearing failure is a definite possibility. Seals are not rated for this rotational speed. Internal compressor components may become dislodged. There is a high possibility of damaging vibrations during reverse rotation. Coupling is rated for the rotational speed as long as the train does not become energised. Rotor overspeed can cause excessive stress of the bearing (journal/thrust). Standard face seals may be adversely affected by overspeed and rings may be rotation sensitive. To safeguard against reverse rotation in CO_2 compressors the following changes have been made:

1. During shutdown, anti-surge valve HV-62 (provided from the fourth discharge to the first suction) and the second stage vent HV-61 (provided from the second discharge to the atmosphere) are both open. In addition, HV-63 (provided from the second discharge to the first suction) logic has been changed so that it opens during tripping. In addition, the time taken to open HV-61 has been decreased.
2. The final discharge vent PV-3 logic was changed to open during tripping of the machine. Capacity of CV should be sufficiently high.

Kashif Naseem replies: Reverse rotation can be avoided by installing kickback from casing to casing and installing the NRV at the discharge of the final stage.

Ali Salman Bokhari of Agritech Ltd. in Pakistan joins the discussion: In my view, reverse movement of the shaft is only possible in case of high poly-tropic/discharge head or in simple words "surging". Once the compressor is tripped due to actuation of the surge counter security, reverse movement is almost impossible because:

- kickbacks will automatically open and equalise the pressure between the suction and the discharge ends of the compressors;

- generally auto valves at the compressor discharge open automatically to relieve the discharge line;
- additional protection in terms of NRVs is also available;
- gas in the compressor at the discharge side does not have much force to first stop the compressor, nor does it have much capability to provide the force required for causing reverse rotation.

In case of reverse rotation, what is important point is the speed of the compressor i.e. high speed will definitely cause vibrations and damage to seals.

Sometimes there are some design constraints regarding relieving the third stage pressure through the fourth stage and uneven depressurisation of inter-stage piping and equipment. This uneven depressurisation generates enough torque to rotate the shaft in the reverse direction. Latterly, the problem was resolved by instantaneously opening the 2-1 recycle valve with application of the solenoid valve along with the second stage vent and by modifying the interlock system.

In my view, there should be no reverse rotation in the compressor if there are no design constraints. Anti-surge, vent and non-return valves are provided in order to protect the machine from such problems in worst case conditions.

Let me share our experience as regards design constraints. We have a turbine-driven centrifugal CO_2 compressor comprising LP and HP casing with each casing consists of two stages. The original equipment manufacturer is MHI (Japan). The anti-surge system is provided by CCC (USA) consisting of 1-1, 2-1 and 4-3 kickbacks. Under normal operating conditions the machine is designed to raise the pressure from 0.9 kg/cm^2.g to 178 kg/cm^2.g. A few years ago, we did an emergency shutdown due to a problem in our national gas headers. The compressor tripped due to actuation of low pressure security at the first suction. This was surprising because everything was going smoothly as per standard operating procedures. Latterly it was found that the 2-1 kickback opens rapidly letting down the pressure from 44 to approx. 0.9 kg/cm^2.g in order to meet the flow requirements at the first suction. This sudden opening results in the formation of dry ice, even after the injection of hot gas and restricts the flow passage downstream of the kickback. This design constraint was resolved by some counteractive measures. ■

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

The Indorama Eleme urea plant in Nigeria.

PHOTO: INDORAMA

Africa's new fertilizer plants

Sub-Saharan Africa remains one of the few regions in the world with large, untapped and disconnected or so-called 'stranded' natural gas – historically the rationale for much merchant nitrogen and methanol project development. But can it overcome lack of infrastructure and funding issues?

New gas discoveries around Africa led to a rash of new export-oriented nitrogen project proposals a few years ago. However, while there have been some new project completions in Nigeria, elsewhere progress has been much more patchy and difficult.

Gas

Sub-Saharan Africa's natural gas production was estimated at 65 bcm in 2016, 10% higher than in 2015, and is expected to have risen to 73 bcm in 2017. Nigeria is the region's largest gas producer, with output of over 47 bcm, followed by Angola and Mozambique, with 12 bcm and 5 bcm, respectively. The Democratic Republic of Congo, Tanzania, Côte d'Ivoire and Equatorial Guinea are also gas producers – see Table 1. Gas production has become a major focus for oil companies in response to strong investment in gas-to-power projects across the region. However, these countries require additional investment in gas processing and transporting infrastructure if they are to increase output significantly.

Africa's gas reserves have grown significantly in recent years, boosted by discoveries offshore in Tanzania and Mozambique which are estimated at 70 trillion cubic feet (tcf) and 180 tcf, respectively. Recent discoveries offshore Senegal and Mauritania could boost the region's gas reserves further, once appraisals of the finds have been conducted. Discoveries offshore Mozambique during appraisals support USGS estimates that East Africa's offshore region could hold over 440 tcf of natural gas reserves.

In May 2017 BP announced a partnership with Kosmos Energy to bring newly discovered natural gas resources off the coast of Mauritania and Senegal onto the world market. Kosmos discovered the gas in 2015, the largest of which was the Tortue field, with around 15 trillion cubic feet of gas (420 bcm), but the two companies put total reserves there at up to 50 tcf (1.4 tcm). A production sharing agreement has been signed earlier this year with the governments of Mauritania and Senegal, and a final investment decision is expected this year.

Table 1: **African gas production/consumption, 2017, billion cubic metres**

Country	Production	Consumption
Algeria	91.2	38.9
Egypt	49.0	56.0
Equatorial Guinea	6.2	2.1
Libya	11.5	7.6
Mozambique	5.7	2.7
Nigeria	47.2	26.9
South Africa	1.1	4.5
Tanzania	1.1	1.5
Others	12.0	1.6
Total	225.0	141.8

Source: BP

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Mozambique has around 4.0 tcm of discovered gas reserves, but according to the US Geological Survey (USGS) there is still another 5.1 tcm to be found (mean estimate), of which 2.9 tcm are described as "high probability" and a low probability of up to 8.1 tcm, which would put it 5th in the world, with more than the US or Saudi Arabia. Even the probable estimates put Mozambique on a par with Venezuela or the UAE.

Nevertheless, funding gas projects remains a major challenge in West Africa, owing to the poor commercial terms for domestic gas suppliers. Despite huge demand for power and the presence of huge gas reserves offshore, governments have been hesitant to change electricity tariff regimes. This has prevented higher gas prices for power, slowed progress with gas-to-power projects and stalled the creation of a viable gas market. However, since late 2015 there have been moves to raise electricity tariffs in Zambia, Ghana and Nigeria. These efforts were driven by the devaluation of these countries' currencies, which drove up the cost of feedstock fuels and gas and gave greater urgency to the need to make tariffs more cost-reflective.

LNG

Africa's two major LNG exporters are Algeria, which exported 14 bcm in 2017 (10 million t/a), and Nigeria, which exported 30 bcm (22 million t/a). As well as these major exporters, sub-Saharan Africa also has LNG export plants at Bioko Island in Equatorial Guinea, which has a capacity of 3.7 million t/a, and more recently the Soyo LNG plant in Angola, with a capacity of 5.2 million t/a. For a while at the start of the decade, sub-Saharan Africa was the focus of intense exploration and production activity and the aim was to export large quantities of this as LNG. However, the slump in the global gas market from 2014 has put back a number of these projects. Nevertheless, the forecast is that – with some Australian LNG export projects starting to look less certain, there may be a significant shortfall in global LNG markets approaching in a few years, and this has renewed the impetus for LNG investments. As a result, there are still a large number of new LNG projects under development in sub-Saharan Africa, including;

- In Cameroon, Bermuda-based Golar LNG started operations with its 1.2 million t/a floating LNG (FLNG) platform, the Hilli Episeyo, in March this year. The company is aiming to develop a similar platform, Fortuna LNG, for offshore Equatorial Guinea, together with Schlumberger and Ophir Energy, but this was dealt a blow last year when Chinese banks offering $1.2 billion pulled out, delaying the decision to proceed, and a decision on Fortuna is likely to rest on successful operations in Cameroon. Equatorial Guinea meanwhile also recently announced a master gas plan to gather gas from other fields, possibly including neighbouring Gabon, Cameroon or Nigeria (see Syngas News, this issue). A second 4.4 million t/a LNG train for Atlantic LNG in Equatorial Guinea has been designed (by Bechtel) but not so far proceeded with.
- Mozambique's government is drafting of a master plan for the gas sector, covering the uses to which the gas can be put and institutional reforms in the public and private sector, and the development of gas infrastructure. It recently approved Andarko's plans for a large scale LNG project in the country. The Mozambique LNG project will be Mozambique's first onshore LNG development, initially consisting of two LNG trains with total nameplate capacity of 12.9 million t/a to support the development of the Golfinho/Atum fields. A final investment decision is expected in April 2019, with the LNG facility expected to be completed in 2022-2023. Financing also closed late last year on the $4.7 billion Coral FLNG project, and construction on the 3.4 million t/a production platform began earlier on this year for completion in 2021 and first gas production in 2022.
- In Tanzania, commercial frameworks to allow LNG exports have been agreed, but the two major exploration consortia, BG-Ophir and Statoil-Exxon, are both waiting to discover more gas to justify the investment. The latest estimate of Tanzania's offshore gas reserves is 630 bcm, but the USGS says there is still some 2.0 tcm to be found, with a 95% probability of >1.1 tcm. Given that both partnerships do not currently have sufficient gas volume to justify individual projects, a joint LNG project could be an alternative development option.
- Nigeria is already the world's fourth largest exporter of LNG, with six trains operational at Bonny Island for Nigeria LNG with a capacity of 22 million t/a. However, a final investment decision was made earlier this year on a $10 billion, 8 million t/a seventh train, and an eighth has also been designed (by KBR). NLNG is a consortium of the Nigerian National Petroleum Corporation, NNPC (49%), Shell (25.6%), Total (15%), and Eni (10.4%). There has another large scale proposal – Brass LNG, for two 5 million t/a LNG trains to be built at Brass Island at a cost of $15 billion – for over 10 years. Brass was initially proposed by a consortium including NNPC (49%), but this time with ConocoPhillips, Eni and Chevron. But Chevron pulled out many years ago, and Conoco did likewise in 2014, taking their technology license with them. The project is now under investigation by the Nigerian Senate for corruption and seems moribund, as does the even more speculative Olokola LNG project, which had discussed 25 million t/a of capacity.

Pipelines

Pipeline developments have been few and far between, as most of the gas is developed for export out of Africa, and so African gas pipelines have mainly been built from North Africa to Europe. The 680km West African Gas Pipeline allows Nigeria to export gas to Benin, Togo and Ghana, although it has suffered from a number of technical issues, sabotage and accidents. Since 2004 Mozambique has been exporting about 2 to 3 bcm/year of natural gas to South Africa through an 865 km pipeline, which Sasol Petroleum International, the South African government, and the government of Mozambique own through a joint venture. The pipeline has a peak capacity of 5 bcm/year of natural gas.

A 4,400km trans-Saharan pipeline project to connect Nigeria to export pipeline networks to Europe has had several incarnations, and is currently based on a route from Nigeria through Niger and Algeria to Spain known as TGSP or NIGAL (Nigeria-Algeria). However, the $12 billion (but estimates run as high as $20 billion) development, backed, like so much in Africa, by Chinese money, remains stalled, amid concerns about the security of Nigeria's gas. Attacks on pipelines are common and in spite of occasional ceasefires the government has not been able to prevent attacks by militant groups.

Fertilizer demand

Africa, especially sub-Saharan Africa, as a relatively minor consumer of fertiliser, accounting for just 2.5% of world urea consumption in 2016, according to the International Fertilizer Association (IFA). Global fertiliser application rates are around 100 kg/hectare. By contrast, in Africa these levels are around 10-20 kg/ha, and consumption is highly concentrated among a handful of countries, with five countries (Ethiopia, Kenya, Nigeria, South Africa and Zambia) accounting for almost two-thirds of consumption. African leaders adopted the Abuja Declaration in 2006, calling for increasing average fertilizer use in sub-Saharan Africa (SSA) from less than 10 kilograms per hectare (kg/ha) to at least 50 kg/ha by 2015. However, this goal was missed by a considerable margin: by 2014, the application rate was less than 20 kg/ha in Africa.

The region has vast amounts of arable land and extensive agricultural production (albeit with low yields) but, up until now, has had very limited fertiliser production – apart from South Africa. Agriculture has been identified as a key development mechanism to improve wealth and diets in the region, especially as it continues to be one of the parts of the world where populations are continuing to ruse fastest. However, achieving the same kind of 'Green Revolution' in Africa that has been seen in Asia and South America has proved more elusive, because of the continent's diverse, rain-fed farming systems, limited irrigation and lack of rural infrastructure. Debt forgiveness programmes earlier in the century and a commitment to increasing agricultural productivity by governments has had a positive effect, especially in countries like Malawi, but the rise in domestic fertilizer use remains small and patchy, and prices for fertilizers too high to be afforded by most small farmers. As a result, the region remains a large net importer of fertilizer, and one potential way around this problem would be to use domestic gas reserves, where available, to produce fertilizer locally which could then be supplied by national governments to domestic farmers at subsidised rates. Needless to say, however, this has not always gone down well as a selling point with developers of fertilizer projects, who have preferred to look to export markets to recover the high costs of setting up in a low infrastructure environment.

PHOTO: INDORAMA

Another view of the Indorama facility.

Fertilizer industry

Sub-Saharan Africa's fertilizer industry has historically been mainly sited in South Africa and based on ammonia from coal gasification using Sasol technology. On the nitrogen side, Sasol's Nitro arm was founded in 1981 as Sasol Fertilizers. Today the company operates a 300,000 t/a plant at Sasolburg and two trains at Secunda with another 250,000 t/a, all based on coal gasification. Sasol also has downstream capacity to manufacture nitric acid, ammonium nitrate and ammonium sulphate, and operates a 140,000 t/a methanol plant at Sasolburg, again using gasified coal as a feedstock. AEL, formerly the African Explosives and Chemicals Industries (AECI) Group, manufactures ammonium nitrate for explosives use, using ammonia sourced from Sasol, as does mining company Omnia, which has nitric acid, AN and CAN facilities at Sasolburg. Omnia recently expanded production at Sasolburg, adding a 330,000 t/a nitric acid and ammonium nitrate plant and inking ammonia supply deals with Qafco and Sasol.

Zambia likewise developed coal-based capacity, and including 100,000 t/a of ammonia production at Kafue, operated by Nitrogen Chemicals of Zambia (NCZ), as well as downstream nitric acid, ammonium nitrate and ammonium sulphate production. Most of this capacity has been closed down, but the AN plant was re-started in 2013 using ammonia imported from South Africa, and in 2017 it produced 120,000 tonnes of AN.

Zimbabwe operated an electrolysis-based ammonia plant at Kwekwe using electricity from the Kariba Dam, but this closed in 2012 due to the high costs involved. Again ammonia is imported from South Africa to operate the AN plant at the site, run by Sable Chemicals, but plans to convert the ammonia plant to coal gasification were suspended in early 2014.

Nigeria

Nigeria has been the main country outside South Africa to develop its own nitrogen fertilizer industry. This began in 1987 with the National Fertilizer Company of Nigeria (Nafcon) plant, which operated 500,000 t/a of urea production at Onne, near Port Harcourt in the east of Nigeria. The company suffered from financial and operating problems throughout the 1990s however, and Nafcon was sold on in 2005 to Egypt's OCI group, becoming Notore Chemical Industries. Notore refurbished the plant and reopened it in 2010. A subsequent debottlenecking project increased capacity to 430,000 t/a of ammonia and 750,000 t/a of urea in 2013.

Indorama

Several projects to build new nitrogen capacity in Nigeria followed, but delays in gas allocations and difficult financing slowed development. The first new project to be commissioned was the Indorama Eleme Fertilizer and Chemicals Ltd facility at Port Harcourt, River State, developed by Indonesian chemical giant Indorama Corp. Toyo Engineering and Daweoo Nigeria built the plant using KBR ammonia technology for the 2,300 t/d ammonia plant and a Toyo license for the 4,000 t/d urea plant (1.3 million t/a) – the largest single train urea plant in the region. The facility was commissioned in 2016 at a cost of $1.5 billion, financed by the International Finance Corporation (IFC) and a consortium of 15 European and African banks. Indorama has offtake agreements with

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Helm and Trammo for export sales via the port of Onne, 16 km from the plant, as well as selling domestically in Nigeria.

Dangote

The other major nitrogen development in Nigeria is being conducted by the Nigerian-based Dangote Group, owned by Africa's richest man, Aliko Dangote. Saipem designed the plant using its own urea technology and a Haldor Topsoe license for the ammonia plant, with UFT granulation technology for the urea. The plant is a huge one; two 2,200 t/d ammonia plants feeding two 3,850 t/d urea plants, for a total of 2.5 million t/a of urea capacity. It forms part of a huge Dangote complex in the Lekki Free Trade Zone east of the capital Lagos, where the company also runs a refinery and petrochemical facilities. A price tag of $2 billion has been put on the urea development, which is due to be completed later this year, with commercial production likely in the first quarter of 2019. Dangote is projecting that it will sell 20-25% of the plant's output domestically, another 15-20% in West Africa, and 55-65% of its output on the global market.

New capacity

There are a number of other projects under development in Nigeria, but timescales remain very much more open to question. The Brass Fertilizer and Petrochemical Company is looking at a 1.3 million t/a urea plant at Brass Island in the Niger Delta, using gas from Shell's OML 33 field. However, the remote location has pushed the price tag, including an associated 1.7 million t/a methanol plant, to $3.6 billion, including a dedicated export jetty and a 300 million scf/d gas processing plant. Investment money is reportedly coming from China for the project, with a Topsoe ammonia license. Site preparation has reportedly begun, with a completion date of 2020 at the earliest.

A proposal being developed by India's Nagarjuna Chemicals and Fertilizers seems to be dead, but existing producers also all have plans for new capacity. Notore has plans to add another ammonia-urea train, with 560,000 t/a of ammonia and 990,000 t/a of urea capacity, with front end engineering and design work completed by Mitsubishi Heavy Industries in 2013, and signed a joint venture agreement with Mitsubishi over the development, but work has yet to begin on this. Indorama also says that it is planning to double urea production capacity at its Eleme, Port Harcourt complex to 2.8 million t/a. The Eleme II project includes two new 2,300 t/d ammonia and 4,000 t/d urea plants. Indorama has already engaged technology licensors and EPC contractors for the project's front end engineering design (FEED) phase, and is now arranging finance through the IFC. The project has a provisional start-up date of 2020-2023.

Table 2: **Nitrogen consumption in sub-Saharan Africa, 2016, '000 tonnes N**

Country	Consumption
Cameroon	23
Cote d'Ivoire	81
Ethiopia	186
Kenya	108
Nigeria	560
Senegal	73
South Africa	425
Sudan	83
Tanzania	85
Zambia	21
Zimbabwe	41
Others	264

Source: IFA

Other projects

While there have been a number of other project proposals for the region, outside of Nigeria development has been much more tortuous. India and Ghana signed a memorandum of understanding to set up a 1.2 million t/a ammonia-urea plant in western Ghana, to be operated by Rashtriya Chemicals & Fertilisers (RCF), but the Ghanaians' inability to guarantee gas supplies led to the project foundering in mid-2014. The same year, Indian firm Tata Chemicals Ltd walked away from the Gabon Fertilizer Company development with the government of Gabon and Singapore-based agribusiness Olam International, which had been aiming to build a 1.3 million t/a ammonia-urea plant at Port Gentil. A plan by German engineering firm Ferrostaal to develop a nitrogen complex in Cameroon has also made little progress, and likewise a Japanese project for Angola to produce 580,000 t/a of urea next to the LNG plant at Soyo has not progressed beyond the design phase. Ethiopia has discussed a coal-based fertilizer complex, but lack of foreign currency and disagreements over the development appear to have stymied that for now.

Other projects which are still under development include an ammonia-urea plant at Mtwara in Tanzania by the Tanzania Petroleum Development Corporation, in a joint venture with Haldor Topsoe, Ferrostaal and Pakistan's Fauji Fertiliser Company. The $1.8 billion complex will have a urea capacity of 3,850 t/d (1.3 million t/a) and a 2,200 t/d ammonia plant. Land has been purchased for the project, but there is no firm completion date as yet, and best guess is 2022 at the earliest.

Yara said late last year that it is "working on" a 1.3 million t/a urea project in Mozambique, at a potential cost of $2 billion, but that it had yet to decide on the framework for the development, such as the involvement of other project partners. Overall, the likelihood of any new capacity outside Nigeria in the next few years looks slim.

Too many projects?

Nigeria's urea imports fell from 600,000 t/a in 2013 to 20,000 t/a tonnes in 2016, as rising domestic output displaced imports – Nigeria's urea production rose from 280,000 t/a in 2015 to 695,000 tonnes in 2016, after Indorama's plant entered production, supplementing production from the country's existing Notore-operated plant. At the same time, urea exports have grown sharply from 50,000 tonnes in 2013 to 330,000 t/a in 2016, mainly to South America, the US and South Africa. However, while domestic consumption represents a relatively small fraction of Nigeria's urea installed capacity, Dangote for one believes that there is potential for this to grow significantly. The company suggests that Nigeria's domestic fertilizer consumption could eventually grow to 1.7-2.9 million t/a under some scenarios, up from around 1 million t/a currently, and urea consumption could rise from 400,000 t/a to up to 1.4 million t/a. Even so, the completion of the Dangote project will see Nigerian capacity rise to 4.5 million t/a, making it already very dependent on exports, at a time when global prices have been low. The viability of some of the new urea expansion projects seems open to doubt in the current environment, and IFA has suggested that no new urea plants beyond Dangote are likely to be completed in Africa before 2022. ■

The outlook for urea

China has dominated the urea market for two decades: first as the largest importer to feed rapidly growing domestic demand; then, following huge over-building of capacity, as its largest exporter and price setter; and now, as the country seeks to crack down on environmental issues, by removing large sections of production from the market.

Urea continues to be the most popular and widely traded of all nitrogen fertilizers, seeing a steady rise in its use, especially in Asia. Because of its high nitrogen content (46%), it is seen as one of the most cost-efficient ways of delivering nitrogen to soils.

Urea demand

Although industrial uses for urea, such as urea solutions for selective catalytic reduction (SRC) systems in heavy duty vehicles, continue to rise at a higher rate (around 4% year on year), it is increasing from a lower base, and demand for urea still remains centred predominantly (just over 80%) around its use in nitrogen fertilizers, although the share of urea demand accounted for by technical and industrial uses has risen from 12% to about 18% over the past decade.

Global demand for nitrogen fertilizer has slowed as agricultural markets have matured. Demand for agricultural urea is now rising at about 1.5% per year as opposed to 3.5% per year a decade ago. The primary cause of this has been increasing focus on nutrient use efficiency in plants, leading to a fall in demand in Europe and slowing demand increases in North America. But the greatest sea-change has come in China. China has recognised the problems caused by nitrate leaching into water courses caused by over-application and inefficient application of fertilizer and is now taking steps to tackle it. China has set itself the goal of capping nitrogen fertilizer demand in 2020 and thereafter reducing it in a similar way that Europe has managed. Meanwhile, India's shortage of domestic nitrogen production has led the government to focus on ways of eking out the urea that it does have; switching to slightly smaller bag sizes and insisting that all domestic urea be coated with neem oil, which acts as a controlled release agent.

There are also other changes to global patterns of consumption, especially in Asia, caused by a switch away from cereal production (traditionally a large consumer of nitrogen) in China, where the maize stockpiling policy has been relaxed, towards more fruit and vegetables and increased production of oilseeds, especially soybean. Global population growth is slowing, grain prices have relaxed after their peak around 2007-13, and stocks are relatively higher. The upshot is that nitrogen fertilizer demand is continuing to slow, and so the prospects for increased demand for urea do look more limited for the years ahead.

Nevertheless, demand is still increasing, just at a slower rate. There is still increasing demand in Latin America, especially Brazil – which is set to overtake North America as the third largest regional consumer, and meanwhile, as our article elsewhere in this issue notes, there are strenuous efforts to encourage greater fertilizer use in Africa, in the hope that the continent can benefit from a 'green revolution' in the same way that Asia and Latin America have. IFA predicts that nitrogen fertilizer use will increase at 1.2% year on year out to 2022, by which time it will represent 112.4 million tonnes nutrient.

Feedstock

Turning to the supply side of the equation, feedstock prices remain the dominant factor in deciding ammonia and hence urea plant profitability.

The global gas market is changing rapidly as gas-on-gas competition begins to replace oil-indexed or controlled pricing, and gas availability is also now becoming a major factor, with the Middle East – outside of Iran – no longer having the supply of gas available as it used to as more and more gas-based power production is developed and urban populations rapidly increase. As Table 1 shows, Middle Eastern countries still remain among the largest exporters of urea, after Russia, which is also gas-rich, and China with its coal-based production. However, outside of Iran, new plant developments there are now fewer and further between, and the PIC plant in Kuwait is actually expected to close soon. The only regions with significant 'stranded' natural gas in large reservoirs are Central Asia and Africa, and both of these have now become focuses for new ammonia-urea plant development, as we discuss below.

Table 1: **Urea figures for major producers and consumers, 2016, million tonnes N/year**

Country	Production	Consumption	Exports	Imports
China	28.48	24.40	4.08	0.00
Russia	3.73	0.97	2.76	0.00
Qatar	2.60	0.11	2.49	0.00
Saudi Arabia	2.13	0.18	1.95	0.00
Oman	1.58	0.03	1.55	0.00
Iran	2.19	0.87	1.32	0.00
Bangladesh	0.54	1.01	0.01	0.48
Brazil	0.61	2.90	0.00	2.29
India	11.33	14.59	0.00	3.26
United States	3.43	6.59	0.15	3.63
World	**80.17**	**80.17**	**23.17**	**23.17**

Source: IFA

Non-merchant urea is for the most part concentrated in the countries with highest demand; China, India and the USA, and has been constrained historically by lack of natural gas supply in India and the US. However, India has now decided to make a major push back towards the self-sufficiency it last enjoyed in the 1990s in spite of the cost, by importing liquefied natural gas (LNG), while the US has seen domestic gas production soar because of shale gas drilling to the point where the country is now a gas exporter once more, and domestic ammonia/urea capacity has surged on the back of cheap feedstock. This in turn is likely to lead to increasing displacement of imports from these countries – indeed the pattern can already be seen. US imports of urea fell to 6.5 million tonnes in 2016 and 5 million tonnes in 2017.

While natural gas prices have been depressed by wide availability from LNG projects and the US shale gas boom, there has been a slow rise in European prices, from around $5.50/MMBtu last year to around $7.50/MMBtu this year, putting pressure on European producers. Hardest hit has been Ukraine, whose access to Russian gas has been constrained by the conflict between the two countries, and where urea production has all but ceased.

China

As noted in our introduction, China has been the dominant factor in the urea market over the past two decades or more, due to its large and rising population and rapid industrialisation. Now however the effects of the government's 'one child' policy are starting to make themselves felt. This has led to major demographic shift towards and ageing population and fewer new young workers entering the labour market. This in turn is seeing a seismic shift from China being the workshop of the world to a major consumer-driven society instead, and the slowdown in Chinese growth which has led to the slump in commodity markets in general.

Added to that has been a major concern about quality of life from China's smog-choked cities and China's desire to do more to tackle climate change – China has installed more renewable electricity in the past decade than the rest of the world put together. Now the government is tackling the oversupplied fertilizer market by closing older, smaller, less efficient plants. There has also been a crackdown on polluting industries near major population centres, especially during winter when smog can be at its worst.

The Chinese government is also looking to tackle overcapacity in the coal sector and move China's energy production to a more sustainable footing. This involves the closure of over 800 million t/a of coal mine production. Not only has this pushed up coal prices, making some of China's older and less efficient urea plants less internationally competitive – anthracite prices have risen drastically over the past couple of years – it has also led to a resurgence in gas-based power production, which has reduced availability of gas feedstock for China's gas-based urea plants, especially during winter. This forced the closure of over 9 million t/a of urea production in December 2017 during a cold snap when gas was required for power production.

All of this has drastically reduced China's urea capacity. CRU estimates that 13 million t/a of urea capacity was permanently closed in the period 2013-15, and they project that a further 15 million t/a of capacity has or will close from 2016-2022. Most of this will be based on expensive anthracite coal, at the top of the cost curve for Chinese producers. This must be balanced against new, more efficient Chinese urea capacity, mainly operating off low-grade bituminous coal, and the period 2018-22 could still see an additional 12 million t/a of new capacity start operation, which will still see a slight net addition to Chinese urea capacity over that period. However, seasonal shutdowns because of feedstock and/or environmental restrictions mean that effective capacity will continue to fall, with net utilisation rates not far above 70%. Chinese urea production fell in 2016 by 7 million t/a, and the figures for 2017 are expected to show another 4 million t/a or so of contraction. This in turn has reduced China's urea exports from 14 million tonnes in 2015 to 8.5 million tonnes in 2016 and 4.5 million tonnes in 2017. The figure to May 2018 was just 550,000 tonnes.

New investment

With Chinese production falling, new urea capacity will come from elsewhere in the world. Prices remain relatively low at present, with the industry suffering from overcapacity following the previous investment cycle, and this makes the conditions for financing new urea plant developments much more difficult. While Table 2 shows that there is around 19 million t/a of net new capacity under development, it can be seen that most of the plants are either already commissioning or due to come on stream soon, and there are few plants scheduled towards the end of the period. Furthermore, some of the plants, such as in Malaysia or Iran are either speculative, or, as in the case of Iran, subject to possibly delays or cancellation due to financing difficulties (see below).

India

India continues to push Prime Minister Modi's vision of becoming self-sufficient in urea production by 2021. The problem for India – and the reason that there has been no new grassroots plant built since the mid-90s and that India has consequently become the largest importer of urea in the world – is one of feedstock availability. Now the country is looking to begin building new urea capacity based on LNG imports and refurbish old, closed urea plants to close up the import gap, which stood at 8.5 million tonnes in 2016, although this fell to 5.5 million tonnes in 2017.

One feedstock India has not turned to in earnest is coal – Indian coal is low quality and has high ash content, although it can still be suitable for gasification. However, poor experiences with previous coal-based plants and a row over allocating coal to a proposed new development have pushed the prospects of coal-based urea back into the next decade. A new urea plant based on coalbed methane (Matix Fertilizers) came on-stream in the northeast, but has been plagued by lack of gas availability.

Table 2 shows two of the most advanced projects, but there are plenty more in India. However, which will be completed and when, and whether they will have sufficient gas available to feed them when they do come on-stream still remains open to question.

Iran

As we described in our article in March/April 2018 ('Iran's growth spurt', *Nitrogen+Syngas* 352, pp26-29), Iran had looked to be one of the bright spots in new urea capacity building, with 4.9 million t/a of new urea capacity set to join the 6.6 million t/a already in operation by 2020. However, this burst of new capacity building, or rather capacity completion, as many of the plants had begun construction, has been contingent on the relaxation of UN sanctions on Iran, especially financial sanctions. With the election of Donald Trump and a much more hawkish US administration, the possibility of financial sanctions being re-imposed on Iran and even the pos-

Table 2: **New urea capacity, 2018-22**

Country	Plant	Location	Capacity, million t/a	Onstream
Azerbaijan	SOCAR	Sumgayit	0.6	2018
Brunei	Brunei Fert Ind	Sungai Liang	1.3	2021
China	Several	Various	0.4 (net)	2018-20
Egypt	Kima	Aswan	0.5	2019
India	Chambal	Gadepan	1.4	2019
	RCFL	Ramagundam	1.3	2019
Indonesia	Gresik	East Java	0.6	2018
Iran	Lordegan	Lordegan	1.1	2019
	Masjid Soleyman	Masjid Soleyman	1.1	2019
	Kermanshah	Kermanshah	1.3	2020
	Hengan	Assaluyeh	1.1	2021
Malaysia	Petronas	Siptang	2.4	2021?
Nigeria	Indorama	Port Harcourt	1.3	2018
	Dangote	Edo	1.3	2019
Russia	Metafrax	Gubhaka	0.6	2019
	KuybishevAzot	Kuybishev	0.5	2020
Turkmenistan	Turkmenkhiniya	Garabogaz	1.2	2018
United States	Dakota Gasification	Beulah, ND	0.3	2018
Uzbekistan	NavoijAzot	Navoij	0.6	2019
Total			**19.0**	

Table 3: **Urea production and consumption and net surplus/deficit by region, 2016, million tonnes N/year**

Region	Production	Consumption	Surplus
Western Europe	2.99	4.80	-1.81
Central Europe	1.25	1.81	-0.56
FSU	6.19	2.64	+3.55
North America	5.33	8.26	-2.93
South America	2.22	6.08	-3.86
Africa	3.71	2.47	+1.24
Middle East	10.40	2.78	+7.62
South Asia	14.63	18.58	-3.95
East Asia	33.23	31.24	+1.99
Oceania	0.19	1.49	-1.30

Source: IFA

sibility of conflict in the region has grown much more likely, and it seems certain that much of this capacity will now be delayed beyond 2022 if not cancelled altogether.

Africa

Our article elsewhere in this issue looks at the situation in Africa in more detail. Briefly, the discovery of gas in various parts of sub-Saharan Africa led to a plethora of export-oriented projects in locations as disparate as Mozambique, Angola, Cameroon, Tanzania and Ethiopia. However, the fall in urea prices and the cost of developing new projects where there is such a lack of infrastructure has led to the cancellation or delay of most of these projects, and only a couple of large plants in Nigeria have actually made it to (or almost to) completion. Table 2 shows a couple of these plants, but these may be the last for a while.

Central Asia

All of this has left Russia and Central Asia as the place where there is still that magic combination of cheap, plentiful natural gas with no alternative use or outlet and, although parts of the region are also a long way from end-use markets or export ports, domestic demand in Russia and the CIS is growing, and there is still some room left for import substitution in some Central Asian countries. Thus some 3.5 million t/a of new capacity is due to come on-stream in this region over the next few years. The SOCAR plant in Azerbaijan is due to be on-stream very soon, and Garabogaz in Turkmenistan probably later this year. There are also revamps in Russia as well as new plants next year and 2020.

Urea trade

Because of the large volumes of urea produced in major consuming markets, especially India and China, international trade in urea makes up a minority of the total urea market, but still a sizeable one – about 29%. Table 3 shows the major exporting and importing regions as of 2016, although this masks some intra-regional trade, for example from Indonesia to Vietnam or Canada to the USA. Other regions can almost be considered as appendages of a larger market. For example the Caribbean is mainly an adjunct to the US market, the Middle East is closely tied to the South Asia market, and North Africa is very closely tied in with the European market.

The largest changes in Table 3 over the past few years have been the reduction in Chinese production and exports, and Indian imports at the same time that capacity has increased in the Middle East (mainly Iran) and FSU. North American imports have fallen, although not by as much as might be expected as demand has continued to increase. Africa has become a net exporter, although this includes North Africa and much of the new capacity has been in Algeria and Egypt, as well as Nigeria.

The current surplus in the urea market is set to continue for another couple of years at least as more of the capacity in Table 3 comes to the market. However, as global demand rises towards around 180 million t/a in 2022, new capacity additions are set to fall beneath new demand growth from about 2021, leading to anticipated price rises in the medium term. But the continued closure or seasonal shutdown of Chinese capacity, and the prospects of project delays or cancellations in India, Nigeria and Iran, mean that this turnaround could come slightly sooner.

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thyssenkrupp Industrial Solutions ran its 6th Fertilizer Symposium in Essen from May 7th-9th this year, in what was once the heart of the Ruhr mining and industrial region, and still a centre of industrial technology and innovation.

Germany's industrial past, present and future

The TKIS Fertilizer Symposium began as the Uhde Fertilizer Symposium in 1998, and since then has been held every four years, now under the auspices of Uhde's purchaser and parent the thyssenkrupp Group via its subsidiary thyssenkrupp Industrial Solutions (tkIS). What has not changed over those 20 years is that the meeting functions as an opportunity for the company to showcase its technical expertise and new technologies for the fertilizer industry. The meeting has now outgrown the former Uhde headquarters in Dortmund, and this year relocated 20 km or so westwards to a purpose-built conference facility at the impressive thyssenkrupp head offices in Essen, in the heart of Germany's Ruhr industrial belt.

Main pic: The past: the Zollverein coal mine, Essen. Above: The present: TKIS' modern headquarters in Essen.

That industrial heritage was on show at the evening event on Tuesday night, which included a tour of the massive Zollverein coal facility. Now largely idled and reopened as a museum, the huge coal mine complex, Germany's largest, was the largest and most productive coal mine in the world in its 1930s heyday, producing 3.6 million t/a, around 10% of all global coal production at the time.

Market outlook

To set the scene, Integer director Oliver Hatfield presented the outlook for nitrogen and phosphate fertilizer markets. He noted that long-term demand for urea has been slowing; in the decade from 2003-2013 urea demand averaged 3.7% growth per year, but for the 2013-2023 period it has slowed and is predicted to continue to slow to around 1.5% per year on average. Much of this has come from a slowdown in Chinese demand as the Chinese government seeks to make fertilizer applications more efficient, but the Indian government has also been limiting its subsidy cost and effectively rationing urea consumption.

On the supply side, capacity investment is at a cyclical low, but even so is still running at an average of 3-4 million t/a. Indeed, for the period 2017-19, new capacity additions are running at more than the increase in demand. Ordinarily this would be expected to have a rapid impact on supply, but many new plants are either based on subsidised feedstocks or government ownership or both. Furthermore, Indian and Latin American revamps and rehabilitations of old plants, as well as other possible projects around the world, threaten to extend oversupply into the 2020s.

As far as the market goes, China's urea market is rationalising and reducing exports at the same time that the US and India are building more domestic capacity, displacing imports. There is also new low cost capacity in the Atlantic basin, form Russia, Nigeria, and North Africa. As a consequence, many export markets are being squeezed, and urea trade is down 6% over the past two years. The export curve currently suggests a floor at $220-230/t f.o.b. Yuzhnyy in 2018.

The ammonia market is in a similar position, said Oliver, with large tranches of new merchant capacity coming on-stream over the 2016-1 period8. However, there are no new projects scheduled for 2020 onwards at present, and the market is likely to move into deficit at around that time.

On the phosphate site, there has again been a period of substantial investment in supply, with most new capacity in the Middle East and North Africa. This is displacing North American capacity, although China would, he said, be the main source of mid-term volume adjustment. Phosphate prices have also reach a low point over the 2016-17 period and are now recovering.

Current projects

Klaus Nolker gave an overview of tkIS project activity. Recently completed plants since the previous conference include ENPC 1 and 2 at Damietta in Egypt, with twin 1,200 t/a ammonia and 1,925 t/a urea trains; the 3,300 t/a Ma'aden 2 ammonia plant in Saudi Arabia; the CF Industries complexes at Port Neal and Donaldsonville in the US, as well as the Iowa Fertilizer Complex at Wever, with a grand total of 5,500 t/a of ammonia, 9,200 t/a of urea, 2,700 t/a of nitric acid and 8,600 t/a of UAN capacity between the three sites. A revamp at Safco IV, taking the ammonia plant to 3,760 t/a, was completed more recently in February 2018. Current new projects on the slate include the Brunei Fertilizer Industries plant with 3,900 t/a of urea capacity including a UFT granulation section, due for completion in 2021. A number of new nitric acid and nitrate plants have been completed in locations as diverse as Poland, Belarus, Hungary, Vietnam, Egypt, the USA and Turkey. tkIS has also recently got back into building phosphoric acid plants, including one for Coromandel in India and design work for one in India.

Services

One of the areas which tkIS was keen to stress at the conference is the relatively new area – for them – of providing additional services during a plant's operating lifetime – the longest part of a plant's life. Although tkIS has only been involved in this for two years now, as described by Dr Donald Weir, it has access to 1,600 experts in 70 locations, and can cover parts and supply management, asset management, field and workshop services, revamps and outages. Services which tkIS can provide include what they call Plant Intelligence – the use of AI and interactive machine learning. The cost of monitoring a plant in real time with servers and AI systems has reduced dramatically over the past 5-6 years. Now a 'digital twin' of a plant can be maintained to predict plant behaviour and identify issues where real world and digitally-generated data disagree.

Innovations

tkIS' Syngas and Fertilizers business unit covers four distinct areas; Ammonia and Urea; Nitrates and Phosphates; Syngas and Methanol; and Urea Granulation, and all of these technologies were under discussion during the symposium A variety of innovations have been developed across the board, and those described included:

- A new fluidised bed granulation process for ammonium sulphate.
- The Urea-ES (enhanced sulphur) product, using UFT's granulation process as its basis, which incorporates around 13% sulphur and which has demonstrated an average 11% increase in farm yields in trials over 2014-17, and up to 66% in some cases.
- NOx removal from reformer and boiler flue gases to comply with today's emission standards.
- A new method for faster catalyst filling in ammonia converters.
- A new acidic scrubbing system for urea plants which is able to achieve the lowest possible emissions of fine dust (<2.5 micron) dust and ammonia from granulators and the synthesis vent stack – important in an environment where emissions limits on ammonia and urea dust continue to fall. This includes a Kimre *Aerosep* filter system uses super-saturation of gas with a very fine liquid spray and separation of grown particles in "coalescer" pad to remove even sub-micron particles, some of the most difficult to remove from the process stream.
- The use of a bulk flow cooler in urea granulation. This is a new standard concept for small granulation systems, reducing the equipment count by elimination of first cooler and one scrubber.
- Various projects on optimisation of ammonia plants, for example: control of VOC (volatile organic compounds) from CO_2 vent stack.
- A new plate heat exchanger system developed in conjunction with Alfa-Laval for ammonia converters with a combined axial-radial flow.
- Development of ammonia-urea process integration via CO_2 removal. This uses an ammonia-water based scrubbing system rather than an amine-based CO_2 absorber and operates at urea synthesis pressure. As no condenser is required, there is a 7% overall reduction in cooling duty and 2% reduction in primary energy demand, as well as reduced cost for the solvent, and low pressure steam can be made available for other options.
- tkIS has also developed a flowsheet for combined production of ammonia and methanol, offering overall savings in both capital and operating expenditure.

Small-scale ammonia

tkIS has developed a small-scale ammonia plant concept for the use of hydrogen from electric power. The concept is described in full detail in our article elsewhere in this issue. It is based on tkIS' modularised small-scale ammonia plant design for capacities of 300-550 t/d, which was designed with the needs of small ammonia consumers such as nitric acid and ammonium nitrate plants and industrial chemicals producers in mind.

Other companies

As well as tkIS innovations, several partner companies presented technologies. Stamicarbon presented their ultra-low energy urea melt design concept, now in service in two plants in China. MAN described their new MAX-1 axial blading development step for axial flow compressors, which forms part of the new modular nitric acid train package, up to 15% shorter and 30% narrower than conventional trains. Mitsubishi also showcased their compressor trains for natural gas, process air and syngas compression as well as CO_2 compression for urea plants. Johnson Matthey has collaborated with Uhde/tkIS for 20 years now, and reviewed their joint progress over that time with ammonia plant catalysts across the range from purification, reforming, high and low temperature shift and ammonia conversion.

Inspired by
The School of Athens, Raffaello Sanzio 1509-1511
Vatican Museums. Photo Scala Archives

AMMONIA
NITRATES & PHOSPHATES
UREA
MELAMINE
METHANOL
SYNGAS

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Making the most of plant data

New IT technologies now allow the transfer of large amounts of data via the internet which opens up new opportunities for industrial plants, such as remote plant monitoring, remote plant operation and the utilisation of real-time plant data.

Industry 4.0, the fourth major industrial revolution since the first industrial revolution of the 18th century has begun. This revolution has seen the introduction of a wide range of technologies, including internet of things (IoT), artificial intelligence (AI) and cloud computing. Business operations are being transformed, including supply chains and the management of human resources.

Every day plants generate huge amounts of data, which are visualised by DCS systems and possibly stored in a dedicated machine. However, due to lack of resources, most of the time only the most prominent values and changes are really analysed. To get the full benefit from this wealth of information, it is necessary to perform efficient statistical analysis and apply modelling tools to convert raw data into useful indicators.

The utilisation of process data analysis methods for industrial plants offers great potential to improve plant performance. Intelligent modelling systems can be developed which not only analyse actual problems but can also be a guide to solutions as well as being able to predict potential production losses. This provides plants with the opportunity to act in advance and to maintain plant reliability and efficiency.

Several components are required to design digital services on an IIoT (industrial internet of things) platform. A cloud-based IT infrastructure and secure connectivity to a plant are the technology drivers behind implementation of cloud-based digital services. However, it is the knowledge on how a plant is designed, operated, and maintained that makes it possible to deploy the optimal simulations and algorithms on the data being extracted from a plant. In addition, the same knowledge is required to develop useful user-interface software to be used by plant personnel.

KBR's perspective on "big data" for ammonia plants

With the world population anticipated to grow by 30% in the next 30 years, the increasing demand for fertilizers and agricultural goods has continued to spur the construction of ammonia plants globally. Even the US, where no new ammonia plants had been built for almost 20 years, has been looking to capture a lot of that demand by leveraging the abundant supply of low-cost natural gas domestically. As a leading supplier of ammonia process technologies, KBR has been involved in the licensing, designing, engineering, construction and operations support of many of these ammonia plants worldwide over the past decades. During this time period, KBR has observed that in many geographical areas the ammonia industry is experiencing serious challenges related to finding the required skilled labour workforce to operate all these new plants. In places like the US this is further compounded by the fact that many members of the skilled labour workforce will be reaching retirement age over the coming decade. It is therefore not surprising that many operating plants are often too resource constrained to manually inspect and interpret process and equipment data at a frequency required to meet ammonia plant operations reliability goals.

To address this challenge, owner-operators are beginning to engage technology licensors and third party process experts to actively and remotely monitor their plant operations as a way to provide cost-effective expert guidance for improving plant performance and equipment health. The owner-operators are also in the process of leveraging advances in the information technology (integrated operations management systems, big data analytics, machine learning, etc.) and embracing digital transformation to improve profitability. Coincidentally, the process industry is in the midst of an unprecedented growth in the use of data-driven models and advanced analytics to interpret and diagnose plant operations, predict issues in near real time, and prescribe remedial operator action to mitigate process upsets or equipment failure before it occurs. Along these lines, KBR has developed Ammonia InSite™ a cloud-based performance analysis and expert advisory service that is being actively deployed at several ammonia plants world-wide. Ammonia InSite™ uses state-of-the-art web-enabled visualisation dashboards and advanced mathematical algorithms to leverage and unlock the value of near real-time plant data to create a visual "digital fingerprint" of the plant utilising Smart KPIs (key performance indicators). This service utilises operational insight for early detection of incipient problems that if ignored could lead to degradation of process and equipment performance. Smart, proactive, escalating alerts act as early warning notifications of impending abnormal or sub-optimal process deviations and the visualisation platform supports quick identification and exploration of potential sources of problems. This has allowed KBR experts located at different engineering offices worldwide to remotely monitor, analyse and diagnose customers' plant operations, collaboratively engage with them, and to assume the role of trusted advisors to provide timely guidance to improve overall plant reliability and significantly improve profitability.

It is KBR's view that the use of "big data" and predictive analytics perfectly complements the well-established first principle modeling approach to data analysis and advisory. Traditional first principle models are ideally suited for estimating current process and equipment health based on real-time plant operations data as well as for conducting "what-if" analysis and process optimisation. Inherent or derived parameters such as exchanger heat transfer coefficients, compressor efficiencies, specific energy consumption, approach to equilibrium, catalyst activity, etc. are examples of parameters calculated periodically by these first principle models. On the other hand, predictive analytics and machine learning are excellent for early detection and identification of abnormal patterns and incipient issues that can lead to undesirable process excursions or equipment failure. This enables process technology experts to fully leverage their domain knowledge to establish a decision support system that could be used to help plant personnel to make informed short and long-term operation and business decisions.

One recent example of where KBR has investigated the use of advanced analytics and machine learning in an ammonia plant is in the prediction of "foaming" in the CO_2 absorption system. Foaming is typically caused due to the presence of fine particles in the circulating amine solution used for CO_2 absorption. Excessive foaming can cause reduction in absorption efficiency and result in sudden breakthrough of CO_2 which in turn can cause serious process upsets in the downstream units. Foaming is not a directly measured phenomenon. However, increase in pressure drops in the flash columns and/or the absorber columns can typically be used as early indicators of excessive levels of foaming. A data-driven model that utilises the flash column pressure drop as a leading indicator was developed by KBR to predict with almost 95% certainty when foaming could become a significant issue. These initial findings are extremely promising and validate the applicability of predictive analytics in ammonia plants.

From KBR's experience, combining process know-how with traditional mathematical methods and advanced analytics has given it the opportunity to provide trusted advisor mentorship to ammonia plant personnel. It has allowed it to adopt a three-pronged approach for achieving higher reliability of plant operations by simultaneously driving ammonia plant operations towards maximum production, minimum energy consumption and extended equipment uptime.

tkIS big data analysis in ammonia and urea plants

Although it is not the main aim of a fertilizer producer to control the plant via a smartphone, it does offer at least the possibility to access the plant data from outside in order to check the plant status and to provide recommendations to the operators inside the plant.

The same plant data that is being accessed by a producer as a selection on a mobile device could also be transmitted as a whole to a process licensor like thyssenkrupp Industrial Solutions (tkIS), who can use its detailed and deep technology know-how to run an analysis on the plant data to generate a detailed report about the status of the plant. Such a report would give recommendations to the fertilizer producer with the target to improve its reliability, to increase the production or to improve the efficiency (e.g. energy and water consumption) of the plant.

tkIS can offer several options to run the data analysis for industrial plants (see Fig. 1). One possibility would be a detailed plant process simulation (e.g. Aspen Plus®) which takes the swarm of process data from the plant as an input and the simulation is fitted afterwards iteratively to the actual plant status ("digital twin"). By such a simulation-based analysis the necessary recommendations for the plant producers are derived. Such an approach is called "white box modelling".

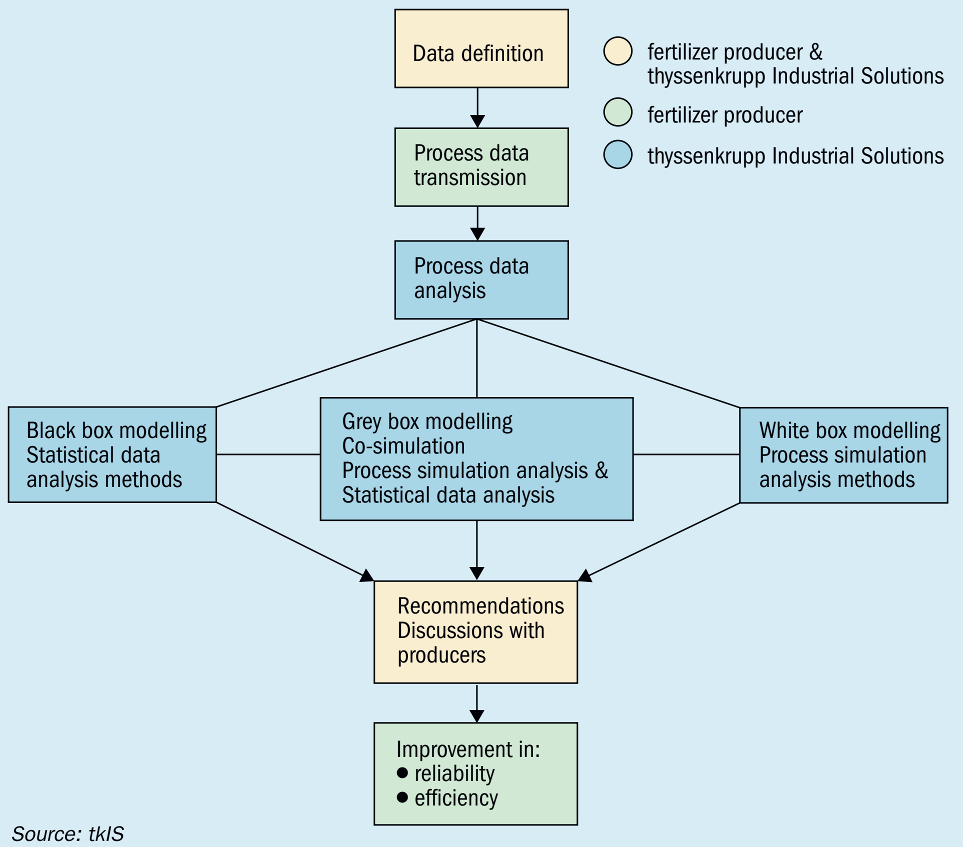
Alternatively the plant data analysis can be carried out without any deeper process knowledge. Based on statistical methods variate interdependencies between plant parameters are derived which can be used to detect abnormalities or potential optimisations. The same targets in terms of efficiency and reliability are also used in this method, e.g. to find the decisive parameter which might cause a plant trip and to prevent it. Such a behaviour analysis of the plant is called "black box modelling" since the detailed process steps inside the plant are irrelevant for the analysis itself.

A third possibility to run a plant analysis would be a co-simulation, which is a combination of the white and black box modelling approaches. A detailed plant simulation would be set up and for data fitting purposes to match the real-time plant data, statistical methods can be used. The results are transferred back into the process simulation. Such an approach is called "grey-box modelling".

Fig. 2 shows a simulation and information cycle during a digital plant analytic process.

To run a precise and fast analysis based on submitted plant data, it is important to

Fig. 1: **Modelling methods for plant data analytics**



Source: tkIS

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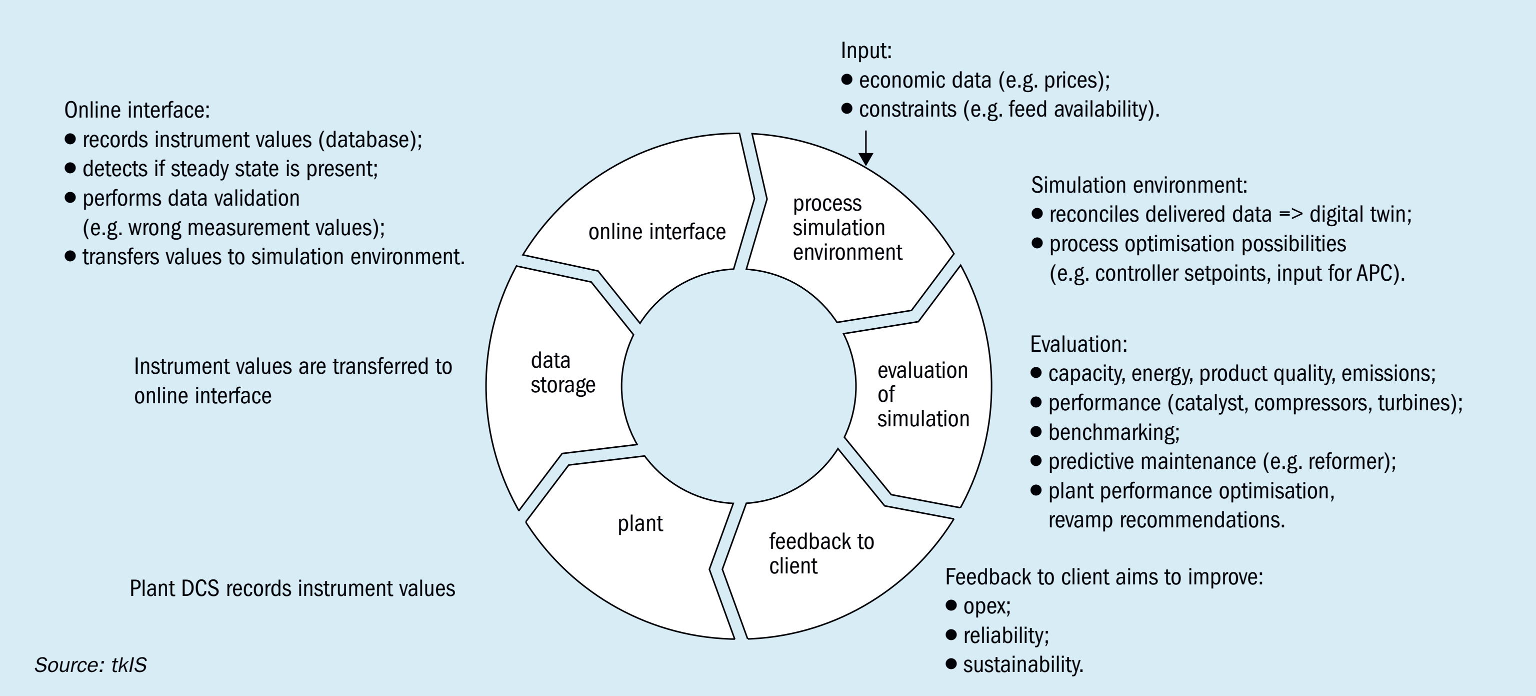
Fig. 2: **Simulation and information cycle during digital plant analytic process**



Source: tkIS

first prepare the data. This is done in the data storage itself, e.g. on a server run by the process licensor. The data are transmitted there via an online interface and then validated in terms of the detection of wrong values and the presence of steady state conditions. Afterwards the data is transferred to the analytical environment, where it is also possible to analyse the data in relation to outside economic influences and constraints.

A higher frequency of the same or at least similar analysis steps would make the analytic system more and more intelligent. In this way, so-called neuronal networks can be built, which derive data connections on a further advanced level by self-learning.

The collection and transmission of data from the plant to the process licensor, is preferably carried out online but can also be done offline. Online means the data is transferred via a secure one-directional data connection from the IT infrastructure at the plant into a data collection system at the facilities of the process licensor. Nowadays such big amounts of data are typically collected in clouds, offering all parties similar secure access.

Alternatively the process data are transmitted offline from the plant to the process licensor. The data is extracted from the plant control system via scripts into a database format and transmitted afterwards to the process licensor via e-mail or manually, e.g. by a USB device. The disadvantage of such an offline approach is that only a delayed discrete analysis is possible. Compared to online analysis with continuously submitted data, the offline analysis is slower and less accurate due to the risk of outdated data. Furthermore the offline approach requires more effort in terms of collecting and submitting the data. On the other hand any IT security thoughts are virtually non-existent with the offline approach.

For the analysis itself, in general the resolution of the plant data should be as high as possible. It is not required to collect all plant parameters in a one second interval, but at least for selected data sets this should be possible. In order to achieve the high data resolution with the offline approach the history function in the plant control system should offer this possibility. Normally the data resolution goes down once it is stored for history purposes in the plant control system. To achieve the required high resolution, data has to be collected on a daily basis.

tkIS has gained experience in the field of data analysis within several industries, e.g. morphylane and polypropylene production facilities with good results for the customers, who were able to solve their problems and improve their plant performance and output.

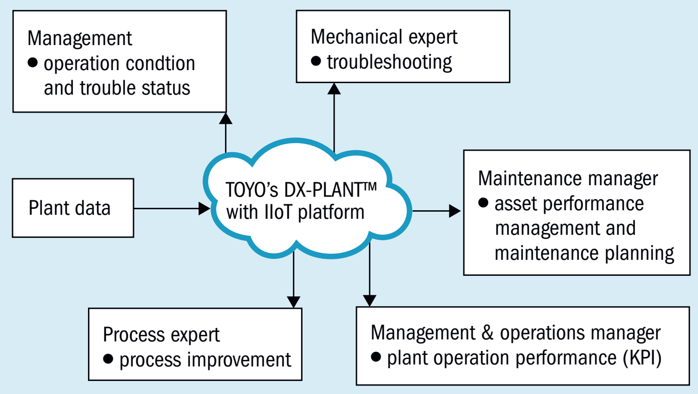
For ammonia/urea complexes the approach is similar and the method has been successfully tested for a reference plant in Egypt. Based on the positive results, tkIS is continuing to offer its services for process data analytics to its customers and also for external technology ammonia/urea plants in the near future.

TOYO's digital solutions for the fertilizer industry

Toyo Engineering Corporation (TOYO), a global leading engineering contractor and urea process licensor, has been developing and applying information technology (IT) to assist plant owners to achieve optimum operation and less maintenance since the 1990s. TOYO has developed several advanced technologies to assist with plant operation and maintenance, such as its remote plant management system (RPMS), operation training simulator (OTS), advanced process control (APC), life cycle management system (LCMS) and risk based inspection / risk based management (RBI/RBM). These technologies improve plant on-stream factor, reliability and utility consumption, and automate plant operation and routine analysis, but due to technical limitations with regard to the transfer of data, data storage and analytical work via the internet, until now these technologies have been offered independently without any cross correlation between them.

In November 2016, however, TOYO and GE (now Baker Hughes, a GE company – BHGE) signed a memorandum of understanding (MOU) for a joint project to explore digital solutions for the fertilizer and petrochemicals industry. Under this MOU, TOYO and BHGE are jointly developing a set of digital solution systems named "DX-PLANT™ (DX: Digital Transformation)" on GE's unique cloud-based platform for industry, Predix, using TOYO's expertise on processes and plant operations.

Fig. 3: **New way of business and role of TOYO's DX-PLANT™**



Source: TOYO

Fig. 4: **Phasing approach for DX-PLANT™/Fertilizer**

PHASE 1: PLANT INSIGHT

Digitalisation of plant for:

- Transferring data (through internet)
- Storing data (cloud and reliable security)
- Visualising data (access to web through various devices)
- Monitoring and advice by expert

PHASE 2: REALISATION OF DIGITAL TWIN

Digital transformation of plant for:

- Analysis of big data (AI: machine learning, deep learning)
- Optimising operation (OPM: operation performance management)
- Predictive maintenance (APM: asset performance management)
- HR management (field service management)
- Integration with ERP

Source: TOYO

GE already offers digital solution services in the field of aviation, power and healthcare, which are core business areas for GE, and has a strong track record in providing asset reliability solutions around the world, through advanced sensors, combination of data driven and physics based analytics, and troubleshooting expertise. However, to apply this technology to industrial plants, process knowledge and engineering know-how are essential for analysis of the data.

As shown in Fig. 3, with TOYO's DX-PLANT™, a large amount of data is transferred and stored in the cloud based platform on a real-time basis, permitting any person (e.g. management person, process expert), who has access to this system to monitor the current plant condition at any time and from any location in the world with devices like a PC, tablet or smartphone connected to the internet. In addition, a plant owner can communicate with TOYO referring to real-time data or past records to find solutions to issues that arise, and by being able to understand the plant status at a glance, management and operation managers can discuss future planning based on visualised key performance indicators (KPI). This feature will shorten the time required for root cause analysis (RCA) of problems and optimisation of operating conditions.

Phasing approach

TOYO is developing DX-PLANT™ using a phased approach as shown in Fig. 4.

The first phase "Plant Insight" (digitalisation) focuses on transferring and storing data in DX-PLANT™/Fertilizer for further development. The activities of the second phase, "Realisation of Digital Twin" (digital transformation) will be determined together with the owner according to their objectives.

Fig. 5 shows the DX-PLANT™ concept. DX-PLANT™ is an Industrial IoT (IIoT) system which improves plant profitability by continuous monitoring and analysis of plant operations and key performance indicators (KPIs) of industrial plants. Through DX-PLANT™ with this new approach TOYO provides four categories of service:

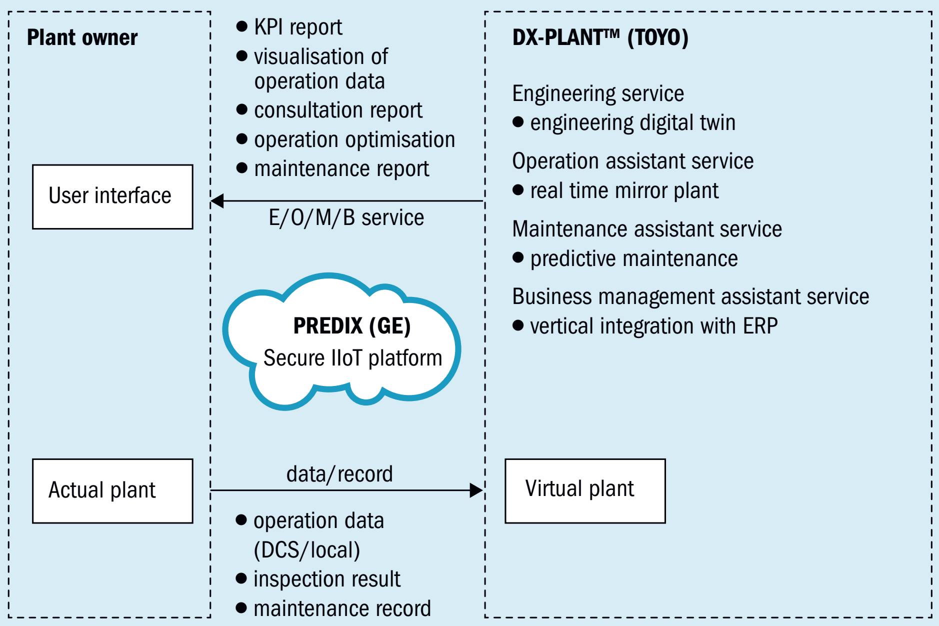
E: Engineering information sharing and recording

TOYO owns all of the engineering information such as 3D models, equipment datasheets, and process data in order to design and construct an actual plant. 3D models with such engineering information will be used to create a virtual plant in DX-PLANT™. This virtual plant also stores operation and maintenance historical records. The integrated storage of engineering, operation and maintenance information in a virtual plant will enable quick and easy access to the related information from any location.

O: Operation assistant service

DX-PLANT™ provides visualisation of KPIs and operating data. Users can monitor the plant condition at a glance from any location because KPIs and status diagnoses are displayed on the refined dashboards after processing plant operating data using the licensor's application. Automatic operation guidance service for process optimisation is also provided. Suggestions to correct or improve the operating

Fig. 5: **New digital solution architecture**



Source: TOYO

condition is provided in real-time around the clock. In addition, Digital Twin modelled by a physical based static/dynamic simulator (white-box model) and big data analysis (black-box model) will be implemented in DX-PLANT™ to optimise plant operation for high performance.

M: Maintenance assistant service

The status of monitoring equipment is crucial to prevent unscheduled shutdown and damage of equipment. Real-time rotating equipment monitoring applications by machine monitoring system with predictive analysis system will help maintenance staff and operators to perform suitable maintenance activities at the appropriate time. In addition, DX-PLANT™ will offer real-time corrosion monitoring by actual measurement and corrosion simulation of key static equipment with alert functions to predict an abnormal condition. A risk based inspection/risk based management (RBI/RBM) approach for asset management will also be applied. These services enable maximum asset utilisation.

B: Business management assistant service

DX-PLANT™ stores the operation and maintenance information which is also essential in terms of plant management. Through the interface with the corporate management system such as enterprise resource planning (ERP), continuous integration between corporate and factory management can be established.

Table 1: **PUSRI-IIB project profile**

Plant owner:	PT Pupuk Sriwidjaja Palembang
Plant capacity:	urea 2,750 t/d (prill urea)
Location:	Palembang, Indonesia
Urea process:	TOYO ACES21®
Project scope:	EPCC Turn-key lump sum
Contractors:	REKIND: ammonia unit and associated utility and offsites TOYO: urea unit

Source: TOYO

The introduction of DX-PLANT™ to all plants owned by a company would enable global optimisation. That means DX-PLANT™ can offer corporate level real-time feedback and help users to make more appropriate decisions.

DX-PLANT™/Fertilizer in PUSRI-IIB

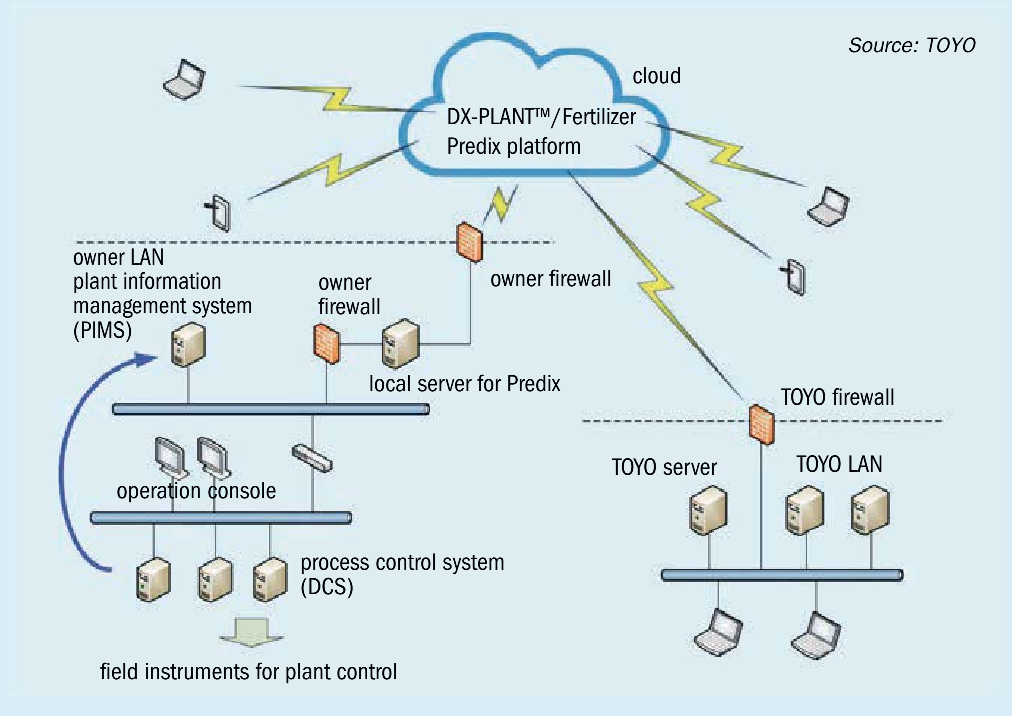
As a first step towards DX-PLANT™, in December 2017 TOYO launched DX-PLANT™/Fertilizer for a 2,750 t/d urea plant (PUSRI-IIB) owned and operated by PT Pupuk Sriwidjaja Palembang (PUSRI) in Palembang of South Sumatra, Indonesia which is a subsidiary of state-owned Indonesian fertilizer company, PT Pupuk Indonesia. Table 1 provides a project profile of the PUSRI-IIB urea plant.

Fig. 6 shows the DX-PLANT™/Fertilizer configuration that has been applied at PUSRI-IIB. Plant data from the process control system are stored by the plant information management system (PIMS) in OWNER LAN and the data are transferred to DX-PLANT™/Fertilizer on the Predix platform. The TOYO server in TOYO LAN collects the required data for data processing at the licensor's application and provides the licensor analysis output to DX-PLANT™/Fertilizer. Any user at any location with internet connection can access DX-PLANT™/Fertilizer.

The phasing approach described earlier and shown in Fig. 4 was applied to the PUSRI-IIB project and service for phase 1 was implemented in DX-PLANT™/Fertilizer in terms of the EOMB concept. In addition, the foundation for integration with ERP as B service has been prepared for phase 2.

A sophisticated dashboard design makes it easy for personnel to understand the conditions/status/required action at a glance.

Fig. 6: **DX-PLANT™/Fertilizer (PUSRI) configuration**



Future plan

The plan for the future is that once several plants are connected on the DX-PLANT™ platform, TOYO will establish a "Digital Solution Center" as shown in Fig. 7. The Digital Solution Center will consolidate the data and know-how of plant owners, licensors and manufacturers to provide maximum utilisation of the data and their know-how to users.

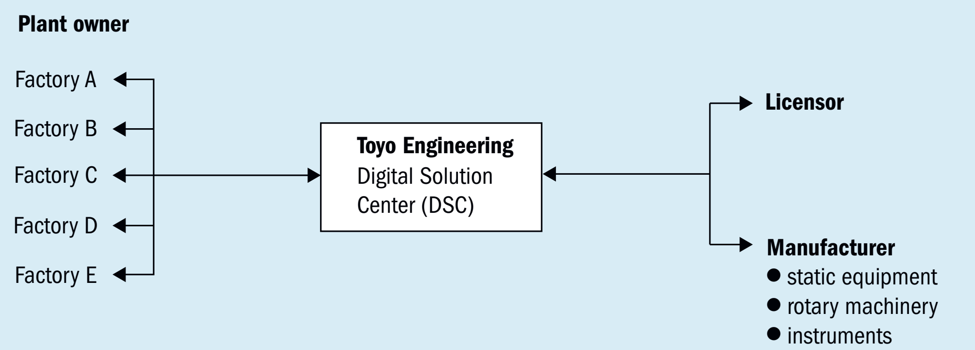
Currently, plant owners, licensors and manufacturers communicate with each or multiple parties to resolve any problems they face. To make it simpler, TOYO's Digital Solution Center will provide a common infrastructure to bundle communication channels, even between plant owners with the following functions:

Operation service

- Remote monitoring and technical assistance service: Based on the remote monitoring, technical assistance service will be provided for optimum operation.
- Dispatch supervisor: Supervisor dispatch will be timely arranged for smooth start-up or troubleshooting.

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

Fig. 7: **Digital Solution Center (DSC)**



Source: TOYO

Maintenance service

- Remote monitoring and technical assistance service: Based on the remote monitoring, technical assistance service will be provided for appropriate maintenance.
- Dispatch supervisor: Supervisor dispatch will be timely arranged for shutdown maintenance.
- Spare parts management: Global optimum spare parts management will be configured by storage share.

Business management

- Production plan and maintenance plan: Based on the remote monitoring, advisory service will be provided for owner's production plan and maintenance plan.
- Integration with ERP: Corporate level real-time feedback for appropriate decision will be achieved by the integration with ERP.

Casale remote engineering services

Casale has very wide experience with plants of many types thanks to its revamping activity. This experience is available to Casale clients through its customer care services, which is focused on continuous improvement through innovative techniques of plant operation, optimisation, maintenance and troubleshooting, all of which contribute to improving the reliability and durability of the plant.

CaRES (Casale Remote Engineering Services) is an innovative product which enhances the value of plant operating data by analysing and interpreting it, using sophisticated numerical techniques and Casale's proven simulation techniques. The benefits for the plant owner are:

receive better performance indicators for the whole plant and for single equipment items;

- receive operational advice from Casale experts on improving plant performance;
- prevent shutdown and equipment failures by early detection of malfunctions.

Implementation steps

The first step is to define the scope of the service. You can start by analysing a single section and scale up later to the whole plant. A Casale engineer will discuss the most relevant key performance indicators (KPIs) for the scope and help you decide on the essential Distributed Control System (DCS) tags that are required for the analysis.

In the next step, Casale will install a dedicated machine (called a "Node") at the plant site. The Node will be configured to read the selected DCS tags and will be granted read-only access to the DCS so that it will never interfere with DCS operations. The Node technology is compatible with 99% of existing DCS configurations.

The node will securely and automatically transmit the data to the Casale Data Center at a specified interval. Data security is crucial so Casale has selected the most mature technologies to encrypt and transmit the data via a dedicated VPN tunnel, keeping the client's infrastructure safe.

Casale remote plant monitoring

Casale remote plant monitoring (RPM) gives clients located in any part of the world direct connection with Casale experts by automatically sending full sets of operating data and receiving back reports on the monitored assets according to a defined schedule and list of contents. Fig. 8 shows how the flow moves between the client and Casale.

The key points and features of Casale RPM are:

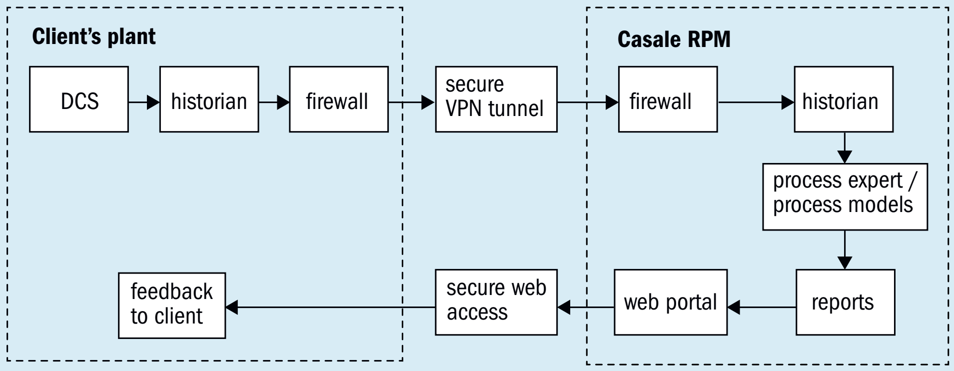
- plant historian: third party data base for plant data collection;
- secure data transfer: from plant to Casale;
- plant models: based on Casale proprietary knowhow and experience;
- Casale reports: analysis and comments on plant operations presented in an easy and smart way;
- web portal: secure access for client's process engineers.

The RPM is tailor-made according to the client's requirements and it will monitor parameters and specified assets such as:

- overall plant performance (KPIs, production, energy consumption etc.);
- section by section performance (such as reformers, shift, CO_2 removal, HP urea section, nitric acid reactors and scrubbers etc.);
- asset performance (main heat exchangers, rotating equipment, reactors, columns etc.)
- early warning indicators to anticipate performance deterioration and propose corrective action.

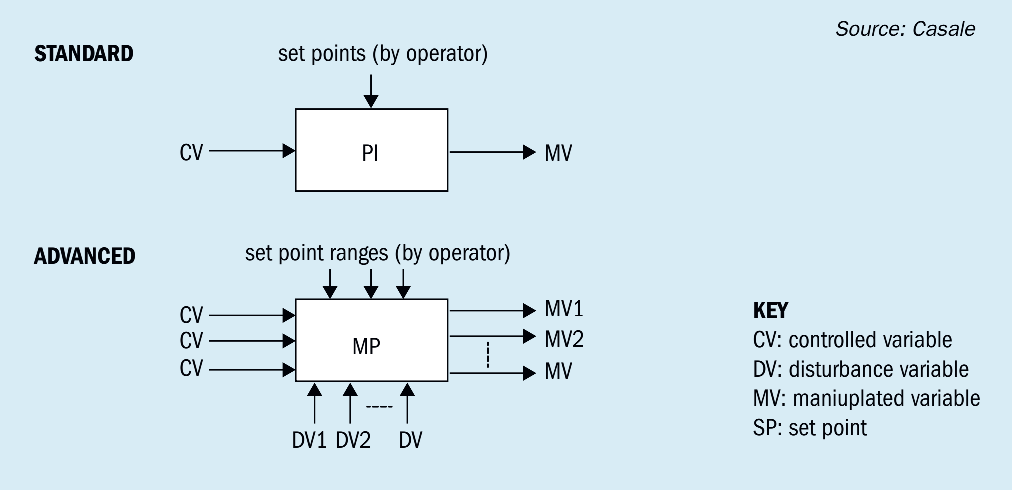
From time to time Casale will deliver reports with a summary of the plant/section/equipment performance and recommendations on process operation.

Fig. 8: **Casale Remote Plant Monitoring information flow**



Source: Casale

Fig. 9: **PID vs MPC controller**



Casale model predictive control

With the collaboration of Rockwell Automation, which provided the calculation engine and interface with DCS, Casale can now propose a model predictive control (MPC), tailor-made for the fertilizer industry, a real-time advanced control system to improve plant performance.

MPC continuously calculates the optimum set point of a number of chosen variables to keep the plant performance at the maximum at all times.

In other words, MPC pushes the process out of the comfort zone of the plant operators and as close as possible to optimum performance, while always respecting all the operating constraints (process and mechanical safety, etc.).

MPC manipulates more than one variable, allows a better and faster process optimisation than a standard PID control loop, see Fig. 9.

Casale MPC is based on a rigorous process model (designed by Casale), implemented in advanced software with an empirical model (provided by Rockwell Automation); in this way, the resulting hybrid model predicts and anticipates plant response in a large range of cases.

Johnson Matthey remote plant monitoring and optimisation

Johnson Matthey (JM) provides a remote monitoring and optimisation service which ensures catalysts are operated optimally, in such a way as to maximise production whilst achieving the required catalyst life.

In the past, this type of work was data intensive and relied on the manual exchange of data between customer plant personnel and JM technical support engineers. As a result, the frequency of data analysis was limited and support was largely reactive. With technological advances, remote plant monitoring has enabled JM to offer an enhanced automated support allowing JM engineers access to agreed plant operating data through an automated, digital, method of data transfer. With this enhanced level of support this enables up-to-date plant information to be analysed on a regular basis.

The data transfer and analysis integration system consists of an IT infrastructure, which allows the secure digital transfer of selected plant data to JM (Fig. 10).

There are many reliable and secure system arrangements for information exchange, typically if the plant historian is open platform communications (OPC) compliant, fully automatic data transfer can be set up via a secure virtual private network (VPN) link, alternatively batched data can be transferred using a file transfer protocol (FTP) with appropriate firewalls to ensure secure and reliable data transfer. Other data transfer techniques are available and JM has solutions that allow the transfer of data even with plants that have the most stringent levels of internet security.

In all cases JM engineers can only access the specific data supplied by the customer. Access to the customer's plant server is not required. Fig. 11 is a schematic demonstrating how data flows from the plant with feedback following detailed analysis by JM.

Always a key area of interest in monitoring performance is to understand trends and evaluate their meaning – in respect of catalyst performance monitoring this means understanding whether the catalyst deactivation is as expected or "normal", such as caused by expected sintering/ageing or something unexpected "abnormal" has occurred possibly poisoning or a wetting incident.

By access to a more complete digital dataset JM can better understand catalyst behaviour and this can lead to higher quality advice in terms of optimising performance.

Typical benefits of this enhanced support include improved catalyst performance analysis enabling more reliable remnant life estimates, early detection of any step-change in performance, e.g. impact on catalyst activity or pressure drop due to fouling, poisoning, wetting, etc., as well as early identification of optimisation opportunities.

Automatically, JM runs full plant data reconciliation models and then follow this with optimisation routines which optimise the operation of both the front-end units and methanol or ammonia synthesis loops.

To illustrate an example of what can be done remotely, consider the unit operation of shift conversion in the front-end, the aim is to minimise CO slip from the CO conversion section.

Looking at high temperature shift (HTS) operation within the ammonia plant, the measurement dataset that would typically be received from the customer would be:

- inlet temperature;
- inlet pressure;
- exit temperature;
- exit gas analysis;
- shift bed temperature profile;
- shift bed pressure drop.

Fig. 10: **Example of digital data transfer**

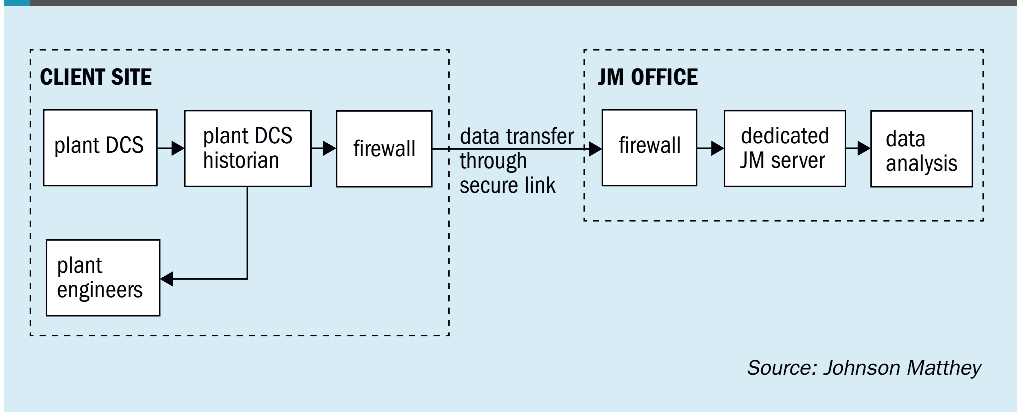
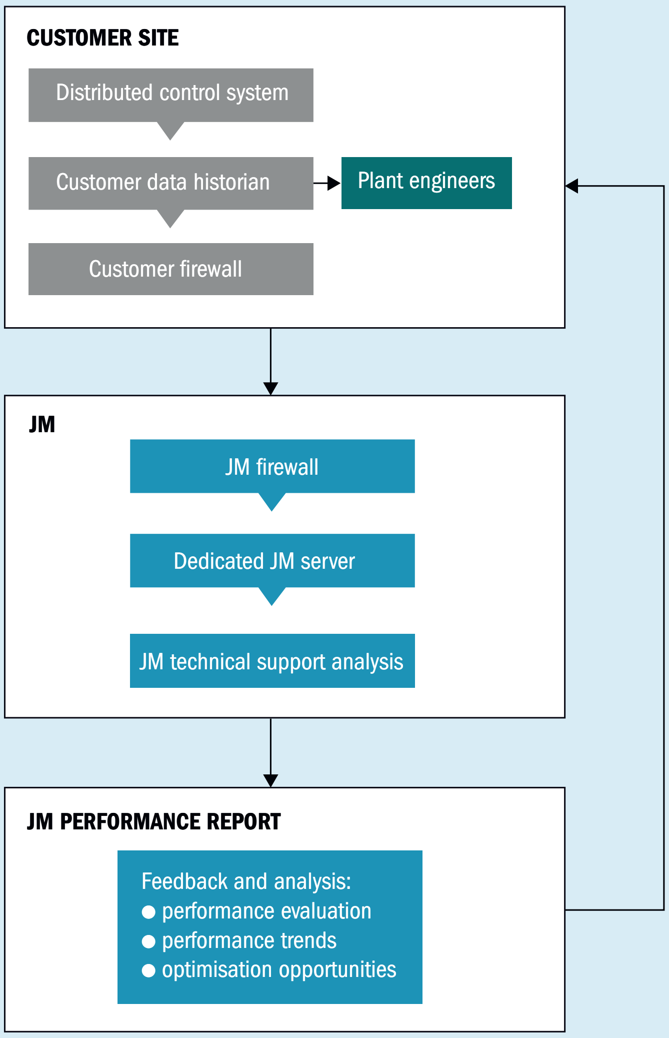
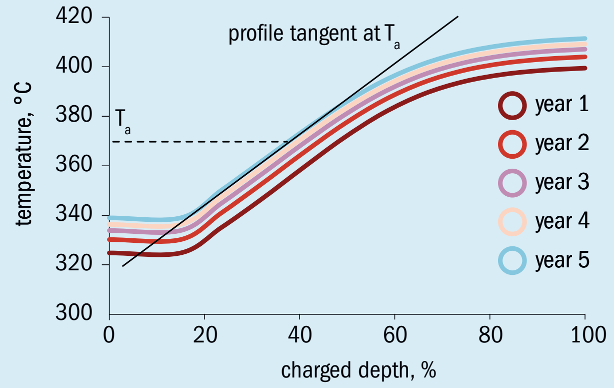


Fig. 11: **Example of data flow analysis and feedback loop**



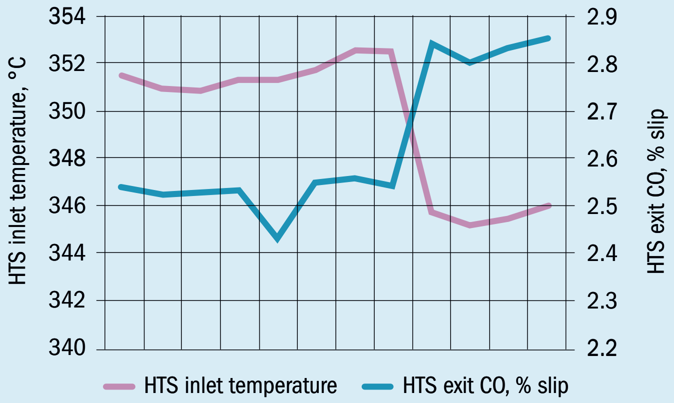
Source: Johnson Matthey

Fig. 12: **HTS data analysis output via remote monitoring**



Source: Johnson Matthey

Fig. 13: **HTS optimisation via remote monotoring**



Source: Johnson Matthey

Within the performance evaluation and optimisation routines, JM automatically models the HTS using kinetic data for the shift reaction simulating the composition and temperature profiles through the bed adjusting factors relevant to actual performance based on fitting to the measured temperatures and exit gas analysis (Fig. 12).

From the corrected measurements, the following data are calculated:

- exit steam:dry gas ratio;
- exit gas flow;
- water gas shift equilibrium temperature;
- water gas shift approach temperature;
- CO conversion;
- temperature profile through bed;
- CO profile through bed;
- options for optimisation of CO.

The data in Fig. 13 of HTS optimisation via remote monitoring shows how JM is able to help customers operate catalysts more efficiently. A recommended increase of HTS inlet temperature of 5°C, resulted in a 10% reduction in CO slip.

This case study illustrates a small example of an optimisation function that can be achieved remotely.

The models built for the plant are complex and by working with customers interested in remote monitoring JM is able to develop solutions that are bespoke with optimisation and reporting routines agreed across unit operations, for the whole plant including loop converters, with the aim of maximising total production.

Haldor Topsoe's online solutions

Haldor Topsoe is combining its experience as a technology licensor, catalyst supplier, and provider of technical services as it moves toward supplying cloud-based digital services for its customers. In order to obtain full value of such digital services, as much plant operating data as possible should be available for upload. In most plants the transmitter data can be retrieved from the plant historian, and the laboratory data is available from the laboratory management information system (LIMS). However, for technologies based on steam reforming, the important tube wall temperatures (TWT) measurements are normally obtained by IR pyrometry, and thus not directly available for automatic upload. In order to address this issue, Haldor Topsoe has already introduced two solutions; TrueTemp™ and Topsoe Furnace Manager (TFM). TrueTemp™ is an online application that works together with regular IR pyrometers, which easily bring the TWT measurement online and carry out the required corrections of the raw measurements for background heat radiation. TFM, on the other hand, to a fully automatic imaging system that continuously measure and survey the tube temperatures and burner status in the steam reformer or any other furnace, thus upgrading the steam reformer to be safely and efficiently monitored both from the control room and by cloud-based algorithms. After having introduced these solutions for TWT and burner overview in steam reformers, Haldor Topsoe will continue to develop and launch additional online solutions targeting larger parts of the plant.

XSIGHT digitalisation providing new value for customers

The current oil and gas business scenario is characterised by the utmost attention to environmental issues, a constant desire for lower capex and opex, and at the same time, the continuous search for new products and innovative processes that are more competitive in an extremely challenging market and which can better address global environmental and energy issues.

In this complex environment, major contractor Saipem is following a digitalisation roadmap to improve its efficiency and provide new digital services.

In the context of industry 4.0, given its experience in process technologies, XSIGHT a Saipem Division, is developing predictive analytics methodology to provide decision making support for owners of operating plants, allowing better productivity and better planned maintenance to cut costs and reduce unforeseen plant and equipment shutdowns, resulting in shorter and fewer plant stoppages.

This innovative methodology, based on data science, machine learning and artificial intelligence techniques (such as supervised learning, unsupervised learning, reinforcement learning, etc.), has been conceived for the analysis of plant operation and maintenance data and to make analytics in order to predict future events (e.g. to predict when an asset failure might occur) and/or to ensure process/energy optimisation and/or to improve product quality. In addition this methodology allows the easy management of huge quantities of data.

The services offered by XSIGHT are based on the experience of over 60 years accrued during the realisation of mega projects and the innovative methodology of performing services to take advantage of the huge database available.

Using data science visualisation tools and neural networks prediction capabilities, it is possible to analyse huge amount of operating data in a short time frame (reducing engineering man-hours by 80%). Moreover, the neural networks are designed and trained to predict equipment performance with a very high level of accuracy.

These results are achieved by integrating the engineering competences of XSIGHT with data science and machine learning, based on a complete plant overview.

In a case history the neural network was set up together with a decision tree machine learning algorithm after a clustering application, and the outcome allowed the cause of abnormal operating conditions to be identified, allowing preservation of the asset value and avoiding potential equipment damage and/or loss of production.

Two main functionalities were considered: predictive maintenance and an abnormal condition identification tool.

The predictive maintenance tool allows the prediction of when and how equipment will fail due to abnormal plant conditions. The same approach used for the case study needs to be generalised for different kinds of equipment using dedicated machine learning algorithms.

The abnormal condition identification tool automatically identified abnormal plant conditions (operational misuse of manual valve) and the related variable sensors. For the case study mentioned, this part was done by a customer but in general in a plant it could be useful to anticipate any abnormal condition and solve the situation before it escalates.

This methodology approach allows both predictive and retrospective analyses; for this case a retrospective approach was implemented to verify what had been done with the manual traditional approach that did not ensure sufficient evidence. The predictive analysis is also useful for comparing the weight of variables in a short time, facilitating root cause analysis and other applications in term of predictive maintenance.

In general, a predictive analysis is aimed at predicting a future event or condition based on past trends and current system state. The object of the prediction could be an item malfunction event, which makes the item unavailable causing plant down-time (if the item is critical for production) or an abnormal plant condition such as high vibration, high temperature etc.

In this way, XSIGHT can bring value to operations and maintenance data, by supporting customers to achieve their business targets. In future, these data could also be collected in XSIGHT Smart Object allowing customers to benefit in the design phase in a collaborative digital space. Smart Object is an intelligent data repository with its proper representation in 3D virtual space that evolves its attribute during the different phases of project definition. In this environment XSIGHT engineers as an expert librarian, put the right volume (attributes) in the right shelf (data model) for each smart object to cover the entire project lifecycle and the customer can monitor each project phase.

With this approach, data is not organised in a document-centric way, rather it is data-centric, where a single source of "truth" is ensured and deliverables are printouts of data from the data model.

With the digitalisation process operations and maintenance data are linked with each smart object in conjunction with design data, and using predictive analytics new correlations can be found.

In conclusion, XSIGHT is offering the oil and gas industry overall complex configuration assessments performing technologies and using linear programming modelling to optimise plant size and configuration; a discussion on how raw material costs, product price and demand as well as capital expenditure could be managed to come to an optimised configuration which would also minimise EPC phase challenges; definition of EPC value during FEED: assessment of factors impacting on EPC project costs and how they could be managed during early project definition phases through the using of smart object.

In addition, XSIGHT is developing predictive maintenance services – continuous process monitoring using big data analytics, artificial intelligence and machine learning techniques are being launched. Cognitive computing will also be used as a further layer of design verification to improve the quality and effectiveness of the human labour force. ■

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Delivery of Clariant-Hydrogenious Technologies liquid organic hydrogen carrier.

Clariant building on innovation and partnerships

In May, 2018 *Nitrogen+Syngas* was invited to meet with Stefan Heuser, Senior Vice President & General Manager, Catalysts and Marvin Estenfelder, Head of R&D at Clariant's Business Unit Catalysts to learn more about Clariant Catalysts' latest developments, global strategy and ambitions to become a China Insider.

Clariant Catalyst is an independent catalyst manufacturer with a broad portfolio and technology partnerships with multiple leading technology providers.

Clariant Catalysts' strategy for growth focuses on the following main principles:

- maintain innovation leadership;
- strengthen licensing partnerships and customer focus culture;
- execute specific growth strategies for key regions;
- operational excellence;
- creating value through sustainable products and services.

A China insider

World chemical sales are dominated by China and Clariant has ambitions to become a China insider. Although the Chinese economy is slowing down it is moving towards stabilisation and undergoing structural change. The Chinese economy is transitioning to a 'new normal', i.e. real GDP growth of 6 to 7%.

The Chinese 13th five year plan (2015-2020) targets 7% growth for the chemical and petrochemical industry with key focus on moving from traditional to value-added chemicals. Petrochemical integration will result in decreased refinery capacity and the development of high end products, there will be a shift from commodity chemicals to the development of the speciality chemicals industry and there will be a focus on creating self-sufficiency and promoting green technology.

Clariant Catalysts has had a presence in China since the 1970s. Over the past few years, Clariant Catalysts has taken decisive measures to continue to be a Chinese insider by improving its local footprint through local production and local R&D, strengthening local engineering, services and capabilities, maintaining and innovating portfolios for local needs, developing local partnerships, fostering local trends and local sustainability.

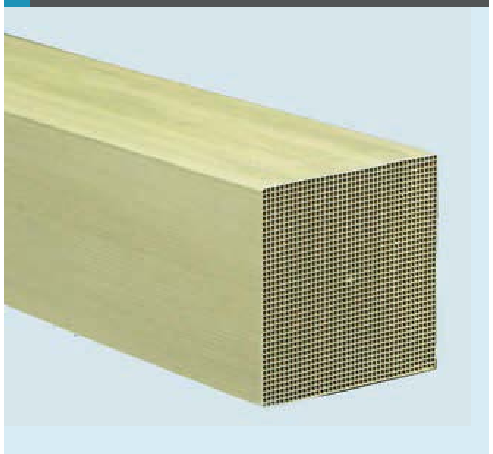
For example, to meet Chinese special requirements for the production of methanol from coal (feed contains iron), Clariant introduced the tailor-made combination of MegaMax® 700C and MegaGuard™ 700 for methanol synthesis. Launched in 2016, MegaGuard™ 700 is designed to protect methanol synthesis catalysts, such as the Clariant's MegaMax® series, from iron poisoning. The new catalyst guard effectively traps and decomposes iron compounds, thus ensuring that the MegaMax® series catalyst maintains its exceptional activity and selectivity throughout its long lifetime.

In China, Clariant Catalyst currently has four offices, more than 200 employees and a single digit number of local licensing partners. By 2022, these figures are expected to grow significantly. In addition, Clariant Catalysts will strengthen and enlarge its laboratory space in China and co-operation agreements with various Chinese universities and institutes.

Meeting sustainability challenges

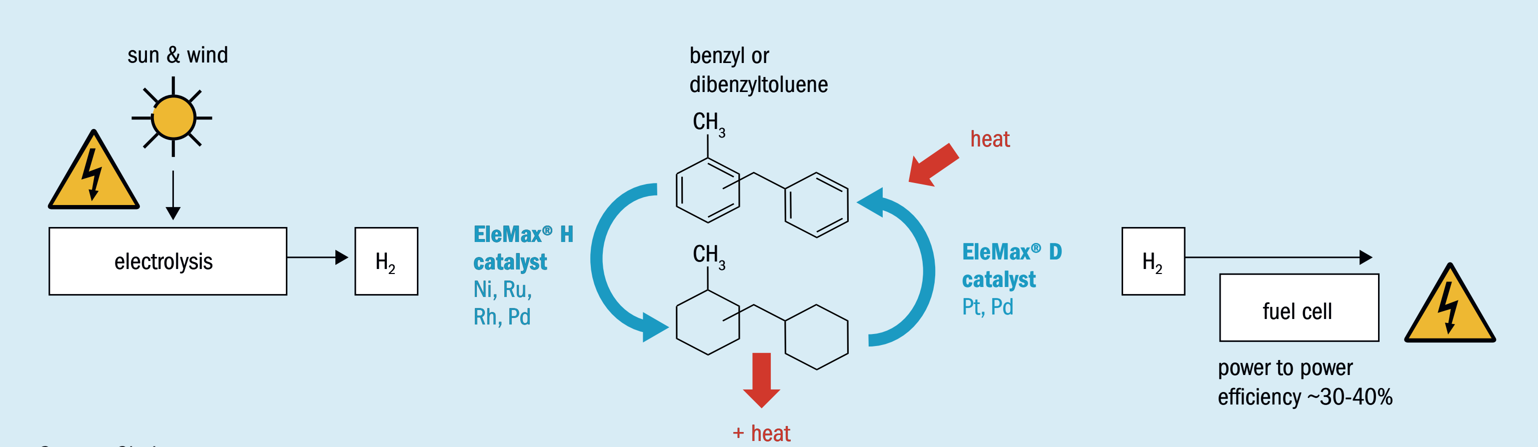
Catalysis is helping to meet today's global sustainability challenges such as: growing GDP, linked to resource use and consumption; air pollution, the cause of premature

Fig. 1: **EnviCat® NOx SCR catalyst, an extruded honeycomb structured block**



Source: Clariant

Fig. 2: **Liquid organic hydrogen carrier (LOHC) – *the* solution for efficient H_2 storage and transport**



Source: Clariant

deaths; and energy transition, moving from the current energy system that uses non-renewable resources and produces GHG emissions to a future energy mix that generates an increasing share of energy from renewables (wind, solar) and bioenergy (biofuels, biogas).

Meeting NOx reduction targets

Clariant recently announced the expansion of its EnviCat® series of catalysts to include a high-performance solution for selective catalytic reduction (SCR) to combat nitrogen oxides (NOx). The EnviCat® NOx SCR catalyst, an extruded honeycomb structured block made from a vanadium based composite (Fig. 1), is designed to facilitate NOx reduction reactions in an oxidising atmosphere. With high selectivity, EnviCat® NOx significantly decreases NOx levels using ammonia as a reducing agent for the conversion of NOx pollutants into nitrogen and water. EnviCat® NOx SCR has been demonstrated to effectively lower NOx emissions from gas fired exhaust streams and is well suited to a multitude of chemical and industrial applications, such as steam methane reformers and nitric acid plants.

NOx consists primarily of nitric oxide (NO) and nitrogen dioxide (NO_2), of which NO_2 is listed as one of six criteria air pollutants under the Clean Air Act by the US Environmental Protection Agency. The product of fossil fuel combustion and industrial processes, NOx contributes to the formation of smog, ground level ozone, acid rain, and other hazards. The effect is significant and harmful to the environment, wildlife and human health. In particular, results of studies suggest that through the formation of pollutant particles penetrating into the lungs, NOx can aggravate or even cause respiratory diseases such as emphysema and bronchitis, among other serious health conditions.

Fig. 3: **LOHC installation – easy and safe hydrogen storage**

The largest output of NOx emissions from non-automotive, stationary sources emanate from coal fired boilers, especially those in power generation. Petrochemical processes also produce large amounts of NOx, originating from utility boilers, cogeneration units, process heaters, steam methane reformers, ethylene cracking furnaces and fluid catalytic cracking (FCC) regeneration units. Other major sources include kilns and furnaces from the cement, lime, ferrous and non-ferrous metals industries.

"Clariant is delighted to be able to offer this important addition to our catalyst emissions reduction portfolio," said Stefan Heuser, Senior Vice President & General Manager, Catalysts. "Not only is the technology highly effective in mitigating the dangerous effects of NOx, it now enables us to provide our customers with cost-effective emissions solutions for both upstream and downstream businesses."

EnviCat® NOx SCR is available in module designs of varying lengths and cell densities, is easily installed and can be configured to the particular dimensions of the plant. The catalyst reduces emissions while effectively controlling ammonia slip under low to mid temperature operation.

Hydrogen storage and logistics technology

With the focus on meeting future sustainability challenges for energy, Clariant announced that it has formed an alliance with award-winning clean energy company, Hydrogenious Technologies, to provide reliable, scalable and safe hydrogen supply solutions for a wide variety of applications.

Hydrogen from renewable energy sources, such as wind and hydro power, has long been recognised as a more efficient and more environmentally friendly fuel. However, fluctuations in weather conditions necessitate cost-effective, large-scale storage in order to ensure a steady supply of electrical energy. Moreover, hydrogen's very low density, high flammability and extreme volatility present significant challenges to both storage and transportation. Conventional storage methods typically involve either physical compression (200-700 bar) or extreme cooling (-253°C) of hydrogen, both of which are energy intensive and carry significant safety risks.

In what has been a major leap forward, Hydrogenious Technologies, has developed a highly innovative means of transporting hydrogen by chemically binding the molecules to liquid organic hydrogen carriers (LOHC). In the unique method, hydrogenation of the liquid organic hydrocarbon dibenzyltoluene via Clariant's EleMax® H catalyst allows hydrogen to be 'stored', while its dehydrogenation with EleMax® D catalyst 'releases' hydrogen on demand (see Fig. 2). The highly active Clariant catalysts are designed to offer exceptional selectivity for loading and unbinding hydrogen in order to optimise the life-cycle and efficiency of the LOHC.

Non-explosive, non-toxic and of low flammability, the diesel-like hydrogen-bound compound is not classified a hazardous good, and remains in a useable and convenient liquid state through a broad temperature range of -39°C to 390°C at ambient pressure. These factors allow considerably easier installation (Fig. 3) at industrial locations as well as commercial and public fuelling sites, even in close range of or within residential areas. It also provides the handling flexibility required to enable the widespread roll-out of hydrogen production from renewable power sources (power-to-gas).

Hydrogenious Technologies' revolutionary solution and Clariant's specialised catalysts now present a safer, more efficient alternative for storing and transporting very large amounts of clean hydrogen from renewable source to enable emission-free mobility and cleaner industry processes. First commercial scale units in operation for example at United Hydrogen Group (Tennessee) confirm the expected technical and economic attractiveness. Clariant will continue to further broaden the applicability and efficiency of this advantageous technology offered by Hydrogenious via catalyst research and expertise.

Marvin Estenfelder, Head of R&D at Clariant's Business Unit Catalysts, welcomed the alliance, stating, "We are delighted to partner with Hydrogenious Technologies in the evolution of renewable energy and global efforts for sectoral integration. The successful development of dedicated catalysts for LOHC technology is not only testament to Clariant's pioneering capabilities, but also reflects the importance of sustainability to our culture, operations, and as a driver for growth and innovation."

Daniel Teichmann, CEO at Hydrogenious Technologies, comments, "As an innovation driven company, Hydrogenious Technologies goes hand in hand with Clariant to provide the energy sector with sustainable energy and mobility. The partnership with Clariant is not only a 'catalyst' for the LOHC technology, but also an acceleration of our mission into a decarbonised world with an economic and ecological hydrogen approach. It is a further step towards our vision to make the much discussed hydrogen economy a global reality." ■

Sustainable ammonia for food and power

Technologies for small ammonia plants are becoming increasingly important as ammonia production is moving toward more sustainable and renewable feedstocks. As the availability of these feedstocks cannot match that of fossil fuels, small and distributed plants are required, as well as dedicated technical solutions to match new and unconventional needs.

Climate change and pollution are the undesirable consequences of a growing world population, increasing wealth and the desire for protein. They are also the cause of diseases, loss of arable land and extreme weather events – also caused by the increase of carbon dioxide (CO_2) in the atmosphere. Because of this, world leaders have announced drastic CO_2 reduction targets at world climate conferences. In order to reach lower CO_2 emission targets, nations have established incentive programs for a renewable energy sector to substitute fossil fuel-based energy production by renewable energy production. The renewable energy market is politically supported because of the CO_2-free production of electric power combined with high acceptance amongst stakeholders. Some countries have gone one step further and have introduced CO_2 taxes. This trend for "green" energy is growing uninterrupted. Specific capital expenditure (capex) for wind and solar energy systems has been decreasing for years and these systems are also becoming more efficient, resulting in a constantly declining energy cost. These are the facts, which make renewable energy interesting, not only for power, but also for other applications such as fertilizer production.

Ammonia from sustainable and renewable feedstocks

Modern ammonia production based on natural gas (NG) or coal has been optimised over more than 80 years. Specific energy consumption is close to the theoretical minimum and the economy of scale for plants with world-scale capacities of more than 3,000 t/d makes this process very cost competitive. However, the capital investment of these energy intensive plants is significant and so too is the high level of greenhouse gas (GHG) emissions that these plants produce.

Until recently the feedstocks for ammonia production were never questioned, but as ammonia production moves toward more sustainable and renewable feedstocks the ammonia market is facing a potentially radical change. The availability of new feedstocks at present cannot compete with fossil fuels, hence small and distributed plants are required, as well as dedicated technical solutions to match new and unconventional needs.

Looking to the future, in some regions it may become feasible to produce green ammonia, where hydrogen is produced from the electrolysis of water instead of steam methane reforming and nitrogen is provided by an air separation unit (ASU), for further processing into nitrate fertilizers or DeNOx fluid. The main drivers could be self-sufficiency, independency, substituting coal or natural gas due to more favourable electric power cost, avoidance of high logistic costs e.g. due to safety considerations or worse accessibility and avoidance of other costs such as fees, custom duties, import taxes or CO_2 taxes. Hence, it could turn out that localised production of a small quantity of ammonia in the direct vicinity of the consumer is an economically favourable option, despite the higher specific investment cost which naturally exists for a smaller plant.

Ammonia as an energy carrier

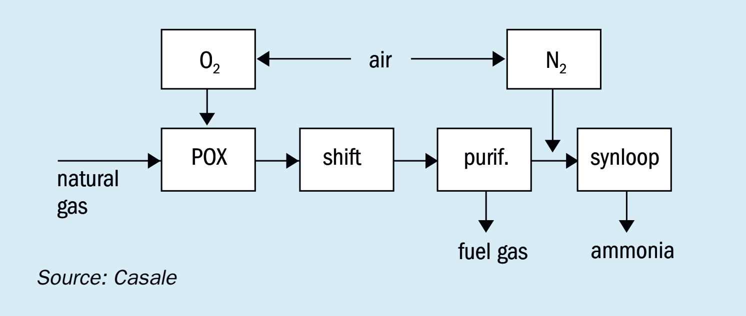
As the electricity system transforms towards a low carbon system, with the increasing deployment of variable renewable electricity sources in the electricity system, balancing supply and demand in the grids becomes increasingly challenging. By nature, intermittent renewable sources such as wind and solar are not always available. Therefore, fossil fuel-fired power plants currently have an important function in balancing the electricity system. In addition, the efficiency of renewable power plants is highly dependent on their location. To overcome this, proper energy storage and carrier solutions or other downstream applications have to be considered and developed. Hydrogen, SNG, methanol, redox flow batteries and ammonia have all been considered in the energy sector as potential energy storage and carrier solutions.

Ammonia is particularly promising as an energy carrier due to its relatively low cost, high energy density, and ease of liquefaction. Furthermore, infrastructure for international shipping of ammonia is readily available and it creates less safety concerns compared to hydrogen.

Benefits of using ammonia as a green solution for long term energy storage include:

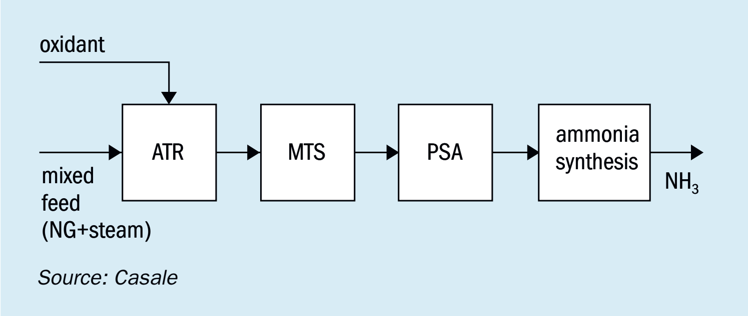
- utilisation of stranded energy sources (e.g. solar, wind, tidal energy);
- peak energy saving by flexibly producing NH_3 when excess available renewable energy cannot be put back in the grid;
- no CO_2 emitted when utilising ammonia or producing it from electrolysis;
- NH_3 has a 45% higher volume energy density than H_2;
- NH_3 is stored in inexpensive pressure vessels at ambient temperature (e.g. NH_3 is liquid @ 7,6 barg);
- NH_3 solves the long term storage issue as opposed to batteries that self-discharge after a short period of time.

Fig. 1: **Casale A60™ ammonia plant block flow diagram**



Source: Casale

Fig. 2: **Casale A600™ ammonia plant block flow diagram**



Source: Casale

Requirements for small ammonia plants

Small ammonia plant requirements are substantially different from those of world-scale plants. Typical requirements for small plants are to:

- minimise capital expenditure (capex) over operating expenditure (opex);
- simplify construction e.g. through modularisation;
- be amenable to reduced manning e.g. achieve a high level of automation.

Small ammonia plants are expected to be built in remote locations, where there is little if any infrastructure available, so plants must stand alone in an efficient way. For example, water consumption (for process cooling) should be minimised, as the plant may not be close to a water source. The specific requirements of small, decentralised ammonia plants also require special characteristics of the ammonia synthesis loop.

Casale small ammonia plant concepts

Casale experience in ammonia synthesis loops dates back to the first half of the 20th century, when Casale was the world leader in ammonia production. In recent years, Casale has delivered more than 200 synthesis loops, with capacities ranging from 50 to more than 2,000 t/d.

Casale proposes two concepts for small ammonia plants: the A60™, for plants with a capacity of up to 100 t/d, and the A600™, for plants in the range 300 to 1,000 t/d.

The synthesis loops of these two plant concepts differ to match their goals. In the A60™ concept, where the main goal is to minimise the number of equipment items, the synthesis loop runs at high pressure (above 200 bar). In this way, ammonia is produced at high concentration and easily condensed via water cooling or even air cooling. The refrigeration section is therefore avoided.

In the A600™ concept, on the other hand, a low-pressure synthesis loop is envisaged. The aim here is to simplify the plant as much as possible, while keeping the main compressors centrifugal for the benefit of reliability. A low-pressure synthesis loop increases the volumetric flow in the synthesis gas compressor, allowing the use of a more reliable centrifugal machine.

As shown in Figs 1 and 2, Casale's ammonia plant concepts were based on natural gas as feedstock but are also valid for alternative feedstocks i.e., bio-based feedstocks derived from wastes and green hydrogen produced from water via electrolysis.

Ammonia plants with bio-based feedstocks

Biomethane is a bio-based feedstock obtained from renewable energy sources. Depending on the basic organic matter employed, it can be first generation (organic waste), second generation (lignocellulosic biomass) or third generation (micro-algae).

Biomethane can be conveniently converted to syngas using Casale's A60™ or A600™ ammonia plant design, depending on the desired capacity.

In the A60™ concept, the feedstock is converted in the Casale proprietary partial oxidation (POX) reactor. Based on Casale advanced burner technology (Fig. 3), the use of POX allows soot-free operations even at very low steam to carbon ratios and with feed gas composition changes. Moreover, POX has a very low minimum turndown ratio, allowing stable operation down to 20% of the nominal load. These features of Casale POX enable the plant size to be minimised while ensuring high reliability and efficiency, as well as long burner life.

Pursuing the idea to simplify and reduce the number of units in the ammonia plant, A60™ foresees a single shift step (at high temperature) followed by syngas purification. The latter is carried out in a highly automated pressure swing adsorption (PSA) unit.

In the A600™ concept, on the other hand, the feedstock is reformed in a single step via autothermal reforming. Casale catalytic ATR uses the heat generated by partial combustion of the feed gas in a patented burner to generate syngas. The use of Casale ATR avoids the need for a steam methane reformer (SMR), greatly simplifying the plant and omitting the reformer stack flue gas, the main continuous source of atmospheric pollution of conventional plants.

Casale ATR assures superior mixing in the flame and a homogeneous gas distribution (both composition and temperature) at the catalyst bed surface, while keeping low pressure drops in both the oxidant and process stream. Moreover, the burner temperature is low, ensuring long burner life and high reliability of the unit.

Similarly to A60™, the water gas shift conversion is condensed in a single step. The technology chosen in this case is a medium temperature shift (MTS) converter,

Fig. 3: **Casale POX burner**

PHOTO: CASALE

which allows safe operation at steam to carbon ratios lower than conventional. Gas purification is performed via PSA, avoiding any solvent wash to remove carbon dioxide and providing a syngas suitable for the ammonia synthesis loop (i.e. no methanation is required).

Ammonia plant from water electrolysis

Casale technologies for the so-called back-end of the ammonia plant are well suited to plants based on hydrogen produced by water electrolysis. In these plants, a (catalytic) purification step is usually required to remove residual oxygen, before the hydrogen is suitable for ammonia synthesis. The nitrogen comes from either a PSA or from cryogenic separation and, after mixing with hydrogen, is compressed to the ammonia synthesis pressure.

As mentioned previously, the synthesis loop design adapts to the plant size. For small plants a high-pressure synthesis is envisaged, while for plants bigger than 300 t/d of ammonia the pressure of the synthesis is minimised. However, the most demanding feature of ammonia plants based on water electrolysis is handling the load variation. Casale has developed and proposes a patented method for protecting the ammonia synthesis loop from repetitive plant load variations.

In fact, repetitive variations of plant load can harm the ammonia synthesis loop. Operating the ammonia plant at a load considerably lower than nameplate capacity means that the amount of catalyst in the ammonia converter is in large excess. If the synthesis loop is run at full pressure at reduced load, the (excessive) catalyst volume will boost the reaction toward equilibrium, resulting in a high temperature of the product gas inside the converter. This higher temperature may exceed the design temperature limits of the material and result in damage to the internals.

A conventional solution to avoid overheating in the ammonia converter when operating at partial load is to reduce the operating pressure of the synthesis loop. In conventional plants, however, the frequency of load variation is very low. Conversely, in an ammonia plant based on water electrolysis, the load may vary frequently. If the pressure of the synthesis is adapted accordingly, this may result in stress fatigue of the synthesis loop equipment, eventually leading to ruptures.

Casale's solution to handle plant load variation consists of increasing the synthesis loop inert content when operating the plant at partial load. To do so, when the plant is operated at partial load the purge flow rate is reduced more than proportionally to the load reduction. Inert accumulation in the synthesis loop reduces the partial pressure of reagents in the converter, depressing ammonia conversion and avoiding overheating.

thyssenkrupp's green ammonia concept

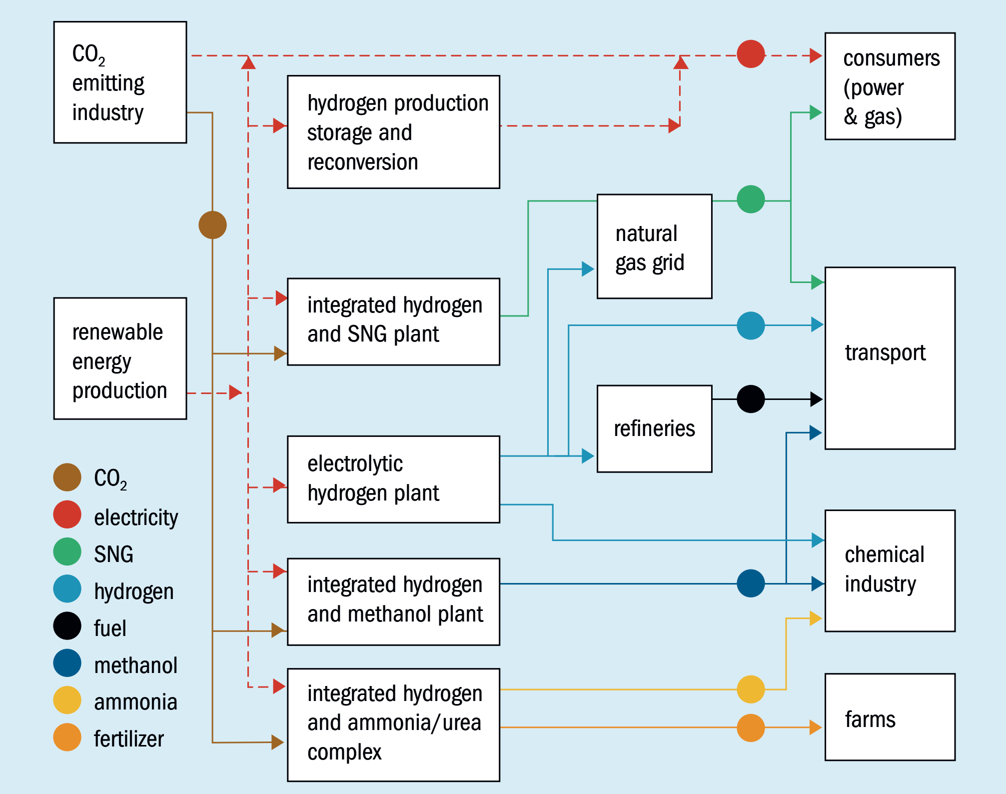
thyssenkrupp Industrial Solutions AG (tkIS) is driven by sustainability and its commitment to work on environmental-friendly solutions for the benefit of future generations. In the syngas market, tkIS is well known for its uhde® ammonia process technology and EPC business since the 1920s providing state-of-the art technology for the fertilizer industry. In addition, tkIS has a major presence in the electrolysis business, where it has also played a major role in the development of the market and is the leading technology supplier.

Using its knowledge and experience in these markets, tkIS has developed holistic and environmental-friendly processes for energy, mobility, the chemical industry and agricultural applications. The basis for all of these applications is its alkaline-water-electrolysis (AWE) technology providing downstream technologies with hydrogen. Energy generated through renewable sources can now be stored with tkIS's AWE and downstream processes to "green" SNG, hydrogen, methanol and ammonia, thus overcoming the biggest bottleneck and concern of renewable energy – fluctuation. Ammonia can also be further processed to nitrogen fertilizers or DeNOx fluids. Hence, there is a variety of environmentally-friendly technologies and applications available (see Fig. 4).

In contrast to a conventional ammonia plant, which produces hydrogen by steam reforming of natural gas, in the concept presented here the AWE produces the hydrogen from the electrolysis of water and the nitrogen required for the ammonia synthesis is produced by an air separation unit (ASU).

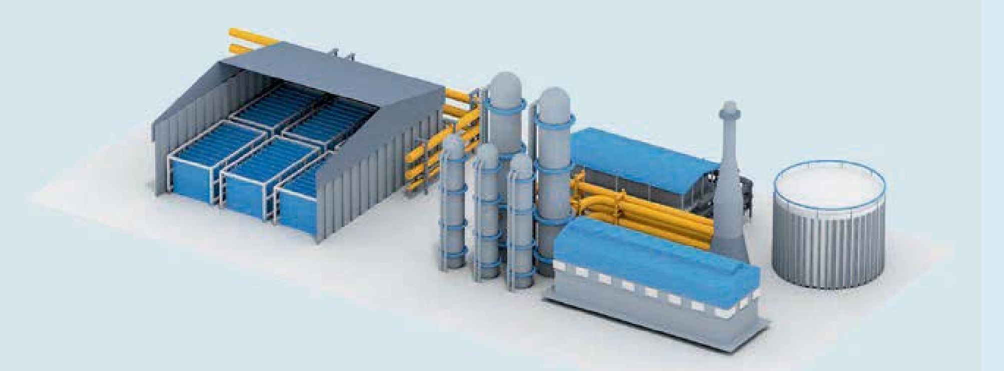
Early on in the development of its green ammonia process, tkIS concluded that one major prerequisite to provide potential customers with the best possible solution is to have a standardised and modularised concept without spending efforts in tailor-made engineering. Modularisation and standardisation of the green ammonia concept is a must in order to enhance the feasibility of this concept. While the AWE and ASU were already fully modularised, tkIS had to spend effort in order to modularise the ammonia synthesis section, resulting

Fig. 4: **Hydrogen value chains by thyssenkrupp**



Source: tkIS

Fig. 5: **2D model of green ammonia production**



Source: tkIS

in a holistic concept from one provider (see Fig. 5). When modularising the green ammonia plant it is advantageous that hydrogen and nitrogen are available at the same conditions. In addition it is advantageous from a modularisation viewpoint to keep capacities at a lower level in order to keep equipment small.

tkIS concluded that quite a high share of customers of onshore and offshore wind parks typically have an installed power of minimum 20 MW available. Based on 20 MW power input and 100 % availability an ammonia output of 50 t/d can be achieved. For this 50 t/d concept it was tkIS's primary goal to maximise the use of low cost equipment in order not to jeopardise the feasibility.

In addition, tkIS has developed a second concept, based on 120 MW power input resulting in 300 t/d ammonia production. Due to plant size, tkIS concluded that for this concept there has to be slightly more focus on energy efficiency in order to compete with conventional process technologies. As plant size is more of an industrial scale, tkIS believes that it could also be a reasonable revamping option in existing ammonia plants to partly substitute conventional ammonia production with green ammonia production. Fig. 6 shows the process units required for thyssenkrupp's green ammonia production.

Electrolysis: AWE

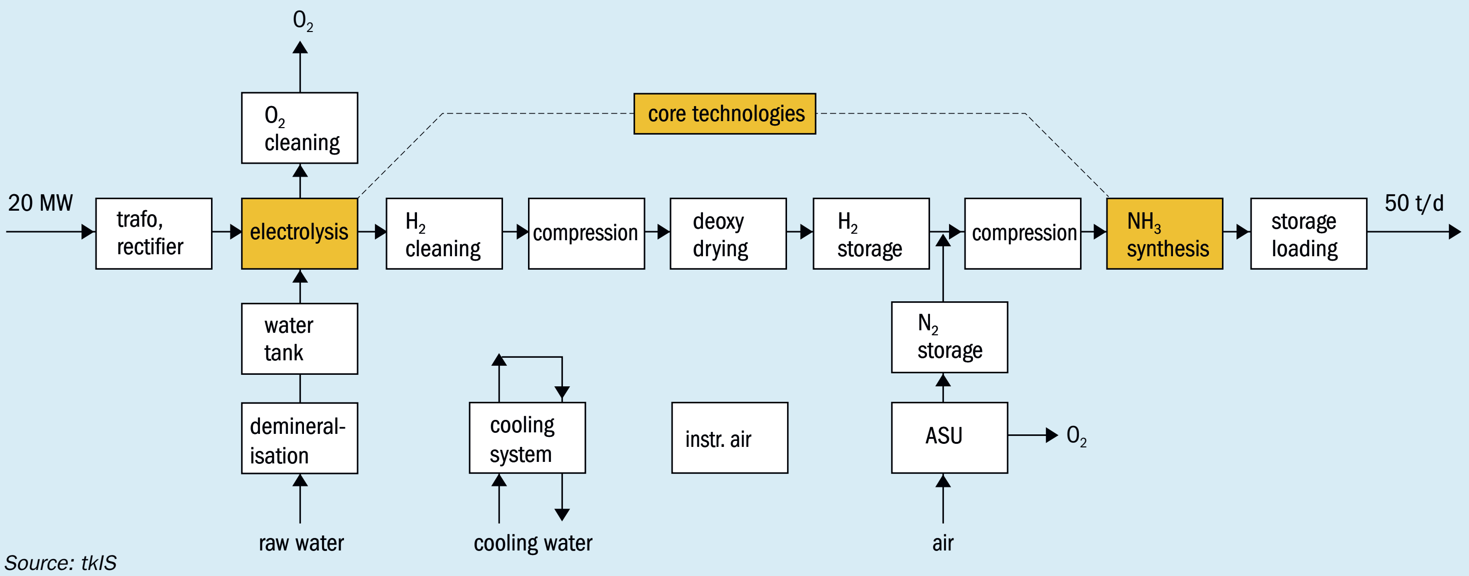
Alkaline water electrolysis is based on the proven chlor-alkali electrode technology developed by thyssenkrupp Uhde chlorine engineers. With more than 600 plants built and more than 10 GW installed capacity, tkIS is the number one electrolysis technology provider in the market. tkIS's electrolysis technology uses the proven zero-gap technology with high efficiency cathode and anode design and coating and optimised high-performance separators and diaphragms.

For AWE-based hydrogen production basically power and water are required. While power is directly fed via a transformer rectifier to AWE, raw water has to be demineralised prior to feeding to AWE. In the AWE process the main outputs are oxygen and hydrogen. Both products are cleaned. The oxygen is not required for this process and could be made available for other downstream processes. The hydrogen generated by AWE is compressed, deoxygenated and dried. Hydrogen is now ready to be fed to the ammonia synthesis. Prior to feeding the synthesis gas compressor with synthesis gas, the stoichiometric amount of nitrogen is added to the hydrogen. Nitrogen is produced in a cryogenic-type air separation unit.

The AWE technology is perfectly suited to the conditions of a green ammonia plant which can suffer from a lack of power due to the fluctuating availability of renewable energy. The AWE can be started-up within minutes and follows load variations within seconds. Hence, the AWE offers the flexibility, which is required from renewable energy sources. A major concern is the ammonia synthesis section. To overcome this situation intermittent storage of hydrogen is installed upstream of the synthesis gas compressor (see Fig. 6). The size of the intermittent storage can be adapted in accordance with the power availability. With these measures in place the ammonia synthesis unit should be able to run continuously.

The design philosophy is based on highly modular, standardised and prefabricated skids with a size of 5 MW each (see Figs 7a and 7b). The design is fairly simple with good accessibility, short connections and a central header design. tkIS's main target is to minimise engineering and construction as much as possible in order to reduce individual project costs and to

Fig. 6: **Process concept of thyssenkrupp's green ammonia production**



Source: tkIS

Fig. 7a: **3D model of 5 MW electrolysis skid**

Source: tkIS

Fig. 7b: **3D model of 20 MW electrolysis skid**

Source: tkIS

provide fast track solutions. In addition, installation of modules and skids drastically eases the whole construction execution.

Ammonia synthesis

The concept of the ammonia synthesis is fairly standard; it is a reaction loop with recirculation of the unreacted components. The synthesis gas compressor compresses the make-up gas to about 260 bar a. While large-scale conventional plants use centrifugal-type compressors, small-scale green ammonia plants use motor-driven piston-type compressors.

To trigger the reaction, commercially proven iron-based catalyst is used. The recirculated gas is split with the larger portion being heated up to 350°C and fed to a 3-bed axial-flow quench converter. The quench converter mainly consists of a pressure bearing vessel and an internal cartridge with three adiabatic catalyst beds. Temperature control between the catalyst beds is achieved by mixing cold, unreacted gas with the reacted gas between the catalyst beds. While large-scale conventional ammonia plants use ammonia converters with radial beds and internal heat exchangers, it turned out to be more feasible to have a converter with direct quench cooling with cold synthesis gas between the catalyst beds.

In contrast to large-scale plants, there is intentionally no steam generator downstream of the ammonia converter in order to save capex and keep the process as simple as possible. In this concept the reacted gas exits the converter and preheats the inlet gas of the quench converter. The remaining heat is used for regeneration of the absorbent in the refrigeration system and is further cooled down in a set of water cooler and chillers.

The ammonia synthesis section also makes use of highly modular, standardised and prefabricated skids sized for road transportation. The modules are fully integrated and pre-tested in order to achieve the best EPC solution with a "plug and play" erection strategy, being able to provide a feasible green ammonia plant concept also in regions with high construction cost or with lack of construction personnel.

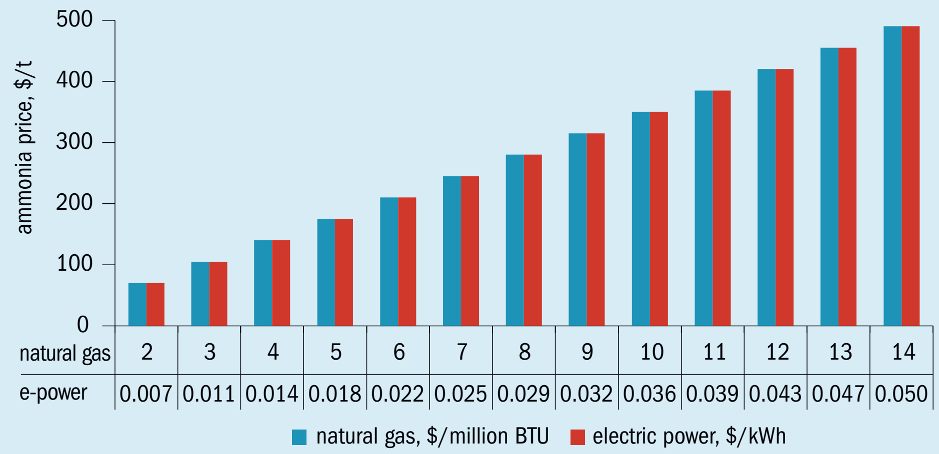
Economic evaluation

When tkIS evaluated the key drivers for the viability of the green ammonia production concept there were five major issues to be considered: capex, availability and cost of renewable-sourced electric power, restriction and cost of ammonia transport, restrictions in CO_2 emission and CO_2 taxes.

From a capex perspective, small-scale green ammonia plants are in the same region as conventional (gas-based) smallscale ammonia plants. The major disadvantage of small-scale plants is the high specific material cost, while the major advantage is the modularised concept, which helps to reduce construction costs and is no longer dependent on high regional construction costs and constraints. Not surprisingly, it turned out that, at higher capacities, economies of scale are in favour of the conventional process, which is caused by the fact that there is no significant specific cost reduction in the electrolysis section when cells are added to achieve higher capacity. That means when comparing the capex of small- scale green ammonia plants with large-scale conventional ammonia plants, small green ammonia plants can hardly compete, but, as discussed, that was not the intention of the small-scale plant concept.

The efficiency of conventional and green ammonia plants is on the same level. Hence, operating expenditures (opex) are mainly driven by electric power cost vs natural gas cost. tkIS has investigated both concepts. Considering the current market price for ammonia of about 330 $/t, green ammonia production is feasible if the electricity cost is below 0.035 $/kWh. In case of conventional ammonia production based on natural gas, the same break-even point is at about 9.50 $/million

Fig. 8: **Break even points for NH_3 product price at different raw material costs**



Source: tkIS

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

Btu (LHV). These values are a rough indication only as no other opex are considered in this case (see also Fig. 8 for break-even points for ammonia market prices at different raw material levels).

In some regions ammonia transport has either been drastically restricted or ammonia consumers are located in landlocked regions which makes ammonia transport quite expensive. Consumers have to add 100-200 $/t for transport to site resulting in about 500-600 $/t of ammonia. Considering this high transportation cost, local production of ammonia will enhance the feasibility drastically. Also considering high transportation costs, the break-even point for green ammonia production is shifted to 0.055 $/kWh. Finally, the issue of CO_2 tax as well as CO_2 emission restrictions need to be considered, which will further enhance the overall feasibility.

The short economic evaluation and comparison with conventional plants indicates that at some landlocked locations with low electric power cost an installation of green ammonia plants might also be an interesting option for the fertilizer or chemical industry. This market is rather small compared to conventional ammonia market. However, renewable energy sector is primarily interested in the most feasible option to store and carry energy in order to enhance feasibility of their power plants and it turns-out that ammonia is a favoured option, which might lead to a complete change in the ammonia market.

NFUEL® mini ammonia plants

Dutch mini-ammonia plant developer Proton Ventures offers modern technical solutions which make it possible to move away from large-scale plants towards small-scale ammonia production units (NFUEL® units).

Proton Ventures can provide customers with small-scale ammonia plants, ensuring customer's independence of transport costs and ammonia price fluctuations. Natural gas, associated gas, flare gas, hydrogen or biogas can be used as feedstock (Fig. 9).

By developing and implementing sustainable, decentralised and small-scale ammonia plants, Proton Ventures' goal is to become a global leader in the supply of NFUEL® mini ammonia production units and contribute to the reduction of the global CO_2 footprint.

NFUEL® mini ammonia plants are based on the Haber Bosch process and are available in three different capacities: 1,000 t/a, 4,000 t/a and 20,000 t/a (see Table 1). Electric power produced from renewable resources (wind, solar and tidal energy) can be used as energy source for these units. This makes it possible to produce green decentralised ammonia which can be used for:

- nitrogen carrier (fertilizer);
- hydrogen carrier;
- energy storage;
- chemical precursor (e.g. for urea, nitric acid, ammonium nitrate);
- fuel (maritime or agricultural);
- deNOx;
- feedstock for fuel cells.

Key consumables for the NFUEL® units are given in Table 2.

The NFUEL® units compensate for variations in the supply and demand of the energy market by employing ammonia as an energy carrier.

The NFUEL® system can use various feedstocks.

Feedstocks for gas-to-ammonia (using SMR) include:

- natural gas from stranded locations (e.g. oil well flares);
- natural gas from smaller gas fields in relation to conventional plants;
- (upgraded) biogas (green gas) (landfill gas or from anaerobic digestors, etc.).

Feedstocks for power-to-ammonia (using electrolysers) include:

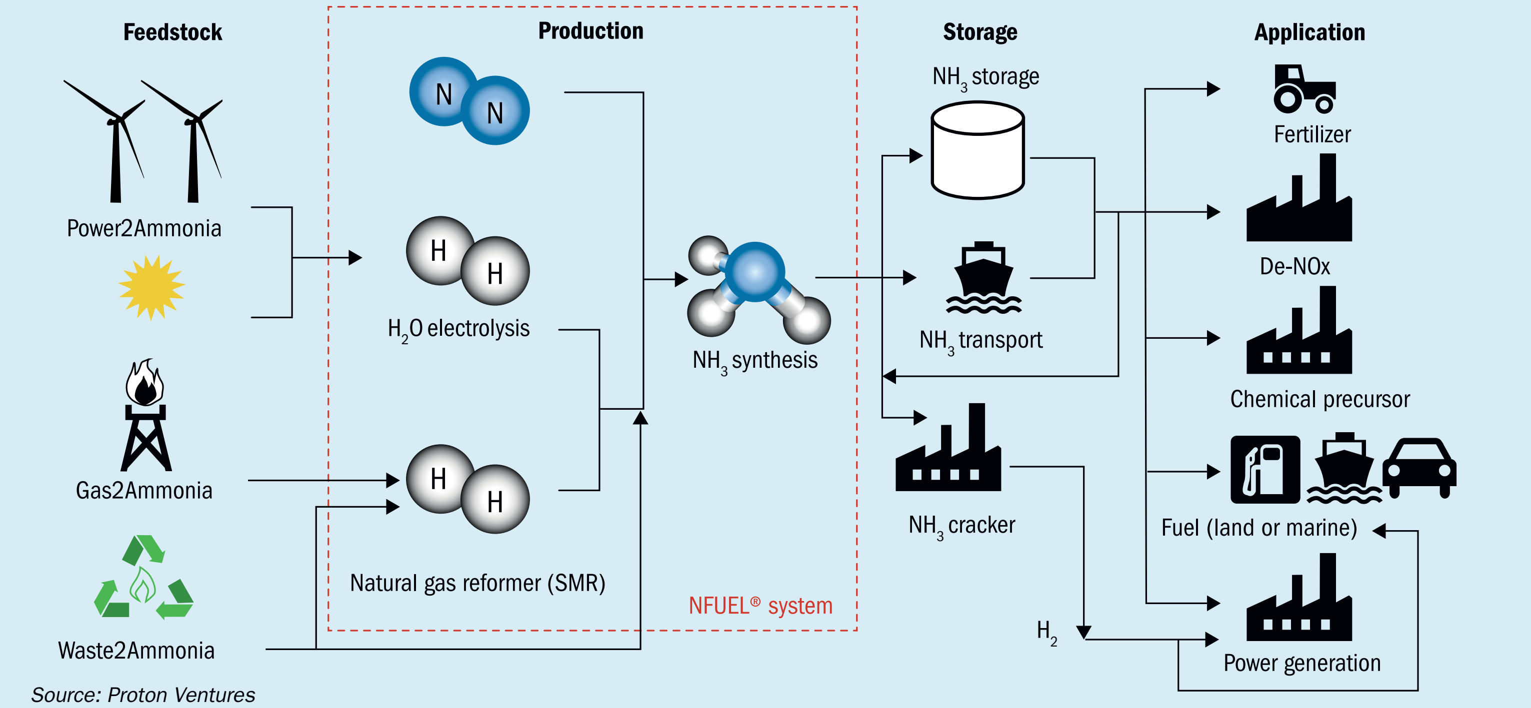
- solar, wind, tidal or geothermal (onshore or offshore);
- stranded (cheap) electricity sources.

Feedstocks for waste-to-ammonia include:

- by-product hydrogen from industrial processes;
- flared hydrogen.

Standardised designs are available for minimum capex and optimised opex. Site activities are minimal thanks to its plug-and-play designed skids.

Fig. 9: **NFUEL® overview**



Source: Proton Ventures

Table 1: NFUEL® mini ammonia plants

	NFUEL® 1	NFUEL® 4	NFUEL® 20
Capacity, t/a (t/d)	1,000 (3)	4,000 (10)	20,000 (60)
Power consumption, MW	1.5	5-6	25-30

Source: Proton Ventures

Table 2: NFUEL® system key consumables

Natural gas, Nm^3/tonne NH_3	835
Hydrogen, Nm^3/tonne NH_3	2,080
Electricity (when H_2 from NG), kWh/tonne NH_3	800-1,000
Electricity (when H_2 from H_2O), kWh/tonne NH_3	10,000-11,000

Source: Proton Ventures

The gas-to-ammonia concept (using SMR) benefits from a lower global emission footprint and can create value-added products from stranded sources. It is only economically viable if there are no large ammonia plants nearby or in places where the feedstock is basically free.

Advantages of the power-to-ammonia concept (using electrolysers) include: the efficient storage of energy in liquid form, it is CO_2-free and it creates a carbon-free fuel.

A key benefit of the waste-to-ammonia concept is that it makes a value-added product from waste sources. Mini ammonia units are modular, fully transportable, skids/containerised and can be installed in various locations with minimum installation costs. Take, for example, the 180 million Nm^3 of high purity associated gas being flared in the Bakken shale play, North Dakota, USA, corresponding to 180,000 t of NH_3 production. The otherwise flared associated gas can be at close to zero costs, resulting in a market competitive ammonia price.

Industrial references

Feasibility studies for mini ammonia plants of 4,000 to 20,000 t/a have been carried out for companies in the USA, Canada, Germany and Angola, as well as various feasibility studies for governmental organisations in The Netherlands. Industrial references for 20,000 t/a NH_3 reactors include two units in China, one in Argentina and one in Switzerland.

ISPT feasibility study on power to ammonia

In a recent power-to-ammonia (P2A) study the Institute for Sustainable Process Technology (ISPT) brought together various parties from different sectors of industry to study the storage of electricity in ammonia (NH_3) with the objective to investigate under what conditions:

- NH_3 can be produced using renewable electricity;
- NH_3 can be used to store electricity and;
- NH_3 can be used as a CO_2-neutral fuel for a power plant.

In the P2A study the following parties were involved: ISPT, Stedin Infradiensten, Nuon, ECN, Technical University Delft, University Twente, Proton Ventures, OCI Nitrogen, CE Delft and AkzoNobel.

Ammonia was investigated in this study because it provides a pathway to fully CO_2-neutral electricity storage and generation of CO_2-neutral electricity on a scale that is not limited by scarcity of materials or storage space.

The partners in this project studied three cases. The first case relates to electrochemical production, storage and use of ammonia for a rural setting (Goeree-Overflakkee), avoiding grid modification costs and allowing local production of CO_2-free ammonia. The second case allows use of ammonia as a CO_2-neutral fuel in the highly efficient Nuon Magnum gas turbine combined cycle (CCGT) power plant in Eemshaven, thus generating flexible and CO_2-free electricity. The third case assesses the electrochemical production of ammonia at OCI Nitrogen to replace (some of) the current, natural gas based production. In addition, other relevant aspects related to power-to-ammonia including technical, operational, financial, legislative and safety issues were also evaluated.

Study findings

It was determined that CO_2-neutral ammonia produced in an electrochemical way from sustainable electricity will be a feasible alternative to ammonia produced from natural gas in the longer term.

Comparing the processes for the electrochemical production of ammonia resulted in the following ranking in order of decreasing efficiency: solid oxide electrolytic cell (SOEC), low temperature solid state ammonia synthesis (LT SSAS), Battolyser, proton exchange membrane (PEM) and high temperature solid state ammonia synthesis (HT SSAS).

A competitive price for electrochemically produced CO_2-free ammonia versus conventional natural gas based produced ammonia (300-350 €/ton) can be achieved when investment costs for electrolysers drastically come down, when costs for emitting CO_2 increase significantly and when there is sufficient supply of relatively cheap CO_2-free electricity.

Electrolysers require a high on-stream time to minimise costs per ton, but due to the production patterns of wind and solar energy, large scale availability of renewable energy is intermittent.

Use of ammonia as a fuel in a CCGT power station is possible by cracking the ammonia into hydrogen and nitrogen before combusting the hydrogen in the gas turbine. Time to market for large scale application is estimated to be five to ten years. As the ammonia will be cracked into hydrogen prior to combustion in the gas turbine, application of ammonia as a fuel in the power sector enables a seamless integration with a hydrogen economy. Use of ammonia as a CO_2-neutral fuel in the Nuon Magnum power station has the potential to reduce CO_2 emissions by 3.5 million t/a when operating on base load producing 10 TWh of electricity. This reduction is equivalent to 7% of the power related carbon emissions in The Netherlands in 2015.

Locally produced CO_2-neutral ammonia, as investigated in the Goeree-Overflakkee case, will be sold on the market. The ammonia can be distributed via the ammonia terminal in the port of Rotterdam.

Since the study results were presented, various other options have been discussed including ammonia as:

- a fertilizer;
- a hydrogen carrier;
- a maritime fuel, or
- ammonia transported to an industrial ammonia producer, labelled as "green ammonia".

Study conclusions

In the cases studied, the production of ammonia using (excess) renewable energy cannot compete with existing fossil based ammonia production. Drastic changes in the production cost of electrolysers to less than 70% of the reference price of 1000 €/kW, supply of renewable energy and a global increase in CO_2 price are needed to make this production route competitive.

Reduction of the CO_2 footprint of ammonia by producing it via electrochemistry rather than by the conventional process from natural gas is only possible if the electricity used is renewable. For grid owners, an advantage of producing ammonia with wind and solar power will be that investments in the grid can be reduced. If the share of wind and solar power increases without demand side management and without energy storage the investment requirements in increasing grid capacity will be substantial. The combination of demand side management and local energy storage can contribute to the reduction of the necessary investments in the grid. Power-to-ammonia enables energy to be transported and stored for periods of days, weeks or even months.

Electricity storage in the form of ammonia will add cost to the overall electricity system. However, large scale CO_2-neutral energy storage will introduce important benefits for the system, enabling a further penetration of intermittent renewable electricity sources, enabling further electrification and providing CO_2-free ammonia as a fuel and chemical commodity.

At deep decarbonisation, flexible electricity production based on application of fossil fuels during periods when supply from intermittent renewable sources is insufficient, cannot be applied unless carbon capture and storage will be deployed. In other words, the initially more costly use of ammonia as a CO_2-neutral fuel for electricity production becomes very attractive and one of the few realistic alternatives.

The installation of additional renewable wind and solar capacity on its own is not sufficient to meet ambitious CO_2 reduction targets of 80-95% by 2050. Large scale storage and import of renewable electricity is required to meet these targets. Power-to-ammonia enables both storage and import and has the potential to contribute substantially to CO_2 reduction targets, offering flexibility for the electricity system and allowing for an alternative to investments in electricity grid infrastructure.

Building a low carbon society in Japan

Reducing CO_2 emissions is a global issue, but for Japan, a country poor in energy resources, it is necessary to build a low-carbon society and promote a stable energy supply through diversification. Japan has big expectations for the future role of hydrogen energy and has a vision to become the world's first new type of low carbon society utilising hydrogen by 2030, and to become a role model to the rest of the world. However, before large-scale use of hydrogen can become a reality, there remains a lot of issues to overcome, such as technology barriers and high cost. The research, development and demonstration of hydrogen technologies with industry-academia-government collaboration under the leadership of the Japanese government will contribute significantly to solve the energy and environmental problems in Japan.

"Energy carriers", a technology development programme for the realisation of a hydrogen society has been launched as one of the themes of the cross-ministerial Strategic Innovation Promotion programme (SIP) spearheaded by the Council for Science, Technology and Innovation in 2014. Energy carriers provide an efficient method to store and transport hydrogen as a liquid.

As part of this program, Japan aims to build a CO_2-free hydrogen value chain by focusing on technology developments for CO_2-free hydrogen production, conversion to energy carriers (liquid hydrogen, organic hydrides and ammonia), as well as storage, transportation and utilisation.

Hydrogen-related research topics being investigated include:

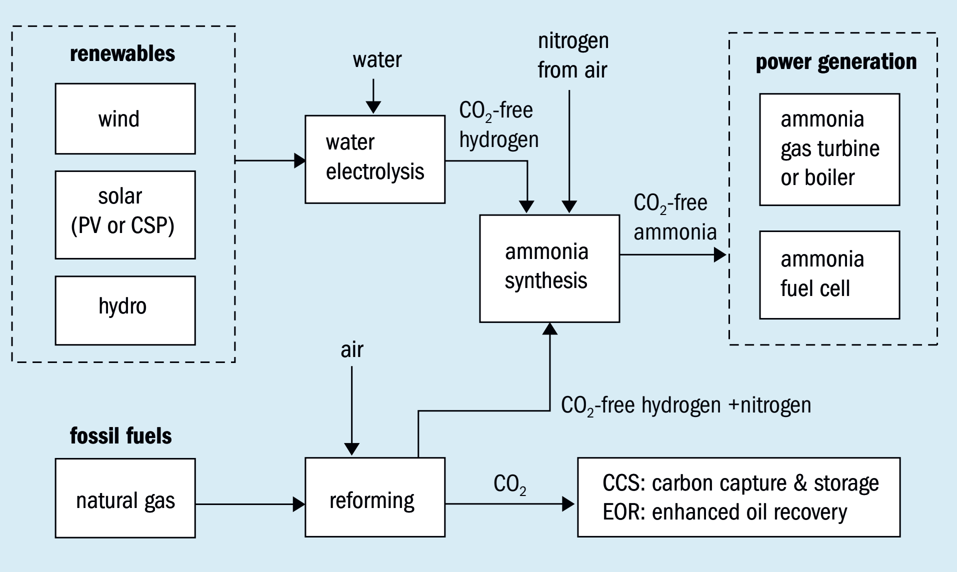
- high-temperature solar thermal energy supply;
- hydrogen production technology using solar heat;
- development of cargo loading/unloading systems for liquid hydrogen and relevant rules of operation;
- development of hydrogen engine technology.

Current ammonia-related research topics include:

- ammonia synthesis process from CO_2-free hydrogen;
- hydrogen stations utilising ammonia;
- ammonia fuel cells;
- ammonia direct combustion.

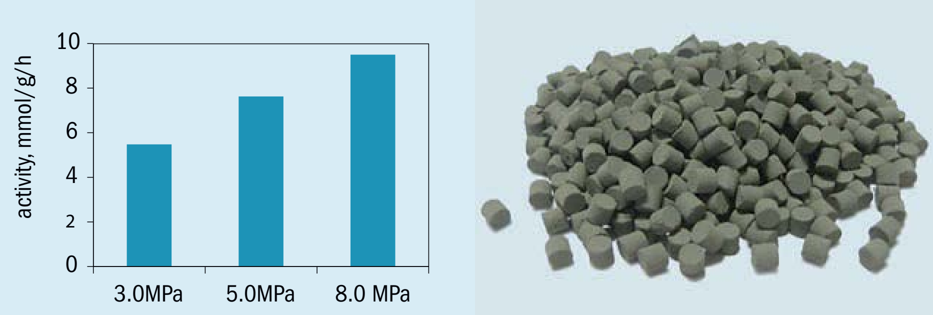
Ammonia is a carrier of CO_2-free hydrogen, which is produced by the electrolysis of water using renewable energy or the reforming of fossil fuel with carbon capture and storage (CCS). Ammonia will also be a promising fuel for power generation both by co-firing with natural gas or coal in existing power plants with some modification and by ammonia fuelled gas turbines in new power plants, as well as a hydrogen source for fuel cell vehicles through the use of catalytic decomposition (see Fig. 10). In the case of renewable energy, the cost of renewable power and electrolysers will be key factors for the competitiveness of the power cost.

Fig. 10: **Supply chain of CO_2-free ammonia**



Source: JGC Corporation

Fig. 11: Development of Ru/REO$_2$ catalyst

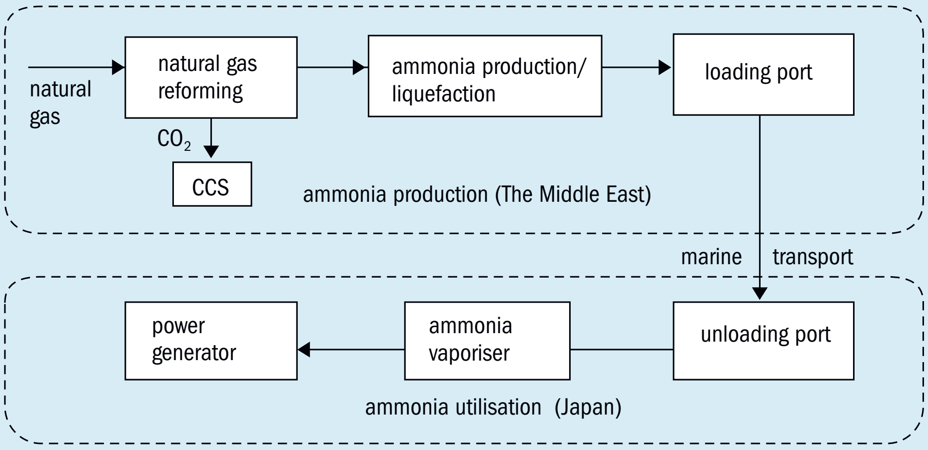


The Ru catalysts, supported by rare earth oxide, were prepared by the impregnation method.

Ru/REO$_2$ catalyst has been produced on a semi-industrial scale.

Source: JGC Corporation

Fig. 12: Outline of CO$_2$-free ammonia chain



Source: JGC Corporation

Table 3: CO$_2$-free ammonia chain cost study basis

Year:	2030 (start time of commercial ammonia fired power generation)
Volume of ammonia supply:	1.26 million t/a
Ammonia production region:	The Middle East
Natural gas and LNG price:	estimated cost in 2030
Cost of CCS:	50 $/t CO_2 (The Middle East) 5,000 JPY/t CO_2 (Japan)
Power generation:	NH_3/LNG co-firing (20/80 based on high heat value)

Source: JGC Corporation

Ammonia synthesis process from CO_2-free hydrogen

Currently, ammonia is mainly produced from natural gas by the Haber Bosch process which uses an iron catalyst under high pressure and temperature conditions. However, the pressure of hydrogen from the electrolysis of water is much lower than the reaction pressure in the Haber Bosch process. If the CO_2-free ammonia is produced using renewable energy, lower synthesis pressure and temperature are desirable for saving energy.

JGC Corporation is playing a major role in the development of an ammonia synthesis process from CO_2-free hydrogen. In this project, new ruthenium catalysts with rare earth (RE) oxide or carbon support have been specially developed for this purpose. The key requirements for the new catalyst are:

- higher activity at lower pressure and temperature compared with the current Haber Bosch process;
- ability to cope with fluctuations of feedstock gas (i.e. hydrogen)

The catalysts were prepared by the impregnation method. The recipe for industrial scale catalyst production has been established and Ru/REO2 catalyst has been produced on a semi-industrial scale (Fig. 11). Process optimisation using the catalyst is being studied. The target capacity for ammonia plants utilising the new process and catalyst is 10 to 500 t/d, depending upon the availability of renewable energy and specific conditions such as ammonia price at the location.

A pilot plant has been designed to confirm the performance of the newly developed catalyst and ammonia synthesis process at the Fukishima Renewable Energy Institute (FREA), National Institute of Advanced Industrial Science and Technology (AIST) in Japan. The pilot plant has a capacity of 20 kg/day of liquefied ammonia and uses renewable power based hydrogen as feedstock. It started operation in April 2018.

Outline of a CO_2-free ammonia chain

Fig. 12 illustrates a potential scenario where CO_2-free ammonia is produced in the Middle East and shipped to Japan to supply the power industry. The power generation cost has been evaluated throughout the ammonia supply chain from renewable energy or fossil fuel reforming with CCS to power generation. The cost of power generated using ammonia as fuel was found to be competitive with an LNG co-firing plant with CCS. The cost study for the supply chain of CO_2-free ammonia was based on the assumptions shown in Table 3.

Topsoe's road map for sustainable ammonia production

Topsoe has a long history in ammonia technology and its target is to become the leading technology provider for sustainable fertilizer and energy storage. Topsoe believes in ammonia being produced from renewable energy, water and air; ammonia being the preferred energy storage media in the power sector; sustainable ammonia being produced that is cost competitive at world-scale capacities as well as at smaller scale; and sustainable ammonia being used to feed and power the world. Topsoe sees the transition as a stepwise process. With these objectives, Topsoe has embarked on a journey towards sustainable ammonia production by developing and marketing hybrid solutions.

Fig. 13: The hybrid plant solution

Source: Topsoe

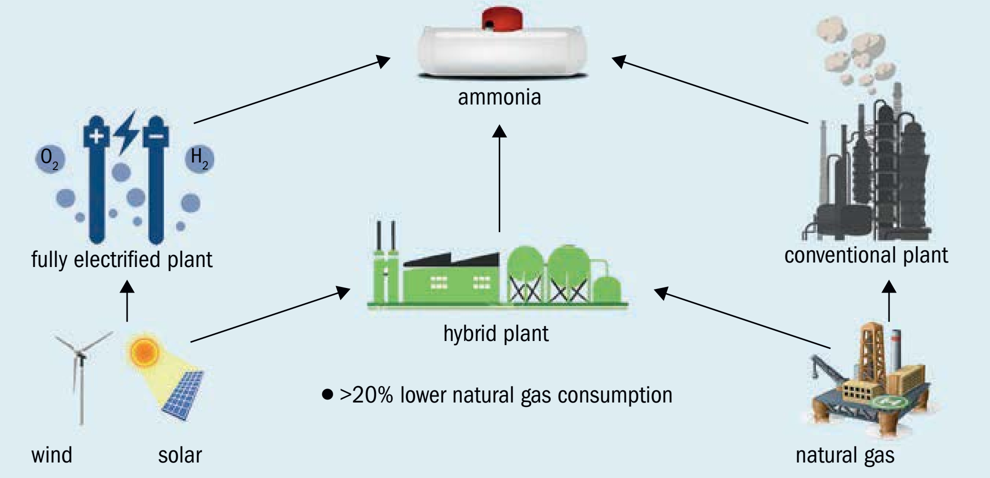
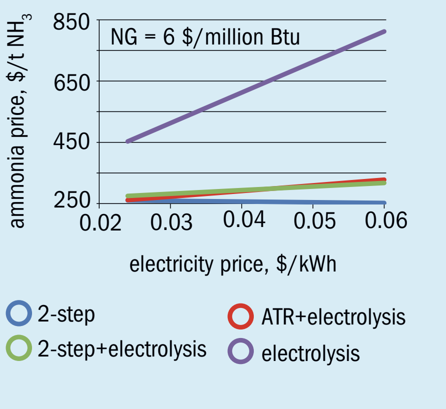


Fig. 14: Ammonia production price, all inclusive



Source: Topsoe

Topsoe has designed the synthesis for a small ammonia plant based on water electrolysis for the production of hydrogen and an ASU for the production of nitrogen. Demonstration plants for small green ammonia plants with a low level of economy of scale using today's technology for water electrolysis have been built and there is now a window of opportunity for a hybrid solution for ammonia production. (Fig. 13)

Looking at the journey from today to a future of sustainable ammonia production, the next step for ammonia production should have some degree of fossil energy substitution by renewable energy. There is economy of scale with usage of up to 25% renewable energy. A hybrid revamp solution adds a relatively small electrolysis unit to an existing ammonia plant. A hybrid grass-root solution is the substitution of up to 25% fossil energy by renewables. Both designs are ready today.

Based on Topsoe studies (with a NG price of 6 $/million Btu) when comparing current specific ammonia production costs for different technologies, the two-step conventional world-scale ammonia plant has the lowest production cost per tonne of ammonia, green ammonia based on AEM electrolysis is approximately double price, while hybrid plants (revamp or new grass-root ammonia plant) can compete when the electricity price is below 3 cents/kWh (Fig. 14). Even modest levels of CO_2 taxation would move this break-even electricity price significantly upward.

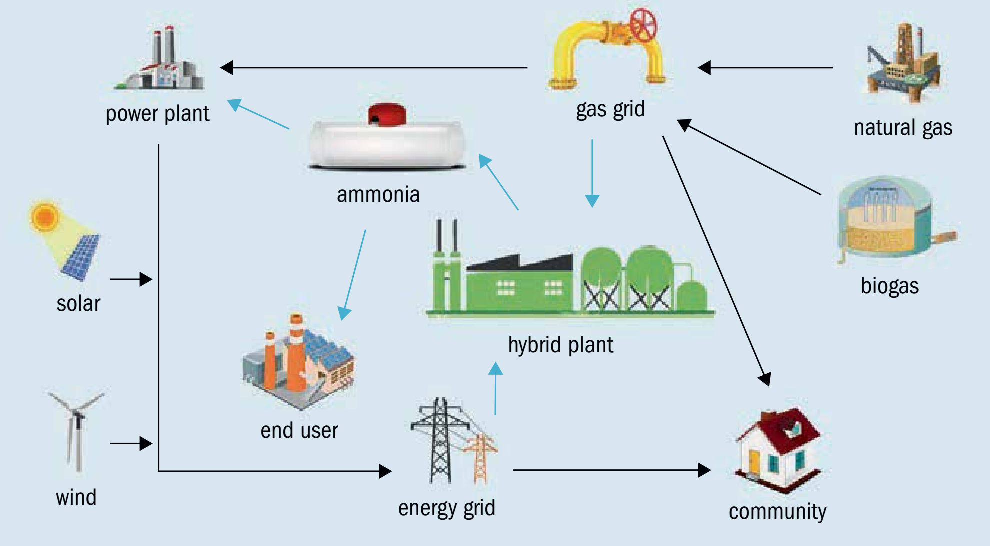
Longer term, Topsoe has ambitions to use more energy efficient steam electrolysis in place of water electrolysis.

Fuel cells can be used but the size of solid oxide electrolyser cells (SOEC) is small (kW scale). Topose wants to progress to MW scale and ultimately GW scale. This is a gradual process, starting with small scale and learning to scale up through development.

Topsoe is pursuing a demonstration plant in 2025 to demonstrate the SOEC to produce syngas in the right molar ratio of H_2 and N_2 without an ASU, and to demonstrate the highest overall efficiency. The knowledge and experience gained from this demonstration plant will be used to commercialise the most efficient, sustainable and cost competitive ammonia production. Existing assets can be reused for revamping, and even for the ultimate process layout the Haber-Bosch synthesis can be reused.

As regards ammonia as a fuel for power production, Topsoe would like to see the hybrid ammonia plant at the centre of the grid. In this way ammonia can be produced from electricity (preferably from renewables) and can then be used to produce fertilizer as today or it can be used as fuel to produce power for the grid even on the days where there is less renewable energy available. In addition, ammonia can be used as an energy carrier for storage or long distance transportation. This will allow for the installation of more renewable energy and more ammonia production. (Fig. 15)

Fig. 15: Ammonia as a fuel for power



Source: Topsoe

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Modular ammonia plants for the US mid-continent

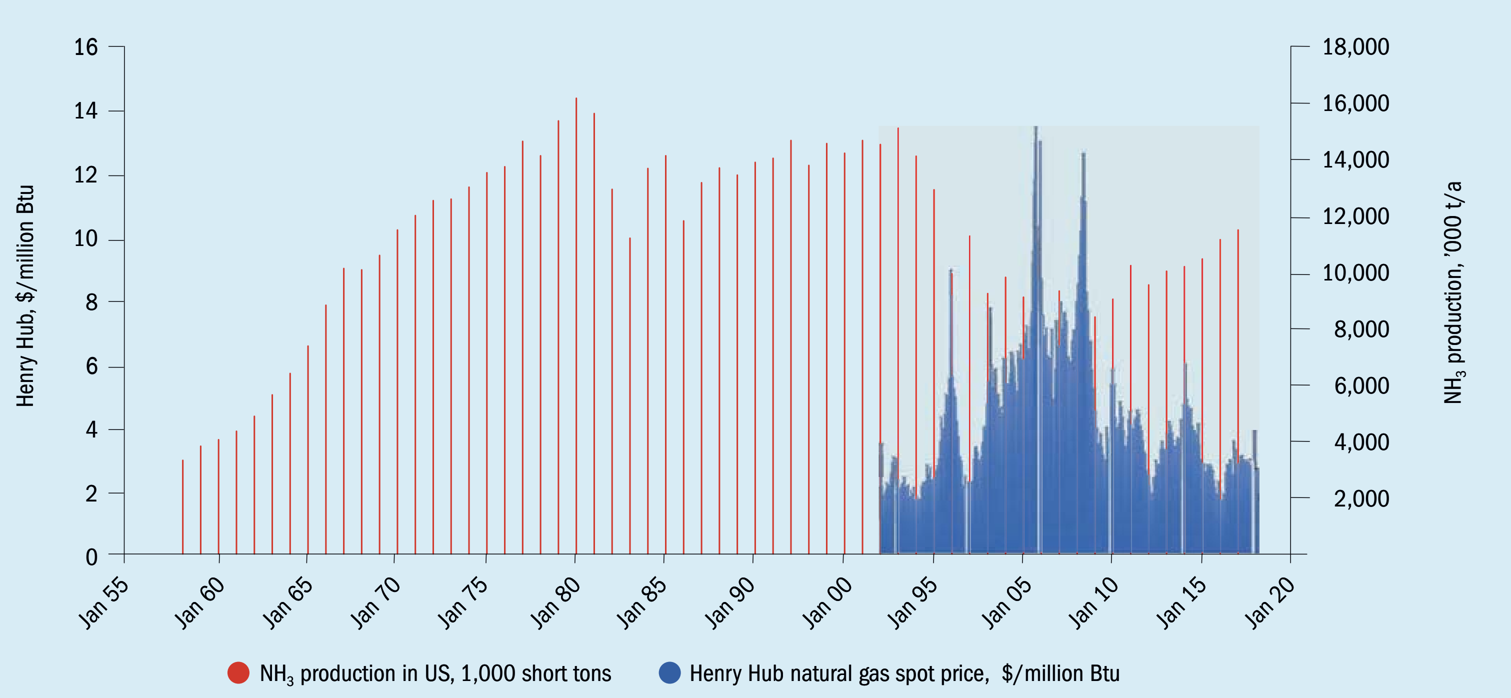
Carrie Lalou of Linde Engineering North America discusses the unique market conditions and challenges faced by fertilizer producers in the US mid-continent agricultural belt which can be addressed by using modular small-scale ammonia production plants for the scaling down of local ammonia production and distribution.

The past three decades have seen a boom, a bust, and a refresh of the ammonia (NH_3) market in the United States. The trend analysis for this can be almost directly correlated to the price of domestic natural gas (NG). As depicted in the graph in Fig. 1, the downward trend from the late 1990s through 2009 can be attributed to the growing uncertainty in natural gas supply, and the price spikes are due to natural and economic disasters during that decade. The recovery of ammonia production in the US (and simultaneous drop in natural gas prices) is directly linked to the discovery and mass exploration/production of domestic shale gas.

The US Geological Survey (USGS) forecast for nitrogen (fixed) – ammonia (January 2018) indicates that the upward trend of domestic production and reduced foreign import will continue for the foreseeable future. Approximately half of the domestic production of ammonia is in the US Gulf Coast (USGC) region (Texas, Louisiana and Oklahoma) driven by the availability of low cost natural gas feedstock, and US producers are still only operating at about three-quarters of rated capacity. As producers have ramped up their production on low cost NG and global demand has decreased, the annualised average price of ammonia has diminished by more than half from $540/ton in 2013 to $240/ton in 2017, fob USGC.

What the future entails for ammonia in the US is not completely clear, but it appears that new construction and upgrading of existing plants will continue in the US over the next four years, growing at

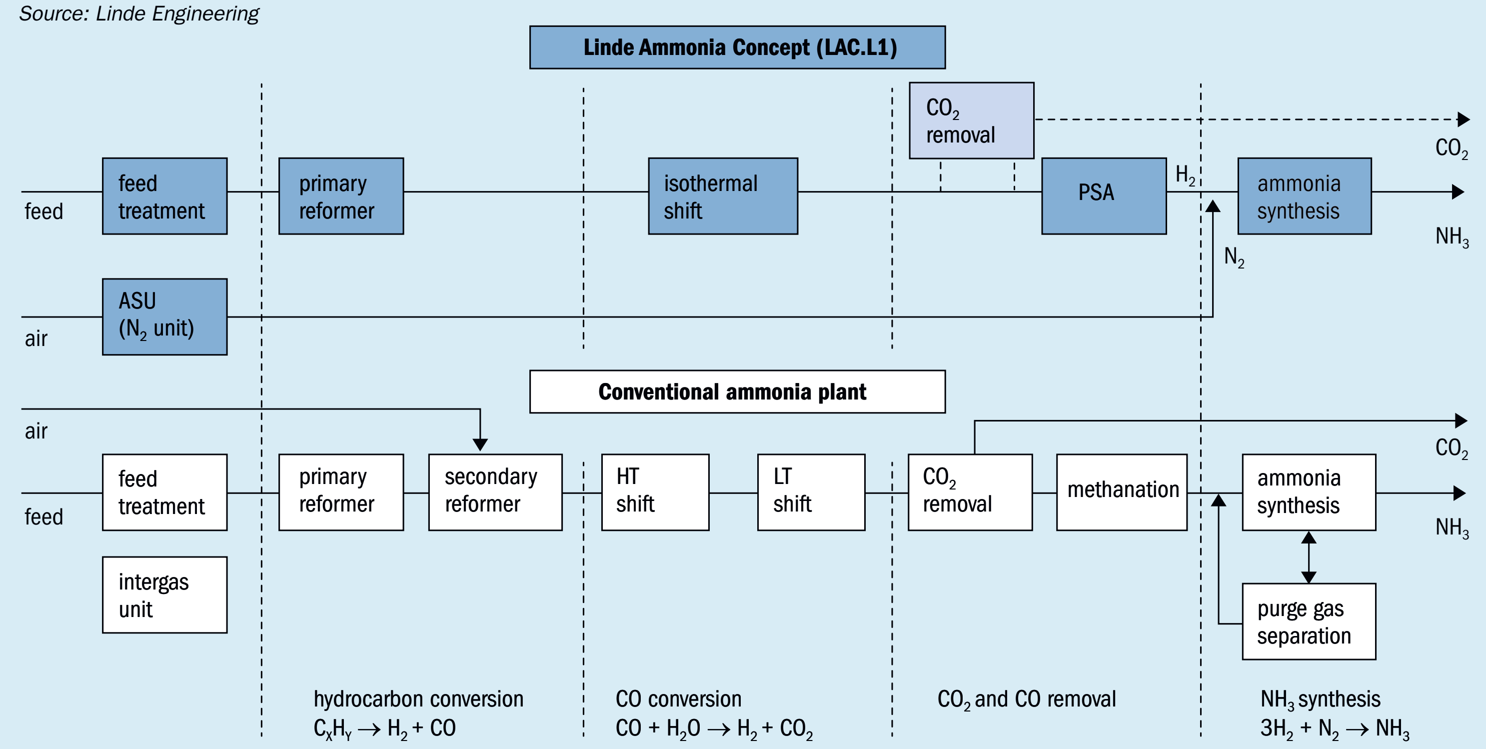
Fig. 1: **NH_3 production vs Henry Hub NG pricing in US, 1958-2017**



Source: USGS; Energy Information Administration

Fig. 2: **Linde Ammonia Concept (LAC.L1)**

Source: Linde Engineering



least another 2.5 million tons of annual production capacity. This will significantly reduce the imported ammonia needs for the US, and shortly thereafter we could see the trend of the US shifting from import to export of fertilizer products, especially with the predicted increase in global demand of 8% over the next four years.

Transportation woes

While the drop in local natural gas prices has certainly put new life into ammonia production in the US, the domestic fertilizer consumers, specifically of anhydrous ammonia, are faced with a new challenge: escalating rail costs. Anhydrous ammonia is labelled as a toxic inhalation hazard (TIH) material. The federal government requires that TIH materials be carried by railroads under common carrier obligation law, however railroad entities believe that the liability of carrying such materials has been unfairly put on them. Attempts have been exhausted to find a good substitute for anhydrous ammonia in the market place, and now consumers are faced with paying hefty freight charges to compensate for the insurance coverage that the railroads carry on this cargo. Additionally, some railroads have limited the quantities of rail cars of anhydrous ammonia that they will carry per train to attempt to cap risk. Over the last four decades, competition in the rail industry has essentially been wiped out – from 31 Class I rail carriers to only seven today (four major) – which has had detrimental effects on remedying the transportation liability situation for the agriculture industry. The Surface Transportation Board was put in place to try and remedy this situation, but to date has not done anything impactful to aid fertilizer consumers (side note: new appointments to this committee are pending and industry players are hopeful for positive change).

Until changes can be made at the regulatory level, shippers of TIHs face hefty surcharges and expensive insurance requirements to transport anhydrous ammonia to the consumers. In the US, significant ammonia demand is in the mid-continent agricultural belt, where, for the most part, demand is met by railed product to the region from the USGC or Canada. There is some local production of ammonia today, however, much of it is converted to other fertilizer compounds that are not classified as a TIH such as urea. This has caused a critical demand for anhydrous ammonia in the mid-continent region to meet the nitrogen needs of the farming industry there.

World scale ammonia production complexes are designed to produce over of 700,000 tonnes per annum. A facility of this size in the mid-continent agricultural belt would still require railcars for movement of the product to the consumers since local, truckable distance demand would not be sufficient to meet that production level. Faced with how to avoid the costly surcharges and insurance, some producers are looking for ways to scale down in order to make localised anhydrous ammonia that can be distributed cost effectively by truck within a 100 mile radius.

Scaling to the market

While the ammonia market in the US has seen a rebirth over the last several years, the challenges that producers are facing to meet the growing demand for fertilizer products in the US mid-continent have not dissipated. Additionally, large scale production of ammonia and derivatives on the USGC are now open to the export market, meeting the fertilizer demands in regions of the world where natural gas is priced at two or three times that of the USGC. With the expansion of the Panama Canal for larger vessels, the export market in the Far East can now access cheaper NG-based products from the US and in larger volumes.

With the agricultural belt consumers competing against this export market for supply as well as facing escalating transportation costs for anhydrous ammonia, the supply availability for the mid-continent is in danger. A solution is desperately needed.

Technology solution

As a means of addressing the rising costs of anhydrous ammonia due to rail costs, Linde Engineering, a global technology and EPC company, is combining its modularisation know-how with technology simplification to design a fully modular small-scale ammonia production plant for the US mid-continent market with a nominal capacity of 100 t/d to 300 t/d.

As a global leader in industrial gases, Linde has developed cost competitive and highly efficient production facilities for the generation of hydrogen and nitrogen; the basis of the Linde Ammonia Concept™ (LAC) (Fig. 2). The generation of high purity hydrogen (H_2) and high purity nitrogen (N_2) with minimal inerts is the foundation of the LAC™. The simplification of syngas generation leads to reduced capital and complexity in ammonia synthesis.

Hydro-Chem, a division of Linde Engineering North America, specialises in modular small-scale high purity hydrogen production to serve the refining, chemicals and fertilizer markets. Based on a foundation of process simplification and full modularisation, Hydro-Chem plants economically produce hydrogen in capacity ranges of 0.27 to 25 mmscfd (300 to 28,000 Nm³/h). These plants are deployed globally in a variety of uses; the smallest are compacted fully onto one truckable skid (HYDROPRIME® Min) and the largest, the HYDROPRIME® Max are based on a box reformer with a single row of tubes, which can be modularised and stacked to maximise shop fabrication and minimise on-site construction. These conventional steam-methane reformer (SMR) based hydrogen production units (HPU) generate high purity hydrogen from pipeline natural gas with high reliability and operational flexibility (Figs. 3-5).

In a simpler fashion from Linde's world scale HPUs, the Hydro-Chem plants utilise a high temperature water-gas shift reactor only (in lieu of the more sophisticated and higher efficiency isothermal shift reactor) in combination with a pressure-swing adsorption system (PSA) to generate the require purity of hydrogen for ammonia synthesis.

High purity nitrogen is the second building block of anhydrous ammonia, and as one of the world's largest industrial gas companies, the production of high purity nitrogen in packaged air separation units is the sweet spot of Linde Engineering. These packaged nitrogen generation plants are deployed worldwide, and can be remotely operated for reduced field operator requirements.

Combining high purity nitrogen and hydrogen at the right stoichiometric ratios from these established and simplified production units is a cost-effective methodology to produce syngas for ammonia synthesis. Maintaining an appropriate level of operating pressure that is available from pipeline natural gas facilitates reduced synthesis gas (syngas) compression requirements ahead of the ammonia synthesis converter. Even the ammonia synthesis converter can be simplified into two stages instead of the more capital intensive and higher efficiency three-stage reactor; this configuration is more cost effective at the exchange of a small amount of efficiency – critical to the economic viability of ammonia production at such small scale. Additionally, the use of extra-high purity hydrogen and nitrogen for the ammonia synthesis removes the need for a purge gas loop within the ammonia synthesis production, reducing capital and conserving energy (Fig. 6).

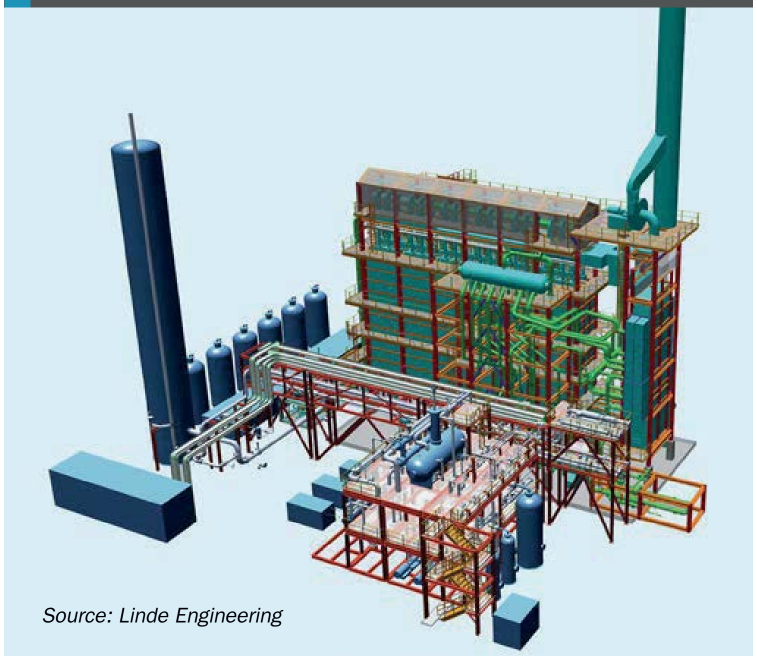
Fig. 3: **HYDROPRIME® Min**

PHOTO: LINDE ENGINEERING

Fig. 4: **HYDROPRIME® Mid**

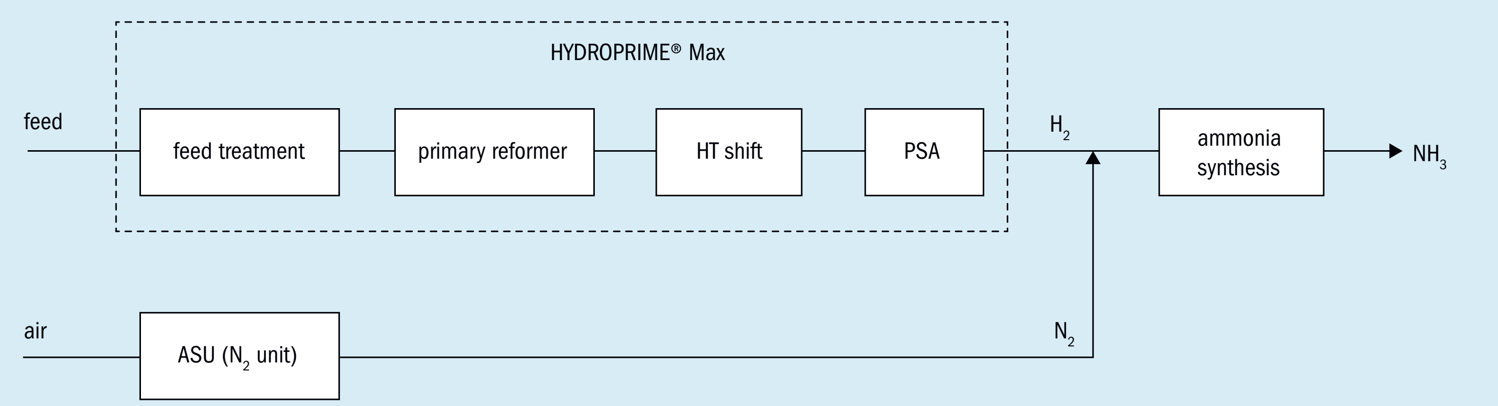
PHOTO: LINDE ENGINEERING

Fig. 5: **HYDROPRIME® Max**



Source: Linde Engineering

Fig. 6: **LAC modular**



Source: Linde Engineering

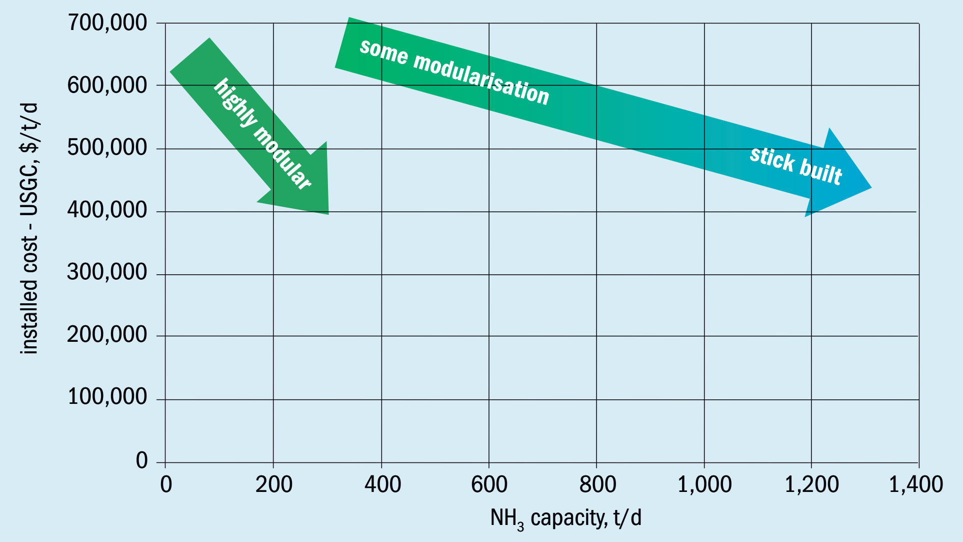
Modularisation for cost competitiveness

It is generally well-accepted that installation costs of production units such as these carry the largest risk in field construction scope. With smaller plants, field construction of a stick-built facility can become a larger portion of the overall installed cost, and therefore exacerbate the risk of the economic viability of the project as related to field construction. To enable projects of smaller scale to have reduced implementation risk, Linde has adopted a "modularise to the maximum" philosophy for all of its process plants. Shop fabrication of equipment on skids that can be trucked, or even super-modules that are transportable by ocean-going vessels, reduces the risk of field errors and misses, and improves quality control in a tightly-monitored shop environment. Additionally, the transportation of a dozen pre-fabricated modules as compared to the transportation costs, schedule implications, and damage risks of moving individual equipment, valving, instruments and bulk piping is significantly favourable.

There are many highly effective modularisation shops all over the globe with this expertise, and Linde Engineering has worked with many of them, as well as having its own shops for this process intensification. In fact in North America, Linde Engineering has a modular fabrication shop at its Hydro-Chem location in Holly Springs, Georgia, as well as on the Port of Catoosa, Oklahoma, where sea-bearing modules can be fabrication and moved down the river to the Gulf of Mexico.

As for ammonia production, the utilisation of the modular concepts already employed by Hydro-Chem for HPUs, packaged nitrogen generation units, and overall process simplification can allow for very small ammonia production that is cost competitive with much larger stick-built or partially modular ammonia plants (Fig. 7).

Fig. 7: **Modular vs stick built**



Source: Linde Engineering

A balance of capital and energy consumption

Ammonia producers looking to build local US mid-continent production for localised distribution are some of the most cost-conscious generators, however, they cannot afford to relax completely on production efficiency. It cannot be ignored that ammonia production requires a significant amount of gas compression; the ammonia synthesis process is more efficient at higher pressures. However, there is a trade-off of capital, compression costs, refrigeration requirements, and energy usage (mostly due to compression and refrigeration) that must be considered. This delicate balance of capital and energy consumption is even more sensitive at these reduced economies of scale, and in regions where electricity prices are often not solely based on natural gas electricity generation. The LAC Modular concept addresses that balancing act by optimising the operating pressure of the HPU and ammonia synthesis plant around ammonia purity and storage requirements for plants which will effectively function as local distribution centres for anhydrous ammonia. The use of Hydro-Chem's modular HPU, a packaged nitrogen generation unit, and a modularised, simplified ammonia synthesis plant that doesn't sacrifice efficiency for capital intensity is a viable option for local US mid-continent demands for anhydrous ammonia that cannot otherwise be economically met.

Editor: RICHARD HANDS
richard.hands@bcinsight.com

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

Contributors:
ALISTAIR WALLACE
alistair.wallace@integer-research.com

MIKE NASH
mike.nash@ihs.com

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

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