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Cover: *Offshore wind farm.*
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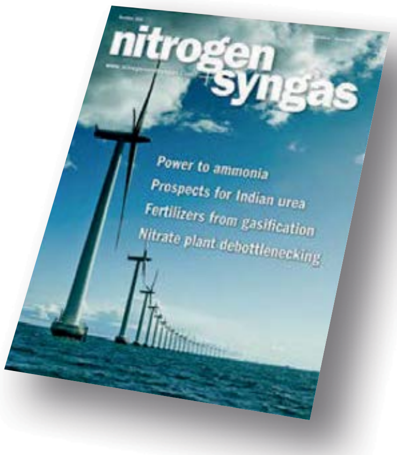
Published by:
BCInsight

Nitrogen fixing gathers pace



> **[This] could have the potential to radically reshape the artificial nitrogen fertilizer industry.**

We've reported before on attempts to spread the nitrogen fixing ability of plants like legumes to staple food crops like cereals. Allowing such nitrogen-hungry plants to absorb that nitrogen directly from the air around them in the same way that they do carbon dioxide is something of a holy grail for bioscience companies, and could have the potential to radically reshape the artificial nitrogen fertilizer industry – currently the market for 75% of the 180 million tonnes of ammonia consumed every year.

There have already been various university-led projects to try and see if cereal crops can be persuaded somehow to mimic legumes' ability to 'fix' atmospheric nitrogen, many involving inoculating plant roots with the same nitrogen-fixing bacteria that legumes use. Inoculation is already used in legumes to boost their own nitrogen-fixing ability. However, the major development in the field which happened last month was that German chemical giant Bayer announced that its LifeSciences division would be partnering with American biotechnology company Gingko Bioworks to launch a new $100 million – so far unnamed – agricultural technology start-up company, bringing the knowledge resources and corporate financial muscle of Bayer to bear on the problem. Bayer says that the new company "will focus on transformational beneficial microbes for plants to provide growers with next generation solutions to their biggest challenges. Initial activities will focus on nitrogen fixation, minimising agriculture's environmental impact. The work combines the synthetic biology leadership of Ginkgo Bioworks with Bayer's deep knowledge and experience in agriculture and microbial products."

The key to legumes' remarkable ability to fix atmospheric nitrogen comes from a symbiotic relationship with a class of bacteria call rhizobia which congregate in the plants' root nodules. The bacteria lie dormant in the soil, but in the presence of the right kind of plants infect the roots and absorb organic acids from the plant as their food and energy source, in return converting nitrogen into ammonium ions, which the plants can process into amino acids and other useful molecules. What the Bayer-Gingko team will be trying to determine is what makes legume roots attractive to the bacteria, and whether this property can be duplicated in other plants, perhaps by genetic engineering. Bayer says that it already has an extensive collection of microbes which it knows work well with particular crops, and Gingko will be helping to modify these to see if they can duplicate the nitrogen fixing properties of rhizobia.

The advantage for famers in places like Africa, where fertilizer can be scarce and expensive, is pretty clear. But at the moment there are still questions about nitrogen leaching. This is, apparently, not just a bane of fertilizer nitrogen over-application. Most nitrogen-fixing crops also produce excess nitrogen which can leach into the environment in a similar way.

But Bayer and Gingko are not the only companies working on this problem. A different approach is being investigated by Plant Genetic Engineering Inc, associated with Stony Brook University, New York. Here the aim is to engineer plants' own cells with the genes that encode the enzymes needed for nitrogen fixation and nitrification. This is already done by cyanobacteria, and Plant Genetic Engineering hope to be able to introduce cyanobacteria into plants in the same way that chloroplasts – the parts of plant cells which conduct photosynthesis – were originally incorporated by plants. Chloroplasts are descended from bacteria that once lived independently of plant cells. At the moment the focus is not on cereal crops but tobacco, mainly because the tobacco plant genome is already well characterised and understood.

The promise of nitrogen-fixing cereal crops is clearly understandable. However, the technical challenges are also clearly equally formidable. Nevertheless, the news that Bayer is willing to commit significant resources to its development is an indication that this is an area to watch.

Richard Hands, Editor

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Price trends

MARKET INSIGHT

Laura Cross, Senior Analyst, Integer Research, assesses price trends and the market outlook for nitrogen.

NITROGEN

A steady string of Indian urea import tenders have provided important price markers for the industry in recent months, in the face of temporarily reduced supply from some key exporters. A purchase tender was announced on 1 September by Indian Potash Limited (IPL), under which it received 325,000 tonnes of its desired 500,000 tonnes. The tender closed on 8 September for shipment by 23 October. The lowest offer was from Comzest at $241.22/tonne c.fr for west coast India and $251/tonne c.fr for east coast India from Amber. IPL made a counter offer of $246.91/tonne c.fr for east coast India and matched Comzest's offer of $241.22/t c.fr for west coast. The final price was settled at $245.50/tonne c.fr. Only 11 offers were made, totalling 729,000 tonnes, because of lack of availability out of Arab Gulf countries including Iran and Saudi Arabia, and higher margin sales into other markets such as Turkey.

In mid-September, the urea price soared by another $20-30/t in the space of a week when IPL announced another import tender on 16 September, for shipment by 8 November. This unexpectedly early tender prompted prices ideas from the Arab Gulf of around $270/t f.o.b., followed by Egyptian sales to the Americas at around $300/t f.o.b. IPL received 16 offers for a total of 1.1 million tonnes of urea under the mid-September tender. The lowest offers received were from Aries at $284.66/t c.fr for east coast India, and from Transagri at $285/t c.fr for west coast. These prices were almost $40/t higher than the previous tender, continuing the price momentum and tight seasonal supply caused by maintenance turnarounds and contract commitments from the usual sellers to India.

The Indian government amended its urea import policy conditions in late-September in order to ensure domestic requirements. On 26 September 2017, the government extended import licenses to two urea producers – Rashtriya Chemicals & Fertilizers (RCF) and National Fertilizer Limited (NFL). Previously, only STC, MMTC and IPL were permitted to issue import tenders. RCF issued its first import tender on 14 October, receiving 17 offers totalling 1.4 million tonnes. The lowest offers received were from Aries at $290.66/t c.fr for east coast delivery, and from Fertrade at $291.72/t c.fr for west coast. RCF ultimately sourced 426,000 tonnes of urea under the tender from a combination of Middle East, Chinese and Baltic sellers, at prices around $5/tonne than the previous purchase by IPL.

Table 1: **Price indications**

Cash equivalent	mid-Sept	mid-July	mid-May	mid-Mar
Ammonia ($/t)				
f.o.b. Caribbean	200	205	285	295
f.o.b. Arab Gulf	230-260	180-190	295	350
c.fr N.W. Europe	240-260	230-250	325	365
c.fr India	240-270	209-240	340	360
Urea ($/t)				
f.o.b. bulk Black Sea	224-234	181-190	175	237
f.o.b. bulk Arab Gulf*	227-232	153-187	176	211
f.o.b. bulk Caribbean (granular)	190-198	160-183	210	218
f.o.b. bagged China	248-255	207-212	210	231
DAP ($/t)				
f.o.b. bulk US Gulf	333-337	344	355	375
UAN (€/t)				
f.o.t. ex-tank Rouen, 30%N	141-143	133-137	157	169

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

The global nitrogen market remains in a state of oversupply, although prices looked firmer in Q3 2017 as the market entered a period of seasonal demand and China remained largely out of the export market. Despite the short-term improved price sentiment, the market still remains in a fundamentally weak state with new capacity additions in the rest of 2017 forecast to keep the market in oversupply. Urea prices were more stable in Q2 and Q3 2017 than at the start of the year, driven primarily by the noteworthy reduction in Chinese export volume which kept price ideas to seasonal buyers firmer than they would have been otherwise.

Typical urea ex-works costs per tonne increased or remained flat in all regions in our sample except Ukraine, where the region continued to benefit from gas diversification and depreciation of the hryvnia. Typical urea producer unit margins grew by an average of 27% between May and August 2017.

Through the early part of 2017, the Chinese government eased production restrictions on coal, leading to price decreases, but more recently, restrictions have come back into play, causing anthracite and thermal prices peaking at their highest levels of 2017. There are suggestions that the Chinese government may reduce operating rates of industrial enterprises (including urea plants) in Northeast China by up to 50% during the winter heating season to alleviate further upward pressure on coal prices.

In contrast, the ammonia price decreased steadily throughout Q2 2017 and into Q3 following a tighter Q1 2017 as a result of temporary supply outages. The Tampa ammonia price was settled at a $25/tonne increase in September and other benchmarks followed suit in preparation for refill application buying.

September marked a turning point in ammonia price sentiment, as price ideas began to improve due to stronger demand in the face of several supply interruptions to key ammonia exporters.

Following a three-month period of consecutive price decreases that began in May, the Yuzhny Black Sea ammonia price broke the $200/t f.o.b. boundary in mid-September, before swiftly moving towards $220/t by the end of the month. The Tampa contract price increased by $30/t between September and October, increasing to $245/t c.fr. Although this price increase was larger than expected, the ammonia price remains drastically below other nitrogen products on a nutrient value basis. ■

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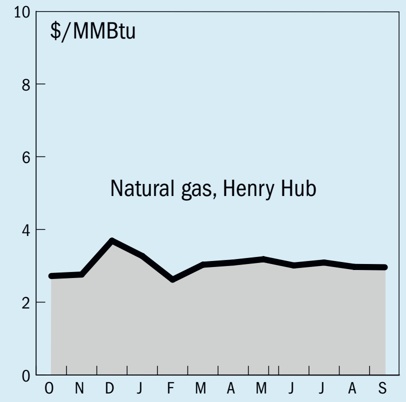
END OF MONTH SPOT PRICES

natural gas



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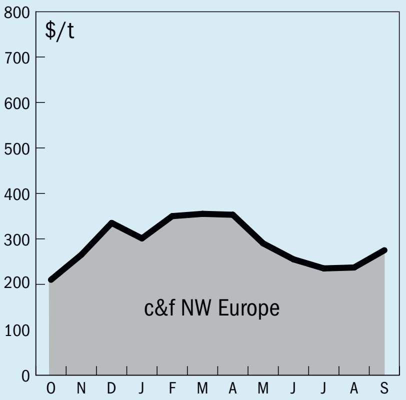
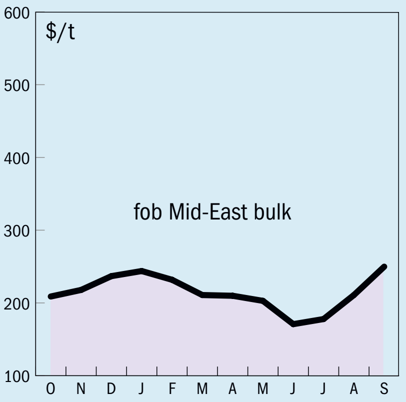
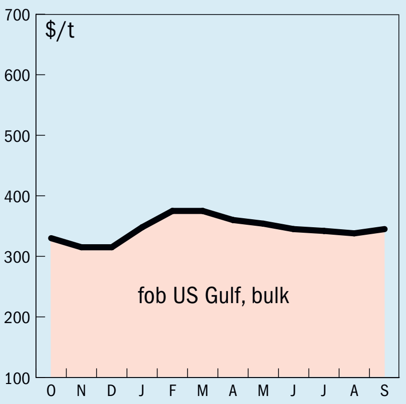


urea



diammonium phosphate



MARKET INSIGHT

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

METHANOL

Methanol prices increased further in September. Asian prices traded $40 higher, in range of $315-355/t, c.fr; China average prices were up $42 at $312.5-355/t, c.fr. Methanex's posted APCP for October is $400/t, an increase of $50/t over its posted price for September. European spot prices (T2 f.o.b. Rotterdam) for September were €9 higher than up their August level at €267/t over the month. Methanex posted its 4Q 2017 West European Contract Price at €330/t, f.o.b. Rotterdam T2, an increase of €10 on the previous quarter. The 4Q 2017 West European Contract Price was settled at €318/t, f.o.b. Rotterdam T2, up €3/t from 3Q 2017. The ongoing suspension of duty on methanol arriving into the EU implemented by the European Commission is likely to remain for the foreseeable future. The official, posted reference prices from the two main US producers for October were $1.19/gal for Methanex (up 3 cents from September) and $1.14/gal for Southern Chemical Co. (a rollover), equivalent to $396/t and $379/t respectively.

In operations, global utilisation rates in September were around 2% lower than August 2017, at around 67% of nameplate capacity or 80% of effective capacity, with unexpected outages in the Middle East and US production units impacted by Hurricane Harvey. In Iran, natural gas restrictions continued to constrain operating rates in early September. In Saudi Arabia, Ar Razi II, III and IV were offline for most of September due to a combination of temporary gas shortages and unexpected operating issues. Trinidad's operating rate in September remained around 89%, while Methanex's Chilean unit continued to be impacted by seasonal gas allocations. In China, overall capacity utilisation was very similar to August, at around 57% of nameplate capacity or around 74% of effective capacity. A new methanol unit, Hualu Hengsheng (1.0 million t/a, coal-based) began its production trial at the end of September, with commercial production expected in October.

In the Americas, methanol demand into all derivatives, especially acetic acid, was impacted by Hurricane Harvey in the first half of the month; the situation eased in the second half of September, as production rates improved and logistics issues were resolved. We will likely see a late year bump in demand from reconstruction efforts in Texas and Florida related to wood products as well as derivatives used in home appliance manufacturing and coatings demand via MMA. Additionally, as up to one million vehicles are estimated to have been destroyed in Houston alone, this will lead to high new car sales in September and 4Q 2017.

In India, port prices started the month at an average of $292.5/t c,fr T1 and finished the month $42.5 higher at $335/t; domestic prices increased from 25 Rs/kg to 26.5 Rs/kg during the month. The increase was due to operational issues in the Middle East, higher prices in China and rising domestic demand. European demand was stable in August. Demand into formaldehyde saw a seasonal decline and an ongoing force majeure at a facility in Germany. Biodiesel demand was stable at low levels, due to pressure from low crude oil prices, which make it less competitive against traditional diesel. Acetic acid demand was steady at good levels, with all major regional producers running. Rhine water levels started and ended the month at a relatively low level of 142 cm, despite rising to 248 cm on 4 September and 223 cm on 15 September. Below a level of around 160 cm, barges have to be short-loaded, increasing unit logistics costs and tightening barge availability.

In China, methanol consumption in the MTO sector increased during, averaging a high level of around 91%. The MTO section of Fund Energy Changzhou has been offline since the end of March, with no re-start date announced. Formaldehyde prices rose with recovering demand and higher feedstock prices. DME operating rates remained very low.

In Southeast Asia, demand into acetic acid improved in the second half of the month with the re-start of the two major regional production units after outages. In Korea, supply was tight and demand into traditional end-uses was satisfied via term contracts. In Taiwan, supply was tight and methanol demand increased in late September after one of the major domestic acetic acid units resumed production. ■

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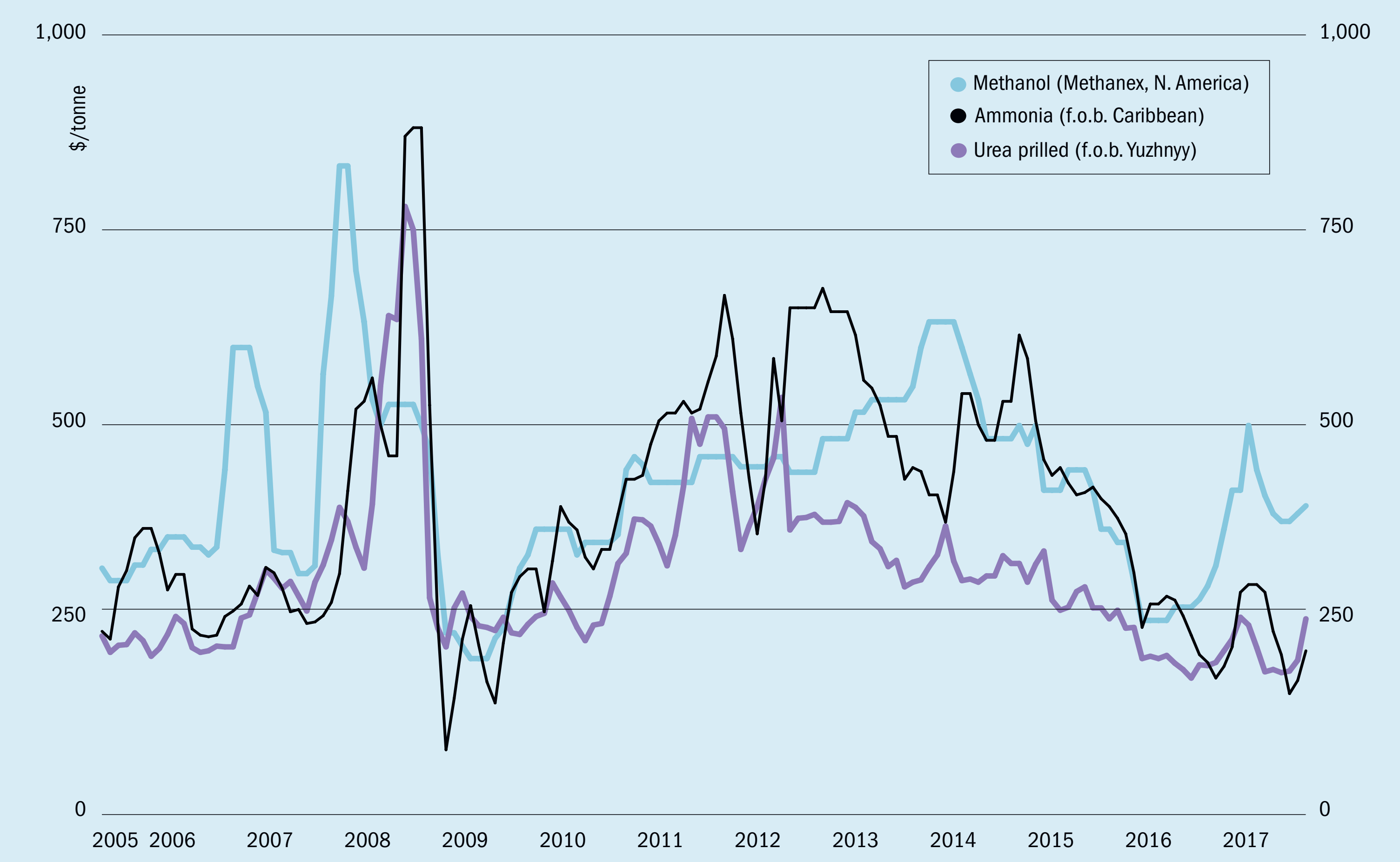
Market outlook

Historical price trends $/tonne



Source: BCInsight

AMMONIA

- Seasonal refill demand for ammonia in the US is forecast to keep prices firm until December 2017. Similarly, the recent spate ammonia supply outages looks likely to continue in the short-term, tightening the supply-demand balance in Q4.
- In Saudi Arabia, the SAFCO IV ammonia and urea plant went offline on 23 September for a scheduled 84-day turnaround which will remove more than 100,000 tonnes of merchant ammonia from the traded market.
- There has been some price firming in 3Q 2017 due to plant outages, but in Q1 2018 ammonia prices are forecast to soften again as planned turnarounds come to an end and seasonal fertilizer demand slows. Prices are expected to remain above $200/tonne f.o.b., however, as high-cost exporters move away from ammonia towards better-margin products and in doing so, reduce some of the oversupply burden.

UREA

- Following the sharp price increases in September and October, the outlook for the remainder of 2017 is uncertain, although prices are expected to reduce from their current levels once Indian buying comes to a close. Lower exports from China have helped keep prices firmer than they might otherwise have been.
- Spring pre-buying in Q1 2018 is expected to stimulate prices somewhat, although developments in regional price benchmarks will be driven by the timing of new project commissioning, such as in the US.
- In Bolivia, the Bulo Bulo granular urea plant moved closer to full completion in October, and government officials from the country's agricultural regulatory agency have carried out final storage facility inspections. Once approval is given, YPFB plans to export around 80% of the urea produced at the 2,100 t/d plant to Brazil, Argentina and Paraguay.

METHANOL

- Methanol prices have been rising on a combination of unexpected outages in places such as Saudi Arabia and lack of gas availability in the Middle East, Chile and other regions. Hurricane Harvey also temporarily impacted upon US production.
- Longer term, the impact of Hurricane Harvey on the Houston area is expected to see a boost to US construction, coatings and new auto buying, which may affect methanol demand into chemical derivatives such as formaldehyde, acetic acid and MMA next year.
- In the EU, suspension of duty on methanol imports is set to continue.
- Chinese MTO production continues to drive merchant demand there, and the knock-on effect of China's dominance in the methanol market is a growing influence on global pricing dynamics, as MTO plants become the global 'buyer of last resort', willing to take methanol at (almost) any price.

Nitrogen Industry News

AUSTRALIA

East coast users face gas shortages

Australia's east coast gas markets are facing a shortfall of gas in 2018 of 1.3-2.4 billion cubic metres according to a recent report from the Australian Competition and Consumer Commission. Although gas is plentiful along Australia's coasts and in some onshore fields, a combination of insufficient east-west pipeline capacity, large new LNG exporters in Queensland and moratoriums on gas exploration and development in states such as Victoria, New South Wales and the Northern Territories mean that there are fears there may not be enough gas for domestic industrial users in future. The government says that it is considering export and/or price controls on LNG to resolve the situation if gas exporters and State regulators are not able to work towards reducing the potential shortfall. Among those complaining of the two-tier market, which sees west coast gas prices at around US$4.90/MMBtu for industrial users, but $8-13/MMBtu for east coast consumers, are fertilizer producers such as Orica, which operates a 360,000 t/a ammonia plant at Kooragang Island near Newcastle, New South Wales. The company's chief executive Alberto Calderon has called the situation "myopic and unsustainable," and said that his own company was at a "crisis point".

UNITED STATES

Stamicarbon acquires 20% stake in Pursell Agri-Tech

Maire Tecnimont says that its Stamicarbon subsidiary has bought a 20% stake in Pursell Agri-Tech, LLC, a US-based start-up company which specialises in developing and marketing polymer-coated, controlled-release fertilizers. Stamicarbon's investment is put at $5.5 million. Pursell Agri-Tech, headquartered in Sylacauga, Alabama, has developed a new technology to coat fertilizers at competitive cost levels in order to produce controlled-release fertilizers suitable for efficient fertilization of broad-acre commodity agricultural crops. The technology combines proprietary polymer compositions and a high-performance coating process to deliver a range of controlled-release fertilizers, notably urea, resulting in, the company says, a highly sustainable crop nutrient solution that boosts farmers' yields while also reducing the potential impact on the environment.

Stamicarbon and Pursell have also entered into an industrial cooperation agreement whereby Stamicarbon will be the exclusive global licensing partner, licensing the technology to interested parties outside North America, such as major urea producers, and large fertilizer producers or distributors, while Pursell Agri-Tech will develop with selected dedicated partners the North American market, where Stamicarbon will act as a non-exclusive licensing partner. The parties will also work closely together in an open innovation platform on the development of other new businesses and technologies.

"This strategic investment opens us a new promising market, such as the coated fertilizers', and represents a new milestone in the Group's strategy of developing innovative technologies adjacent to our core business", commented Pierroberto Folgiero, CEO of Maire Tecnimont Group.

Nick Adamchak, Chief Executive Officer of Pursell Agri-Tech said: "Pursell Agri-Tech is delighted to welcome Stamicarbon as a shareholder and to enter into this strategic partnership with them. We're confident it will allow for better fertilizers to become widely available, paving the way for more sustainable climate-smart agriculture worldwide."

Fire at LSB Industries shuts ammonia plant

LSB Industries was forced to take its Pryor, Oklahoma ammonia plant out of service on September 23rd after a minor fire at the site. The company said that it expected production to resume by the end of October. In the meantime, the unplanned outage will be used to repair damage to electrical controls, wiring and piping. LSB said that no staff were injured, and there was no damage to the reformer or other major equipment items, and no release of ammonia. The company said that it will meet customer commitments for pre-sales of products by either shipping from other facilities or by purchasing them from third parties. As a result, the ammonia plant downtime will not result in reductions of urea ammonium nitrate (UAN) or ammonia sales volumes. The cost of repairs, together with the cost of buying UAN rather than producing it and the lack of contribution to fixed costs will total around $1.5-2.0 million in 3Q 2017 and $2.5-2.75 million in 4Q 2017. The company said that it would provide an update on the progress of the repairs and the impacts of the downtime on financial results when the company reported its 3Q results in late October.

US nitrogen imports to decrease

Fertecon, part of Informa's Agribusiness Intelligence, says that US imports of nitrogen fertilizer will decrease significantly as 11 million t/a of new domestic nitrogen capacity coming on-line over the next few years. Between 2015 and 2018, over 11 million t/a of nitrogen fertilizers capacity will enter the US market (3.6 million t/a ammonia, 4.9 million t/a urea and 2.9 million t/a of UAN). This will displace imports from previous key suppliers; ammonia exports from Trinidad to the US have been displaced to markets in Europe, North Africa and even Asia, while Russian exports to the US have dropped sharply.

The coming years are set to see some further seismic shifts in global nitrogen markets as China adjusts to a low growth environment; concerns over pollution of waterways arising from over-application of fertilizer have led the government to target a reduction in growth to 1% per annum to 2020, with 0% as the long-term target. Meanwhile, low energy prices have flattened cost curves, with implications for low and high cost producers alike. In Sub-Saharan Africa, fertilizer demand in has grown at almost 9% per annum on average, and strong growth is forecast to continue, increasing regional fertilizer consumption by over 4 million tonnes over the coming decade.

Alan Pickett, Principal Consultant at Fertecon commented: "With the global fertilizer market experiencing lower prices across the board in the wake of capacity investments made over the last five years, the less efficient producers are being pushed out while others are developing new products to counteract the resulting decline in margins. The restructuring trends are set to continue for the foreseeable future, but the fertilizer industry is cyclical and prices are expected to recover in the years ahead when the impact of recent investments has been absorbed."

INDIA

Start-up for Matix Fertilisers urea plant

Matix Fertilisers & Chemicals says that it has started production at the company's new $1.1 billion urea plant at Panagarh in West Bengal. The 1.3 million t/a capacity plant, uniquely, uses coalbed methane (CBM) as feedstock. Matix managing director P.R. Dhariwal told local media that the plant is currently operating at 40% capacity, but that it was anticipated that it would ramp up to full capacity by the end of 2017. He added that the plant, located close to the feedstock source as well as the fertilizer consuming region of northeast India, would be key to the fertilizer security of India's north-eastern states. The gas comes from Essar Oil's Raniganj block, with a 30km dedicated pipeline bringing the gas to the ammonia-urea facility. The company has also set up a captive power plant with capacity of 54 MW, which supplies not just the nitrogen complex, but will also be able to supply power to markets in West Bengal and neighbouring Bihar, Jharkhand and Odisha states.

BRUNEI

Brunei awards EPC contract

Brunei Fertilizer Industries has awarded thyssenkrupp Industrial Solutions the engineering, procurement and construction (EPC) contract for the company's new greenfield fertilizer facility at the Sungai Liang Industrial Park. The complex, which is due for completion in 2021, will have a production capacity of 2,200 t/d of ammonia and 3,900 t/d of urea, as well as a downstream granulation plant. thyssenkrupp's scope of supply for this fertilizer complex will include the engineering, supply of equipment, erection, supervision of construction and commissioning as well as various offsite and related utility systems. The new plant project will support the government's long-term development strategy to diversify the country's economy.

Peter Feldhaus, CEO of thyssenkrupp's Industrial Solutions business area said: "We are proud to work together with Brunei Fertilizer Industries to support the country's transformation into a diversified industrial economy. Being selected to develop this lighthouse project is an important milestone for our fertilizer plant business. This major order will further strengthen our market position and growth in the Asia Pacific region."

Dato Bahrin Abdullah, Chairman of Brunei Fertilizer Industries: "We have chosen thyssenkrupp for our investment project as the company combines vast experience in engineering, procurement and construction with proven and cost-efficient fertilizer production technology, ensuring the highest environmental standards. Together, we will help accelerate the nation's economic growth in a sustainable way and expand employment opportunities for its people."

TURKMENISTAN

Urea project 80% complete

State owned Turkmenhimiya's new $1.3 billion ammonia-urea plant at Garabogaz is 80% mechanically complete, according to the company. Construction is being carried out by 5,600 workers working for the EPC contractors Mitsubishi Corporation and Turkey's Gap Insaat. Turkmenhimiya says that emergency diesel generators and air supply units have been completed, and testing of high pressure pipelines is ongoing, and that construction of a gas supply pipeline is nearing completion. At capacity the facility will produce 1.15 million t/a of urea, with around one third sold domestically and the rest exported. Ammonia technology is being licensed from Haldor Topsoe, with urea technology being provided by Saipem. There is also a downstream urea granulation unit which is being licensed by Uhde Fertilizer Technology (UFT). Training of 270 operations staff is also under way, as is construction of an export terminal at Garabogaz. The plant's on-stream date is set for June 2018.

BOLIVIA

YPFB urea plant begins production

The new ammonia-urea complex that has been developed by state-owned Yacimientos Petrolíferos Fiscales Bolivianos (YPFB) came on-stream in September at Bulo Bulo, near Cochabamba in central Bolivia, east of La Paz, according to the company. The plant was built by Korea's Samsung at a cost of $950 million, and will produce 650,000 t/a of urea at capacity. As well as providing for all of Bolivia's relatively modest urea requirements, which stand at around 30,000 t/a, the plant will also export urea. Brazil is the main target market, and an offtake agreement has already been signed. Other potential destinations for the urea include Argentina, Paraguay, and Peru.

GERMANY

New nitric acid compressor train design

MAN Diesel & Turbo has launched NAMAX, a new turbomachinery concept for the fertilizer industry, which the company says will raise production efficiency of nitric acid. The NAMAX concept is based around an AG-MAX1 axial air compressor. While previous designs made use of an intermediate gearbox to couple the machines in the train, MAN says that NAMAX uses a direct drive, meaning that a gearbox is not required, allowing efficiency to be boosted by several percentage points, whilst simultaneously allowing the energy input and operating costs for HNO_3 production to be decreased. NAMAX also comprises a centrifugal compressor for NOx compression, a MAN steam turbine and an axial expander providing the drive power. As all four machines are sourced together, they can be matched for maximum efficiency. MAN says that it will supply a NAMAX compressor train to thyssenkrupp Industrial Solutions for use in an expansion at Grupa Azoty's nitric acid plant in Poland.

SPAIN

AMETEK to supply imaging technology to Air Liquide

AMETEK Land has supplied its real-time, thermal imaging Near Infrared Borescope (NIR-B) 3XR to Air Liquide to monitor catalyst life at its Madrid plant. The NIR-B 3XR, which was launched to the industrial gas sector in 2016, is able to continuously measure reformer tube wall temperature (TWT), for furnace optimisation and monitoring, allowing highly accurate temperature point data to be measured, stored and trended over the lifetime of the furnace. Continuous analysis of the tubes enables more informed decisions, leading to greater plant reliability and productivity.

Gonzalo Navarro, production manager at Air Liquide Ibérica de Gases, Madrid said: "Our steam methane reformers produce hydrogen and carbon dioxide industrial gases and are business critical assets. However, they are also challenging assets to operate and maintain. Our main reason for this investment is to extend tube and catalyst life – and we are already starting to see the benefits."

RUSSIA

Metafrax selects Casale for Gubakha complex

PJSC Metafrax has awarded Casale a contract for engineering, equipment supply and construction management of Metafrax's new nitrogen line, to be built at the company's existing site at Gubakha in Russia's Perm region. Casale will act as technology licensor and EPC contractor for the entire project, which includes: an 890 t/d (290,000 t/a) ammonia plant using Casale's A2000C technology; a 1,725 (570,000 t/a) urea plant incorporating Casale *Split Flow* and *Full Condenser* technologies; and a new 40,000 t/a melamine plant, using *LEM* technology. The ammonia plant will use hydrogen feed from the purge gas of the methanol plant at Gubakha, while a MHI-designed carbon dioxide recovery unit will recover 1,200 t/d of CO_2 from the methanol plant reformers to be used as feed for the urea plant, greatly increasing the integration and hence efficiency of the whole complex. Metafrax had previously contracted Casale to expand the methanol plant from 2,500 t/d to 3,375 t/d over the course of two decades, most recently by installing a new partial oxidation unit section in parallel to the existing reformers.

V. Daut, general director of Metafrax commented: "We decided to proceed in partnership with Casale because we saw a big advantage in having one single licensor for ammonia, urea and melamine, in combination with their deep knowledge of our existing methanol plant. We believe that, with its experience in all kind of revamp, Casale will realise optimal technical solutions for integrating the new units of the complex into our existing methanol plant"

UKRAINE

Sanctions imposed on Russian fertilizer producers

The Ukrainian economy ministry has imposed sanctions against 10 EuroChem subsidiaries, as well as other Russian-owned fertilizer suppliers, including Galaktika, Rusagrokhim, Bosnis, Agrokhimuniversal, Agrocenter-Belgorod, Agrochemcenter-Tambov, Ryazanagrokhim, Yugagrokhim, Zaraiskaya Selkhozkhimiya, Agrarnik, Tselinskagrokhimservis, Yug-Businesspartner, Tandem, Agrochemistry, Farmers Support Society and Balttreidkhim. The ministry claims that the companies are supplying nitrogen fertilizers, particularly ammonium nitrate, to the Donetsk and Lugansk regions without customs clearance – these two regions in the east of the country are currently in the hands of Russian-backed separatist rebels. The sanctions take the form of suspension of foreign economic activities of the companies.

"It is established that these companies are supplying nitrogen fertilizers (ammonium nitrate) to the territories of Donetsk and Lugansk regions that are temporarily not controlled by the Ukrainian authorities without customs clearance via the closed checkpoints or checkpoints on the Russian-Ukrainian border forbidden by the government," the Prosecutor General's Office said. According to the ministry, the funds paid to the self-proclaimed Donetsk and Luhansk Peoples' Republics for customs clearance of mineral fertilizers were subsequently used to finance "illegal armed groups".

EuroChem, which in September transferred ownership of its Russian subsidiaries to its Swiss-based holding company, says that it "considers these restrictions to be indefensible and will shortly apply to the appropriate Ukrainian authorities for a detailed explanation of the decision." The sanctions are currently set to apply for three months from the end of October.

UNITED STATES

Permits invalidated for Kalama project

Chinese-based Northwest Innovation Works (NWIW), aiming to build a $1.8 billion, 10,000 t/d methanol facility at Kalama, Washington State, has suffered a setback in the form of a ruling from the state Shorelines Hearings Board. The Board ruled in an appeal against the award of two environmental permits brought by three environmental groups; Columbia Riverkeeper, the Sierra Club and the Centre for Biological Diversity, in so doing agreeing with the complainants that the Port of Kalama and Cowlitz County had failed to fully evaluate greenhouse gas emissions from what would be the world's largest methanol plant. In its summary judgment, the board wrote it was "troubled by the project's emission of greenhouse gases without further evaluation of potential mitigation measures. Even without including all off-site sources, the project will emit more than one million tons of greenhouse gas annually, increasing Washington's total emissions by more than 1%." The decision returns the final environmental impact statement to Cowlitz County and the port for further analysis, and the two environmental permits previously issued are thereby invalidated.

In response, NWIW says that it plans to evaluate its next possible steps with the project. "We understand that the environmental policy in this state is evolving and we look forward to continuing our collaboration with regulators, stakeholders, and environmental and business leaders," NWIW president Vee Godley told local media.

Work begins on methanol plant relocation

US Methanol says that it has broken ground on its relocation of a methanol plant from Brazil to a brownfield site in Charleston, West Virginia operated by Dow Chemical. The plant will produce 195,000 t/a of methanol using natural gas as feedstock, and is expected to begin production in 2H 2018, according to the company. An appeal against the plant's air quality permit was recently thrown out by the West Virginia Air Quality Board. US Methanol, owned by Czech-based investment group KKCG, also has plans to relocate a second plant, with capacity of 150,000 t/a, but as yet has no firm date for this.

Foster Wheeler awarded methanol plant contract

Engineering consultancy Amec Foster Wheeler, recently purchased by Wood Group, says that it has been awarded a $604 million engineering, procurement and construction (EPC) contract to build a methanol plant in Louisiana. The plant, to be sited at St. James Parish, will be operated by Chinese-owned Yuhuang Chemical Intl (YCI).

"Winning this contract is a further demonstration of how we are leveraging our multi-market capabilities to better serve our clients, extend our presence in high-growth areas, such as the chemicals market, and contribute to the growth of our order book. We look forward to working with YCI to meet the project's challenges, and delivering safely and successfully this new world-scale facility to operate at full capacity," said Jonathan Lewis, CEO of Amec Foster Wheeler.

Small-scale hydrogen plant for California

H2 Renewables is looking to build a small hydrogen plant at Stillwater Business Park in the city of Redding, California, in order to supply hydrogen-fuelled vehicles. While H2 Renewables is generally looking at hydrogen production from electrolysis, local media reports suggest that this plant will actually use steam reforming of methane to produce 8.6 t/d of hydrogen. At a cost of $22 million, the plant is aimed to be up and running by mid-2019. H2 Renewables is reportedly looking to build the plant then sell ownership on to "a Pennsylvania energy company". Grants from the California Energy Commission are available in California to build a network of 100 hydrogen fuelling plants. Although there are only about 1,600 hydrogen fuel cell vehicles currently operating in the state, this is expected to rise to 37,400 hydrogen fuel-cell vehicles on the road by 2023.

IRAN

Japan to provide credit for Veniran methanol plant

The long-delayed Veniran methanol project, a 1.65 million t/a methanol facility in the southern port city of Assalouyeh, looks to be back on again after securing up to €220-230 million of financing from Japanese companies. Touraj Seyyed Arvanaghi, managing director of Veniran Apadana, said the Japanese finance would amount to around half of the costs of the new methanol plant, which is estimated to cost $550 million. The companies will provide a so-called usance (deferred payment) letter of credit, which typically includes a date of repayment up to six months from the date the letter of credit is issued, making it a useful financial tool for meeting short-term investments. Originally the fruit of a now-defunct collaboration between the governments of Venezuela and Iran which aimed to build two methanol plants, one in each country, Veniran Apadana is now owned by the semi-private Persian Gulf Petrochemical Industries Company (PGPIC), Iran's largest petrochemical company, 60% owned by the state, including a 20% direct share from the National Petrochemical Company (NPC).

SPAIN

Air Liquide commended for 3D printed hydrogen reformer

The European Federation of Chemical Engineering (EFCE) has awarded its 2017 Process Intensification Award for Industrial Innovation to an innovative project by Air Liquide involving the development of a 3D printed reactor used to increase the efficiency of hydrogen production. The reactor is a 3D printed milli-structured heat exchanger reactor designed specifically for the production of hydrogen by steam reforming natural gas. The reactor optimises the hydrogen-making process by reusing the heat used in the initial excess steam production and increasing the heat transfer between the hot process streams. According to Air Liquide, reusing heat has helped the reactor reduce operating costs by 20% and CO_2 emissions by 12%. Air Liquide began work on the 3D printed reactor in 2015, and has successfully tested the device at its Paris Saclay research centre (where the reactor was operational for over 3,000 hours).

The company is now building an industrial pilot plant (expected to be up and running by late 2018), and says commercial applications for its 3D printed reactor technology could be available as soon as 2020. It is confident that the reactor technology will positively impact a number of hydrogen-using fields, including oil and gas, floating liquefied natural gas, and even small scale hydrogen microgeneration.

CHINA

China plans massive industrial relocation

China plans to complete a massive $120 billion relocation of chemical plants away from major cities and into designated industrial parks by 2025, according to a document issued in September by the country's State Council. For small- and medium-sized plants, the relocation must begin by 2018 and be complete by the end of 2020, while larger plants must begin the process by 2020 and complete the relocation by the end of 2025. These plants can also be re-engineered to produce non-toxic products, or permanently close if relocation is not possible. Local governments are being required to submit detailed work plans, including company lists and timelines for relocation before the end of this year.

The move is an attempt to tackle chronic pollution concerns. Since 2014, provincial governments have been submitting to the central government a list of chemical plants up for relocation and/or re-engineering, and approvals have ceased for projects in cities, requiring that all new projects be located in industrial parks. So far however, only around 20% of these planned relocations have actually been implemented. A major sticking point has been the sources of funding for the relocation projects. Government support for the projects has typically been than 10% of the total capital required and has come in the form of land, low interest rate loans and tax breaks.

Air Liquide to supply ASUs for MTO plant

Air Liquide Engineering & Construction has signed a supply contract with Yulin Energy and Chemical Corporation, a subsidiary of the Shaanxi Yanchang Petroleum Group, to design and build two large air separation units (ASU) with an oxygen capacity of 1,800 t/d each. The ASUs will provide oxygen and nitrogen for the customer's mega methanol-to-olefin project at the Jingbian Energy & Chemical Integration Industrial Park, Shaanxi Province. Air Liquide has a longstanding partnership with Yanchang Group, the fourth largest energy company in China. In the 2014, Air Liquide Engineering and Construction delivered two 1,440 t/d ASUs to the Yanchang-Jingbian Phase I Project. Two additional ASUs of 1,400 t/d each are currently under construction to supply oxygen "over the fence" to Yanchang for its project Yanan.

BOTSWANA

Tender issues for CTL project

State-owned Botswana Oil Ltd (BOL) has closed a tender for a 20,000 bbl/d coal to liquid (CTL) plant for fuel production, attracting 11 bidders. BOL now anticipates a two month evaluation process, followed by negotiations and contract signing in December 2017. The $4 billion requires up-front investment by the bidder, with the Botswanan government acting as a guaranteed off-taker. Botswana hopes that it will ultimately be able to domestically produce up to 75% of the 1.2 billion litres of gasoline that the country consumes every year. Botswana is seeking to diversify its economy away from diamonds, its biggest export, and reduce its reliance on fuel from neighbouring South Africa, which supplies more than 90% of demand, while taking greater advantage of its more than 210 billion tonnes of estimated coal reserves.

INDIA

Construction begins on Assam methanol plant

Construction work has begun on the 500 t/d methanol expansion project at Assam Petrochemicals Ltd at Namrup in Assam state, following a ground-breaking ceremony inaugurated by Assam chairman Jagadish Bhuyan in the presence of local member of the legislative Naren Sonowal, vice chairman Bikul Deka and managing director Ratul Bordoloi. The project's cost is put at $210 million. Speaking at the ceremony, Sonowal said that the new plant would herald a new beginning for the industrial sector of Assam State and would lead to the setting up of several ancillary industries using the increased methanol production from the new plant, including a 200 t/d formaldehyde plant.

AUSTRALIA

South Australia launches tender for hydrogen plant, buses

The South Australian government has called for tenders for hydrogen infrastructure proposals, and for the supply of hydrogen-fuelled buses, as part of its plan to transform the state into a zero carbon "hydrogen economy," based on wind and solar power – the state currently produces 50% of its energy from wind and solar. The tenders are part of the state government's Hydrogen Roadmap, launched in September under its $150 million Renewable Technology Fund. The government is also seeking to trial at least six hydrogen cell buses in the Adelaide Metro fleet, and is calling for proposals to supply those, along with necessary refuelling and hydrogen fuel production infrastructure.

GERMANY

Shell looking to renewable hydrogen for refining

Royal Dutch Shell, together with ITM Power, has announced that it will build a 10 MW electrolyser at the Wesseling refinery site within the Rheinland Refinery Complex in Germany, in order to supply hydrogen to its refining activities. This would be the largest unit of its kind in Germany and the world's largest PEM (polymer electrolyte membrane) electrolyser. Surplus hydrogen could also be used to help balance energy demands from the electricity grid or be sold to customers for their own uses. The refinery currently consumes approximately 180,000 t/a of hydrogen, which is generated as a by-product of refinery process streams or via natural gas steam reforming.

Shell's partner ITM Power is pivoting from building hydrogen fuelling stations for cars to electrolysers which will turn electricity from the grid to hydrogen for industrial uses or even grid energy storage.

ITM Power CEO, Dr Graham Cooley, said: "Decarbonising hydrogen production in the chemical and refining industries worldwide is potentially a very large market. This pioneering project with Shell aims to demonstrate what can be achieved using our industrial scale electrolysers which can also use low cost renewable energy and help to balance electricity grids." ■

People

Wood Group says that it has completed the acquisition of Amec Foster Wheeler. Robin Watson, CEO of Wood Group commented: "This transformational acquisition creates a global leader in the delivery of project, engineering and technical services to energy and industrial markets. We become a business of significant scale and enhanced capability, delivering services across a broader range of geographies and sectors… we expect to deliver significant cost synergies and incremental revenue synergies in a less cyclical business which retains a predominantly reimbursable, asset light model with a balanced risk appetite." Following the acquisition, **Ian McHoul**, **Linda Adamany** and **Roy A Franklin** have been appointed to the Wood Group Board as non-executive directors.

Gerhard Mestl, Head of Oxidation Catalysts at Clariant, has received the 2017 Applied Catalysis Award from the European Federation of Catalysis Societies (EFCATS). The award was presented to Gerhard Mestl on Wednesday, 30th August at the EuropaCat XIII conference in Florence. The recipient of the EFCATS Applied Catalysis Award is selected by a jury of prominent scientists. According to the organization, the Award aims to acknowledge "individual contributions, which demonstrate excellence, scientific novelty, technical achievements in development and scale-up, interdisciplinary teamwork between scientists and engineers, and clearly show emphasis on actual or potential commercial application". The Applied Catalysis Award is sponsored by the multinational petroleum company BP.

Mestl's award was for his work in selective oxidation. Together with his R&D team at Clariant, Mestl has succeeded in developing high-performance process catalysts that significantly enhance efficiency and sustainability in the production of intermediate and specialty chemicals, such as phthalic anhydride (PHTHALIMAX®), maleic anhydride (SynDane®) and vinyl-acetate monomer (VAMax®).

Prof. Robert Schloegl, Director at the Fritz Haber Institute of the Max Planck Society, stated, "Gerhard unites academic interest and curiosity with the practical sense and perseverance needed in industrial catalysis research. I wish him all the joy coming with such a prestigious award." Marvin Estenfelder, Head of R&D at Clariant's Catalysts Business Unit, also offered his congratulations: "The EFCATS Award is well-deserved recognition for the valuable contribution of Gerhard and his team to a number of exceptional innovations."

CF Industries Holdings has announced that **Susan L. Menzel** will be joining CF as senior vice president, human resources on October 5th, 2017. Menzel will be responsible for human resources strategy and management for the company and serve as a member of the senior leadership team, reporting to Tony Will, president and chief executive officer, CF Industries Holdings, Inc.

Susan L. Menzel

"Sue's proven track record of providing strategic business and human capital leadership, along with her experience partnering with senior executives and boards of directors to improve talent management and maximize employee engagement, will serve CF and our employees well," said Will. "We look forward to having her help us drive continuous improvement both within the HR function and across the whole company."

Calendar 2017/18

NOVEMBER 2017

14-16
Fertilizer Outlook and Technology Conference,
NEW ORLEANS, Louisiana, USA
Contact: Valerie Sutton, The Fertilizer Instutite, 425 Third Street, S.W., Suite 950 Washington D.C. 20024, USA
Tel: +1 202 962 0490
Email: vsutton@tfi.org
Web: www.tfi.org/fotc

25-26
Iranian Nitrogen+Syngas Conference,
TEHRAN, Iran
Contact: CRU Events,
Chancery House, 53-64 Chancery Lane,
London WC2A 1QS, UK
Tel: +44 (0) 20 7903 2444
Fax: +44 (0) 20 7903 2172
Email: conferences@crugroup.com

27-29
12th GPCA Forum, DUBAI, UAE
Contact: Jill Raine,
Registration Team Leader
Telephone: +44 20 8652 3233
Email: GPCA.registrations@rbi.co.uk

FEBRUARY 2018

26-March 1
Nitrogen+Syngas 2018,
GOTHENBURG, Sweden
Contact: CRU Events
Tel: +44 (0) 20 7903 2444
Fax: +44 (0) 20 7903 2172
Email: conferences@crugroup.com

MARCH

6-9
IFA Production and International Trade Meeting, BUENOS ARIES, Argentina
Contact: IFA Conference Service,
28 rue Marbeuf, 75008 Paris, France
Tel: +33 1 53 93 05 00
Email: ifa@fertilizer.org

APRIL

9-12
IFA Global Technical Symposium,
MADRID, Spain
Contact: IFA Conference Service,
28 rue Marbeuf, 75008 Paris, France
Tel: +33 1 53 93 05 00
Email: ifa@fertilizer.org

16-18
SynGas Association Meeting 2018,
TULSA, Oklahoma, USA
Contact: SynGas Association
Tel: +1 225 922 5000
Web: www.syngasassociation.com

JUNE

18-20
85th IFA Annual Conference,
BERLIN, Germany
Contact: IFA Conference Service
Tel: +33 1 53 93 05 00
Email: ifa@fertilizer.org

Plant Manager+

Problem No. 45 Effect on reactor liner in case of reactor hold up

In the case of a failure in a urea plant, when the problem is expected to be solved within a short period, the high pressure synthesis section is typically blocked in (referred to in this article as reactor hold up). All input and output streams are closed and the synthesis section remains partly filled with a solution consisting of ammonia, CO_2, water, ammonium carbamate and of course urea. Several risks can occur during this blocked in situation: 1) as the temperature slowly reduces crystallisation could occur; 2) active corrosion could start as no fresh oxygen is supplied to the synthesis during blocking in and; 3) an explosive gas mixture could occur as hydrogen and oxygen are present.

Sandeep Gochar of GNFC in India initiates a discussion on this topic: I am working in a Saipem technology urea plant. I would like to know what effect keeping the reactor in hold up conditions after a shutdown will have on the reactor liner. Usually Saipem recommends draining the reactor if the shutdown is longer than 48 hours.

Prem Baboo of NFL India replies: Generally, the new practice in our plant is to have reactor hold up solution for no more than 48 hours. The reactor must be drained within 48 hours. Some corrosion was observed due to the low CO_2 purity (98.0 vol-% or less). Secondly the ammonia feed is not pure; it has some oil contents including some sulphur. Chlorine is also present in the passivation air. Our practice is as follows:

- feed liquid ammonia every 15 hours;
- drain the reactor within 48 hours;
- ensure a proper NH_3/CO_2 ratio;
- ensure purity of CO_2 (reduce hydrogen and organic matter slipping from the CO_2 removal section);
- during start-up introduce NH_3 feed 10-15 min prior to CO_2 feed.

Sandeep asks for some clarifications: Feeding liquid ammonia every 15 hours is something new for us but we will definitely look into it. Suppose we have reactor hold up for 48 hours, how does it affect the reactor liner thickness? One more question, which area (bottom, middle, top) of the reactor liner is more prone to thinning in the case of hold up or is the affect uniform throughout the reactor?

Prem replies to Sandeep: The top part of the reactor lining is more prone to thinning. If you feed ammonia then the reduction in thickness at the bottom of the reactor liner is always less than at the top. The solution must be drained within 48 hours. Do not exceed 48 hours. If you have a planned shutdown, first stop the CO_2 feed and then after 8-10 minutes stop the ammonia feed.

Mark Brouwer of UreaKnowHow.com in the Netherlands asks Prem some additional questions: What is the best practice during blocking in of a Saipem synthesis with regard to the following:

- Position of MP vent valve (to avoid accumulation of hydrogen);
- Steam pressure on stripper;
- Do you monitor the temperature in the reactor to assure no CO_2 leaks in?
- When you add ammonia every 15 hours, do you reduce the level in the HP level tank? As the ammonia enters the reactor via the HP ejector, is there a risk that the HP level tank will be empty?
- How much time should expire after start up before another blocking in of 48 hours is allowed?

Prem replies to Mark:

- Whenever there is a plant shutdown the MP vent is in auto mode, the excess pressure caused by inerts ($H_2/CH_4/N_2/O_2/$ Ar and some ammonia, etc.) is released and then the valve closes automatically, i.e. during shutdown the MP vent valve is in closed condition (after the hydrogen and all inerts have been vented out).

- During shutdown the steam pressure is zero on the stripper shell side.
- Yes, the temperature of the reactor must be more than 126°C and is generally run at about 140-165°C.
- Yes, the level in the HP level tank is reduced. If there is no ammonia left, take it from ammonia storage. If it is unavailable for any reason (shutdown of equipment etc.) it is not a problem. We try to drain the reactor within 40 hours for equipment health. There is no harm in draining out the HP loop solution, the effluent (urea, ammonia and CO_2) will be recovered after shutdown. Draining means no effluent will drain out into the open. It should be collected in vessels (ammonium carbonate, urea solution tank etc.). These tanks are at atmospheric pressure and low temperature so there is less corrosion. Equipment health is always better than production loss.
- Another blocking in of 48 hours is permitted once the reactor is receiving feed and all of the solution has been replaced with fresh solution and with passivation air.

Mark asks for some more information: Have you ever experienced passing of the CO_2 valves resulting in CO_2 entering the reactor during blocking in? This would lead to higher temperatures and possibly active corrosion.

What is the reason for adding some ammonia every 15 hours? Does it reduce the risk of corrosion or crystallisation?

Prem replies: As regards CO_2 leakage, there are two feed valves: one is a motor operated angle valve (MOV) and the other is a pneumatic valve also angle (needle valve), so there is less chance of leakage.

When the feed is stopped, stop the CO_2 compressor immediately and there will be no risk of leakage due to the compressor tripping.

If the compressor is operating, the discharge pressure may be reduced to less than the system pressure (reactor pressure) so that there is no risk of leaking.

It is important that the operator stops the CO_2 feed first and then the ammonia to prevent CO_2 leaks.

Ammonia addition reduces the risks of both corrosion and crystallisation.

Sandeep asks another question: What is the logic behind the reactor temperature not being allowed to go below 126°C.

Mark replies to Sandeep: Two reasons are given:
- risk of crystallisation;
- to reduce the temperature shock when the plant is started up again.

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.

A vast solar array at Ouarzazarte in Morocco.

PHOTO: MASEN

Power to ammonia

Making ammonia from hydrogen generated by electrolysis of water has a long history, and today, coupled with renewable electricity, offers the prospect of a carbon neutral source of ammonia. But can the economics possibly stack up?

The history of producing ammonia via hydrogen from electrolysed water is almost as old as the ammonia industry itself. While hydrogen was available from coal gasification, as was used in BASF's first ammonia plant at Oppau in 1913, it required a secondary water-gas shift reaction to generate sufficient hydrogen for the process. Other pioneers quickly looked into using electrolysis to split water into hydrogen and oxygen. In 1919, Luigi Casale built the first electrolysis-based ammonia plant at Terni in Italy using his own high-pressure ammonia synthesis process, followed soon after by Norsk Hydro at Rjukan in Norway in 1927, after Hydro signed a licensing agreement with IG Farben for the Haber-Bosch ammonia process.

Continuing improvements to the syngas generation process gradually brought the cost of production down, and this proved even more decisive once steam reforming of methane began to become the standard way of generating syngas. Nevertheless, a few electrolysis-based ammonia plants were subsequently constructed in the 1940s and 50s near major hydro-electric dam projects, such as at Aswan in Egypt, or the Sebakwe Dam in Zimbabwe. Chile, Iceland, Peru and Canada also all had at one time or another electrolysis-based ammonia plants. The major drawback, however, was the cost of production. It takes around 10-12 megawatt hours (MWh) of electricity to produce enough hydrogen to make a tonne of ammonia. At an average 2017 cost of around \$70/MWh in the United States, this would translate to \$840/tonne of ammonia before any other costs were taken into account. Even though hydroelectric generation tends to be cheaper, it would still require \$550 of hydroelectricity to produce a tonne of ammonia in the US. Compare this to around \$75-100/tonne of ammonia in terms of natural gas cost at prevailing US gas prices, and it can be seen why electrical generation of hydrogen fell out of favour. Globally, only the Aswan plant in Egypt is still operational; the Rjukan ammonia plant in Norway closed in 1991, Iceland's hydroelectric ammonia plant closed in 2004, and the Sable Chemicals facility in Zimbabwe finally ceased production in 2015 and the company switched to buying ammonia from South Africa.

A new paradigm?

On the face of it, then, the future for ammonia from electrolysis seems bleak. However, the growing interest in generating power from renewable sources may yet throw it a lifeline. Of course, hydroelectricity is a renewable power source, and were there to be a carbon cost to ammonia production that might narrow a small amount of the gap between electrolysis and fossil fuel-derived hydrogen. Nevertheless, this would still leave electrolysis at a significant cost disadvantage and could not promote its use without major subsidy. However, large scale installation of solar power and wind turbines is leading to a new issue for electricity producers – the fact that power is not always produced when needed, and that there can be large excesses of power being generated at times of low demand. Were this to be used to produce hydrogen via electrolysis, and thence downstream ammonia, it could be used as a way of 'storing' renewable power in a way which is far cheaper than present battery technology. Storing ammonia compared to hydrogen is more attractive because pressurised storage (at ambient temperatures) of limited volumes of NH_3 can be done at around 10 bar while the equivalent pressures required for H_2 are 350 bar or higher to achieve a reasonable – but still lower – volumetric energy density. Large scale cooled storage (at atmospheric pressure) of NH_3 can be done at -33°C, while it would require a temperature of -254°C for H_2.

P2A

A recent study in the Netherlands looked at the issues surrounding 'power to ammonia' (P2A). Funded by the Dutch Ministry of Economic Affairs, it was organised by the Institute for Sustainable Process Technology (ISPT) in conjunction with Stedin Infradiensten, Nuon, ECN, Technical University Delft, University Twente, Proton Ventures, OCI Nitrogen, CE Delft and AkzoNobel. The

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

purpose of the study, which concluded in February 2017, was to "investigate both technologically and economically under what conditions NH_3 can be produced using renewable electricity; can be used to store electricity; and can be used as a fuel for an electricity production facility. The project studied three cases:

(i) Electrochemical production, storage and use of NH_3 in a rural setting (Goeree-Overflakkee), avoiding grid modification costs and allowing local production of CO_2-free NH_3.
(ii) Use of NH_3 as a CO_2-neutral fuel in the highly efficient Nuon Magnum gas turbine combined cycle (CCGT) power plant at Eemshaven,
(iii) Using electrochemical production of NH_3 at OCI Nitrogen to replace (some of) the current, natural gas-based production.

Using ammonia as electricity storage

The Dutch island of Goeree-Overflakkee has a large concentration of renewable electricity production from wind and solar sources, and a tidal facility is also under consideration. This leads to a net electricity capacity of up to 300 MWe, far exceeding electricity demand on the island, rated at a maximum of 30 MWe at peak. Further investment in the electricity grid is necessary to accommodate the increase in renewable electricity production, to a total of €50 million. Producing ammonia from surplus power was investigated as a way of avoiding this cost, with the ammonia subsequently being transported by truck to existing storage tanks at Rotterdam harbour.

Three alternatives were considered; (a) producing ammonia with electricity from the new 25 MW tidal power facility at Brouwersdam, (b), direct NH_3 production at the Middelharnis grid substation, where power from various wind and solar facilities meet, and more power can be drawn from the national grid, and (c) production of ammonia at a standalone wind park. This has the disadvantage of a more fluctuating and less predictable supply of power.

Overall, the study found that there was no "positive business case" for the production of ammonia from electricity at present. The case where NH_3 is produced directly at the grid substation in Middelharnis, with a capacity of 40,000 t/a from small, modular units, appeared most promising. Other alternatives considered were less interesting because the intermittent production of renewable electricity would mean lower utilisation of the installed assets and the need for larger and costly storage facilities for H_2 in order to operate the Haber-Bosch process section at its minimum capacity of 25%. However, different scenarios for future electricity prices have shown a great variety in the outcome for the NH_3 price, with potential upsides coming from lower costs for electrolysers going forward, and possible subsidy for 'zero emission' fertilizer production/potential future penalties for CO_2-based production.

The project compared electricity storage as ammonia with other ways of storing electricity, using batteries or capacitors, or mechanical options such as flywheels, liquid air energy storage or compressed air energy storage. These are shown in Figure 1, with a comparison with other chemical methods in Table 1, and indicate that ammonia, as well as other chemical storage methods such as methanol is a viable option for large scale storage.

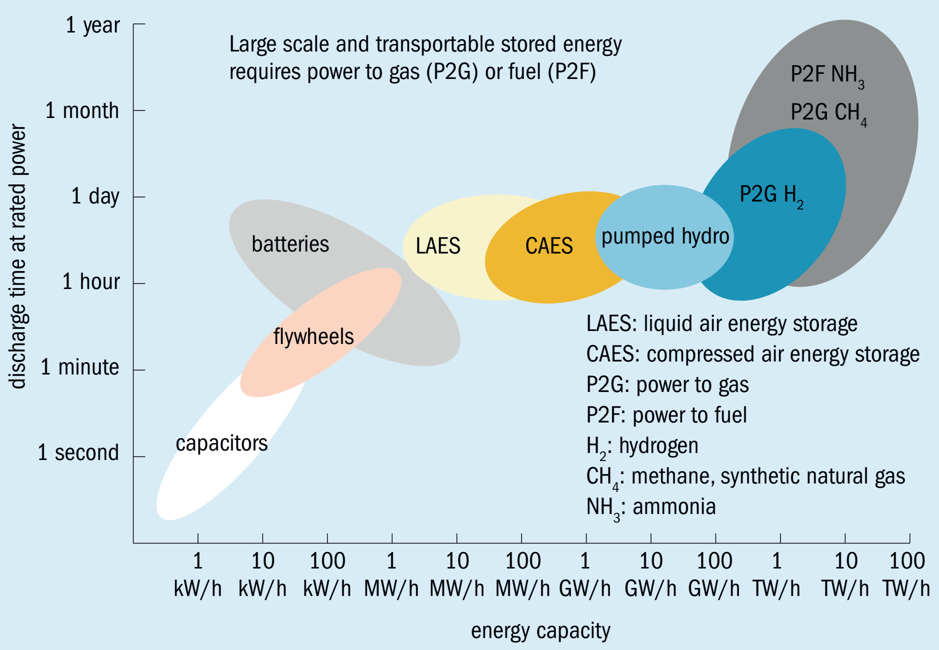
Table 1: Comparison of ammonia as an electricity storage technology

Technology	Physical properties			Economics	
	Pressure (bar)	Temp (°C)	Density (GJ/m³)	Relative CAPEX	Loss (%, 6 mo)
Liquid H_2	ambient	-254	4.8	++	5.5
Pressurized H_2	700	ambient	2.8	N/A	-
MCH*	ambient	ambient	1.7	+++	-
H18-LOHC**	ambient	ambient	2.0	+++	-
Iron sponge	ambient	ambient	6.5	N/A	-
Methane	ambient	-163	11.4	0	3.0
Methanol	ambient	ambient	8.2	0	-
Ammonia	ambient	-33	6.8	0	0.6

** methylcyclohexane ** liquid organic hydrogen carrier*

Source: Institute for Sustainable Process Technology, Power to Ammonia Final Report

Fig. 1: Relative energy storage technologies



Source: Nuon Energy

Burning ammonia for power

The business case was investigated for production of NH_3 from low CO_2 sources as a fuel for the Magnum CCGT power plant. The key issue with the conversion of ammonia to power is the combustion; little is known about ammonia combustion in spite of some work performed on reciprocal engines and direct combustion in gas

turbines. Turbine suppliers consulted were concerned about the low flame speed and hence larger flame size and the risk of high NOx-formation due to the existence of nitrogen containing radicals during the combustion. In theory these could be mitigated by designing a new combustor in which a rich mixture is combusted resulting in low nitric oxide (NOx) formation followed by adding secondary air to create a lean continued combustion. However, such development is not part of the current research and development programs of OEMs.

Ammonia can also be 'cracked' back to hydrogen and nitrogen by heating it to 800-900C. This leaves trace ammonia in the process gas but current ammonia cracker sizes of 10 t/h would need to be scaled up to 200 t/h, adding perhaps a decade to development times. Nevertheless, this seems the most promising option. It was also considered whether ammonia could be used as an intermediate way of storing power at the plant, a so-called 'power-to-power' option. The efficiency of this was only 25-40%, depending on the electrolyser technology, compared to battery storage of 85-90%, but it could handle much larger volumes.

The study concluded that using cracked NH_3 for combustion provides integration options with other H_2 consumers. Ammonia produced from natural gas including carbon capture and storage (CCS) or NH_3 produced from remote continuously available renewable electricity (e.g. hydro or geothermal) shows reasonable costs. This means that the costs of electricity produced from this NH_3 are lower than €150/MWh, making it viable for a SDE+ type subsidy regime. While ammonia can be used to store locally excess renewable electricity at times when prices are low, the economic feasibility is only positive if the investment cost for the electrolysers decreases drastically in combination with high run times for the plant and a positive business model for such storage. The main cost driver for a P2A plant are the electrolysers, being more than 60% of the total CAPEX. A target for cost reduction is 70% of the current base price of €1,000/kW. Nuon aims for co-firing cracked NH_3 as a fuel in the Eemshaven CCGT power plant in 2021 and for a full conversion in 2026.

OCI Nitrogen

A third business case has been developed for a small scale (20,000 t/a) pilot P2A plant at OCI Nitrogen, either at their site in Geleen or in Europoort. At both sites the infrastructure for chemical processes and NH_3 is already present, reducing the investment in utilities and handling as well as reducing the lead time, costs and complexity of the permits. In their submission to the study, OCI noted that ammonia production requires capital intensive installations and large energy flows. For electrochemical-based NH_3 production the investments are even higher. In order to achieve the lowest possible price, energy should be cheap and the installation should run for a large number of hours, and the availability of low cost electricity during a large percentage of the time will be a challenge.

The investment cost for such a plant in the order of €30 million, based on an estimate by Proton Ventures. Electricity consumption and other variable costs (demineralised water, air etc are mainly energy driven) will be equivalent to 10.5 MWh/t ammonia. Assuming relatively continuous operation (>5,000 hours per year), the cost of production at current electricity prices would be around €1,000/tonne ammonia, far in excess of current prevailing market prices, but in 2030 in a high renewable energy scenario case the price differences are smaller, with production costs dropping to around €500/tonne ($585/t). Even this is still higher than prevailing ammonia market prices of around $300/t, but OCI believes that with further optimisation of the operational hours the break-even point could possibly be reached.

The company notes in the report that it has reached the following conclusions from the study;

- If the investment cost, mainly in the electrolysers, could be reduced significantly and/or the pricing of renewable NH_3 is significantly higher and/or the cost for CO_2 emissions are higher, the electrification route could be profitable before the year 2030. Innovations in electrolyser markets such as the battolyser appear to have a great potential. Other ways to increase profitability could be to act on both the day-ahead-market and imbalance market for electricity, and to include avoided investment (e.g. in power grid) and to find subsidy schemes (like SDE+/EIA) or attractive financing models.
- In order to reduce the CO_2 footprint of electrochemically produced NH_3, compared to conventional NH_3, the electricity has to come from a CO_2-free source. When using CO_2 electricity from non-renewable energy sources the CO_2 footprint is actually higher due to the efficiency loss when producing electricity. Per ton NH_3 produced by renewable electricity 1.8 tonnes of CO_2 are avoided compared to natural gas based steam reforming, but if 'grey' electricity based on the Dutch fuel mix is used, the CO_2 emissions are three times higher compared to the one for SMR.
- Although the ultimate goal is to eliminate CO_2 emissions at both electricity and NH_3 production, for traditional NH_3 suppliers it is a logical path to expect that at first the huge existing NH_3 volumes will be decarbonised before using the ammonia for electricity production in gas fired power stations. The natural gas that is no longer used for NH_3 production can be used more efficiently to produce electricity when renewable energy is in short supply. OCI expects that usage of NH_3 on a smaller scale as a fuel for power stations, to develop sooner. This is driven by the market (consumers are willing to pay for CO_2-free electricity) and electricity suppliers looking for ways to implement this technology on a small scale.

Overall conclusions

The report says that P2A has long term potential to contribute substantially to CO_2 reduction targets, as it can offer flexibility for the energy system, play an important role in substituting fossil based NH_3 and allows for smart choices with regard to avoiding high capacity investments in the electricity grid. However, the production of green ammonia from renewable electricity in the Netherlands is not economically attractive in the short term due to limited availability of cheap renewable electricity resulting in a limited number of operating hours in combination with high investment costs, mainly determined by the electrolysers for the production of H_2. Attractiveness might be achieved if the specific investment costs for electrolysers were to be reduced by about 70%.

As prices of electricity generated from solar energy are dropping very rapidly, PV generated electricity has become a potentially interesting source for NH_3 production based on renewable sources. In 2016 prices have dropped by approximately 50% (from $48/MWh to $24/MWh according to the recent record bid by Jinkosolar/Marubeni for a large scale Abu Dhabi project).

Kopernikus – P2X

In Germany, a similar research programme forms part of the so-called Kopernikus initiative. Launched by the Federal Ministry of Education and Research (BMBF), it aims

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to "stimulate comprehensive and integrative research on the energy transition in order to make the current system in a safe, affordable, and clean way fit for the future". It has four components: ENSURE, which addresses new grid structures to transport and supply renewable energy in a reliable and flexible way; P2X, which focuses on options to store energy in gaseous, substantial, or liquid form; SynErgie, looking at technologies for adapting industrial processes to the new energy supply system; and the ENavi project, analysing the interaction of the power, heat, and mobility sectors.

P2X project partners include: Clariant, RWTH Aachen University, Forschungszentrum Jülich, Friedrich-Alexander University Erlangen/Nuremberg, Karlsruhe Institute of Technology, the Fraunhofer Institute, Leibniz-Forschungsverbund Energiewende, Areva H2Gen GmbH, Hydrogenious Technologies GmbH, and thyssenkrupp Industrial Solutions AG. At the moment it is not looking at ammonia, however, but rather using renewable hydrogen in the manufacture of Fischer-Tropsch liquids, methanation, gasoline via renewable methanol, and syngas fermentation to long-chain alcohols. The programme runs form 2016-2019.

ARPA-e REFUEL

In the US, work on similar projects is being conducted under the auspices of the Advanced Research Projects Agency – Energy (ARPA-e) via its Renewable Energy to Fuels through Utilisation of Energy-dense Liquids (REFUEL) program. ARPA-e says that this seeks to develop "scalable technologies for converting electrical energy from renewable sources into energy-dense carbon-neutral liquid fuels (CNLFs) and back into electricity or hydrogen on demand. REFUEL projects will accelerate the shift to domestically produced transportation fuels, improving American economic and energy security and reducing energy emissions."

Real world projects

Real world applications have so far been very small scale. In Iowa, a scientist from the Jet Propulsion Laboratory (JPL) developed a renewables to ammonia system at his late father's farm. The Raphael Schmuecker Memorial Solar-Hydrogen System began by installing an electrolyser to work off solar power to run a hydrogen-fuelled tractor, but in 2013 also began producing 85 kg/year of ammonia for use on the fields. Ultimately it aims to scale up to run the entire farm and generate sufficient ammonia fertilizer to cover its 300 acres (2.0 t/a) by using solar energy.

But a much more ambitious project is now under way in Australia, where Yara is finishing a feasibility study on building a demonstration plant to produce ammonia using solar power in Western Australia. The company already operates a gas-based ammonia plant at Pilbara. Once the feasibility study is complete, Yara said at a local conference in Pilbara that it hopes to move to engineering and design and begin construction during 2018, with a targeted completion date and start-up time of 2019. The first stage will be a 2.5 MW demonstrator plant at the existing Pilbara site, producing 66 t/a of ammonia, which Yara says it hopes will gain it experience with the process. However, the next stage is for a scale-up to hundreds of megawatts of solar power, generating 10,000 t/a or so of ammonia, and Yara says that this "could grow to a full replacement of our current natural gas consumption by producing hydrogen with a solar field …or even a step further" – the third stage would be a 4-20 GW solar array, generating up to 500,000 t/a of ammonia, and a potential fourth stage would be multiple plants at this scale, with the ammonia not just being used for fertilizer but also for fuel or as a hydrogen carrier. Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO) is also conducting research into a catalytic membrane which will split ammonia back into nitrogen and hydrogen and allow the ammonia generated by solar power to be used as a hydrogen transport vehicle. While metal hydrides (which have been suggested as a method for storing and transporting hydrogen) carry only 3% of their weight as hydrogen, ammonia is 18% hydrogen by weight. The project partners believe that this might offer a way of linking areas with a high density of solar energy such as Australia's western deserts with energy consuming states like Korea and Japan which have only half the intensity for of solar light and far less space to develop large solar arrays.

The future is ammonia?

So is ammonia derived from renewable hydrogen the energy carrier of the future? Many people seem to think so, but various extremely large caveats need to be stated at this point. Ammonia is often cited as a 'clean-burning' fuel, generating in theory only water and nitrogen, but in fact as any nitric acid plant operator will tell you, it actually tends to generate large quantities of nitrogen oxides. For this reason the Dutch study cited above effectively ruled out ammonia as a power plant fuel. Secondly, ammonia is toxic, and its transport and storage is under increasing scrutiny, especially in the United States. It is one thing to ship it in an LNG carrier from Australia to Korea or Japan, but quite another to imagine any kind of ammonia distribution infrastructure across those countries.

The cost angle of generating hydrogen from electrolysis continues to be the real bugbear of the process, with figures of \$850-1150/tonne ammonia at current wholesale electricity prices, in addition to the large capital expenditure of the electrolysers. There are expectations that the cost of electrolysers will come down as they become more widespread and new technologies mature, and the cost of electricity is likewise likely to fall as renewable power becomes more widespread. Even so, a projected 2030 cost of \$500/t means that ammonia will still be more expensive from renewable sources than from natural gas or coal gasification, albeit not much more so at the top of the current ammonia price cycle. But even if the economics can potentially be made to stack up, there are other drawbacks. One of the advantages cited is that the hydrogen can be generated during times of surplus production from renewables and used as a way of 'storing' that energy. Unfortunately, an intermittent source of hydrogen is an incredibly inefficient way of running an ammonia plant, so considerable hydrogen storage capacity could be needed to ensure a constant supply to the ammonia synthesis section. And if the ammonia is then to be converted back into hydrogen, a lot of work needs to be done on the 'cracking' of ammonia back to nitrogen and hydrogen – it is no coincidence that Australia, ARPA-e and the Dutch project have all focused on this as one of their major research areas. However, given sufficient time and money, it is probable that this process can be made far more efficient than it currently is.

Having said all of the above, there is nevertheless now a concerted push from many governments and the involvement of many research institutes and major technology companies, and it seems likely that the concept of ammonia as an energy carrier as part of a 'decarbonisation' strategy may be with us to stay. ■

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The prospects for Indian urea

India has unveiled plans to end urea imports by 2022. However, many such pronouncements have come and gone over the years – is this one any more likely to come to fruition?

Earlier this year, India's government announced ambitious plans to end imports of urea within five years. As India is currently the world's largest importer of urea, and has completed no new urea plants since 1999, this has raised eyebrows in international markets. Can the government achieve its dreams of returning to the kind of self-sufficiency in nitrogen production that India enjoyed in the 1990s?

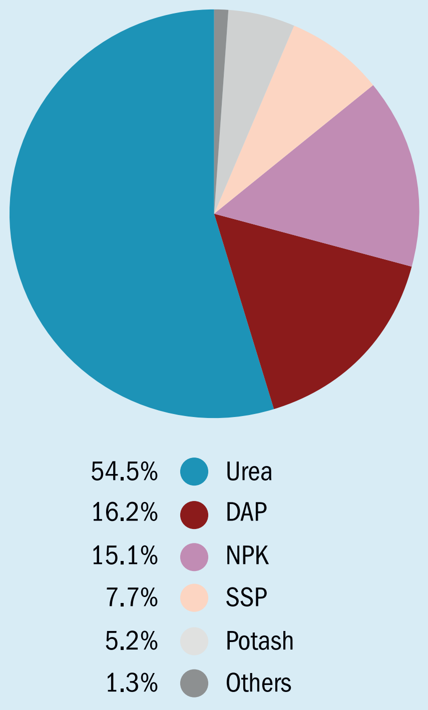
Economy

As China's economy has slowed, it had been hoped by many around the world that India would be able to somehow compensate. For a while this looked to be the case – India's economy grew at a very high rate of 9.1% for 1Q 2016. Since then, however, growth has slowed quarter by quarter, to 7.9% in 2Q 2016, 7.5% in 3Q 2016, 7% in 4Q 2016 and 6.1% in 1Q 2017, and the most recent figures show a further slump to 5.7% for 2Q 2017. Some of the blame has been placed on the government decision to withdraw 1,000 and 500 rupee notes from circulation in an attempt to reduce the size of the off-books economy and encourage more payment of income tax – widely avoided in India's largely cash economy. The introduction of the Goods and Service Tax in July has likewise caused uncertainty in the run-up to its imposition. However, this has been very much a sectoral slump – services continue to expand at 8.6%, while manufacturing is down to a 1.2% expansion for 2Q 2017, compared to 10.7% a year previously, due to widespread de-stocking, and agriculture, which accounts for 15% of GDP, grew by 2.3%. A bigger structural problem is unemployment and under-employment, as much investment has been in capital-intensive industries which do not employ many people. Nevertheless, current forecasts see India's economy recovering to 7-8% growth over the next few years.

Agricultural demand

While it now has shrunk to only 15% of GDP, agriculture continues to be a vital part of the Indian economy, employing more than 50% of the working population and supporting 58% of rural households. Agricultural exports represent 10% of India's exports and the country ranks 3rd in this worldwide. However, while India's growth in agricultural productivity since independence has been a remarkable success story, in recent years productivity has fallen, and rice yields per hectare are 47% lower than in China. Crop intensity and irrigated area continue to rise: overall, IFA predicts that cereal production in India will rise by 7%, with the gain coming almost exclusively from enhanced productivity. Development of irrigation and better use of rainfall water will be influential. But in order to markedly increase productivity, more and better balanced fertilizer use is required. India's average application rate is around 150kg nutrients per hectare, 50% lower than for neighbouring Bangladesh and barely one third of China's rate.

Fig. 1: **Fertilizer use, India, 2016-17**



Source: The Fertiliser Association of India

The main hurdle to this lies in farm incomes and the ability to buy fertilizer. The government has attempted to maintain food security and enhance farm incomes via minimum support prices (MSPs) for major agricultural commodities, revised and up-rated each year to ensure that there was a rising floor to agricultural prices, helping to stabilise income increases and guarantee farmers a return on investments which help raise productivity. However, in recent years there has been a complaint that MSPs have not kept pace with rises in input prices for farmers as deregulation in fuels and other markets begin to have an impact. The government has also attempted to reduce subsidy rates for fertilizers, with the price per kilogram of nutrient in the Nutrient-Based Subsidy (NBS) scheme steadily falling since its peak in 2011.

Nevertheless, India's food grain production rose by 8.7% in the 2016-17 financial year, to a record 273 million t/a, including a 4.5% increase in rice production and a staggering 37% increase in pulses, thanks in part to a good 2016 monsoon after a couple of poor years, and the government is targeting a similar figure for 2017-18 after a monsoon that delivered 95% of average rainfall from July-September this year.

Fertilizers

India's fertilizer market is dominated by urea. As Figure 1 shows, applications in the 2016-17 farm year (July-July) were 54.5% of all fertilizer use. Because of its importance to Indian farmers, India has always fallen outside the NBS scheme,

and the government subsidises it more heavily than other fertilizers. This has had the unfortunate effect of over-emphasising its use at the expense of other nutrients such as phosphorus and potassium, leading to some of the stagnation in farm productivity, as well as continuing to make it too important to switch to a lower subsidy system. It is currently not clear to what extent this will change once India switches to the new subsidy system – so-called direct benefit transfer or DBT, in which the fertilizer subsidy is paid direct to farmers to encourage them to purchase it rather than to manufacturers. This has already been trialled in some areas of the country, and is due to be rolled out nationwide on January 1st 2018.

In the meantime, cheap agricultural urea has also had the side-effect of it being smuggled out of fertilizer markets and into industrial uses, such as the manufacture of plywood/particle board, the smoothing of textiles, and even as a common adulterant in milk, because it is so cheap. In order to tackle this, as well as to eke out India's limited domestic supplies of urea, the Indian government has responded by mandating that all urea sold in India must now be coated with neem oil, at a rate of 350ppm per tonne. Neem is a tree in the mahogany family native to India, and India has 60% of the world's neem trees. It is fast growing and happy with low water conditions. The government attributes this to the increase in grain production last year in spite of an apparent 2 million t/a drop in urea consumption for 2016-17 to around 28 million t/a. As well as preventing diversion of urea into other areas (estimated at 500,000 t/a), neem oil also slows down the rate of hydrolysis of urea into ammonium and then nitrate ions, which is the form in which it becomes available to plants. In India's warm and moist climate, this can happy very rapidly, leading to the nitrogen leaching to water or volatilising into the atmosphere before plants can absorb it. Slowing down the rate that this happens makes more nitrogen available to the plant and so increases the effect of each kilogramme of urea spread on the field.

Finally, since June the government has also mandated that urea be sold in 45kg bags rather than 50kg bags, in the hope that this will lead farmers to less urea, arguing that a 45kg bag of neem-coated urea is equivalent to a 50kg bag of uncoated urea in terms of its nutrient effectiveness.

Urea production

India's urea consumption has historically run at around 30 million t/a, rising to 32 million t/a in the 2015-16 farm year although, as noted above, it fell for the first time in several years for the 2016-17 growing season. Current projections are for modest growth in nitrogen consumption, of the order of 1.5% per year. Set against this, domestic production has lagged some way behind, reaching about 22 million t/a in 2015-16, leading to 8 million tonnes of urea imports. The reason for this has been an effective moratorium on building new urea plants since 2000. While India struggled through the 1990s to achieve self-sufficiency in urea production, subsidies were high and feedstock availability was expensive or uncertain – many plants used naphtha as a feedstock, which was increasingly expensive due to high oil prices, and even when the government forced them to change to natural gas feedstock, demands from the power industry meant that allocations to fertilizer producers were also frequently cut.

India's shortage of natural gas has been a perennial issue for the fertilizer industry, which represents a large slice of India's natural gas consumption. Indian gas production actually peaked at 49 bcm in 2010, according to BP. Since then it has fallen year on year, and in 2016 dropped another 6% to 27 bcm. At the same time, gas consumption has also fallen, mainly due to lack of availability, from 61 bcm to 45.7 bcm in 2015, although last year this increased to 50.1 bcm. This means that the country's gas deficit has increased, from 12 bcm to 23 bcm, and this is made up with imports of LNG, 60% of which came from Qatar in 2016. India actually has considerable untapped natural gas reserves, onshore in the northwest and northeast of the country, and offshore in the southeast and Bay of Bengal. In addition to this, there are reserves of coalbed methane and shale gas which remain largely undeveloped. However, one of the major issues has been that government price controls on gas have made it uneconomical for companies to develop these reserves, and it is hoped that the slow liberalisation of India's gas industry may help with this. In the meantime, there are ambitious plans for new LNG import terminals, five of which are due to come on-stream in the period 2017-19, which should double the country's ability to import gas by that time. This is important because – although gas represents only 7% of India's energy needs, with coal responsible for the vast bulk of them – India has huge coal production and reserves – one third of gas consumption is by the fertilizer industry.

If a shortage of natural gas is the main hurdle for expanding urea capacity, there remains the option of using coal gasification, which has been the preferred solution for China, and which could also be used by India, with its huge coal reserves. The development of coal-based urea capacity has however been coloured in India by its experience with two coal-based plants which were built at Ramagundam and Talcher in the 1970s, which suffered from all manner of production issues and which were finally closed down. In addition, the high ash content (35-45%) of Indian coal means that certain types of gasifier are not suitable. Nevertheless, there has belatedly been a push to develop more coal-based urea capacity, although this has not been without its own problems.

New urea policy

All of which brings us to India's current situation. There are 30 urea plants in India, many of them of considerable vintage, all of them converted to run on natural gas and many of them dependent on relatively expensive LNG as feedstock. Successive debottlenecking and improvements at these plants have led to a slow rise in capacity, and efficiency improvements to bring down gas consumption, but production of urea has also been hindered by gas availability and government efforts to keep a lid on subsidy payments by setting a cap on production from individual units called 'reassessed capacity' beyond which subsidy payment was linked to the so-called 'import parity price'.

In April 2017, the Indian government unveiled a $8.5 billion plan to turn the country into a net exporter of urea by 2022. In addition to the moves already noted – coating of urea with neem and supply in smaller bags in an attempt to reduce consumption – production will be boosted by lifting the production cap and the rehabilitation of several older, mothballed plants as well as construction of new, greenfield capacity. The policy aims to help shield farmers against global price fluctuations and limit government subsidies, as well as tying in with Prime Minister Narendra Modi's 'Make in India' push to boost domestic manufacturing, attempting to create more jobs.

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New capacity

Current plans call for the re-start of five idled urea plants previously operated by the Fertilizer Corporation of India (FCI) and Hindustan Fertilizer Co. Ltd (HFCL). The plants are at Barauni in Bihar state, Sindri in Jharkhand, Talcher in Odisha, Ramagundam in Telangana and Gorakhpur in Uttar Pradesh. Major state utility companies such as Gas Association of India ltd (GAIL) and Coal India Ltd (CIL) are involved in financing and providing feedstock for the units, which will be operated by existing fertilizer firms. CIL and the National Thermal Power Corporation (NTPC) have formed a joint venture to revive the FCI plants in Sindri (in conjunction with the Indian Oil Co.) and Gorakhpur, with feedstock to be sourced from GAIL's proposed new Jagdishpur-Haldia pipeline, which will bring LNG from the northeast coast at Haldia into the interior of Uttar Pradesh. This would also connect to the former HFCL Barauni unit.

At Talcher, the aim is to effectively scrap the old facility, which closed in 2002, and build a new 1.2 million t/a ammonia-urea plant based on coal gasification as a feedstock, with investment cost put at $1.2 billion. This includes opening up a new coal mine 8km from the plant site itself and moving 500 families who currently live on the land to be occupied by the mine. A new operating consortium has been formed from FCI, Gas India Ltd (GAIL), Rashtriya Chemical and Fertilizer Ltd and Coal India Ltd. Gorakhpur, Sindri, Talcher and Barauni together would add a total capacity of 7.5 million t/a of urea, in theory making India approximately self-sufficient. Commercial production at the four new plants is targeted for 2021/22.

> **Affordability is one thing, though, and availability is another...**

However, in addition to these rebuilds at brownfield sites, there are also greenfield developments around the country. Foremost is Matix Fertilizers in West Bengal, where construction is complete and the plant is in commissioning. The aim is to run the 1.3 million t/a facility from coal-bed methane sourced in the local area, from the Essar Oils Jharia and Raniganj coal fields 30 km away. A pipeline has been constructed and Essar says that it has now achieved sufficient production to feed the plant.

Another project is the revival of the FCI site at Ramagundam in South India (originally one of the two coal gasification plants), where Ramagundam Fertilizers, a joint venture between FCI, National Fertilizers Ltd and Engineers India, is spending $810 million to build a new 1.3 million t/a gas-based ammonia-urea plant. The targeted start-up date is currently 2019. Chambal Fertilizers and Chemicals, which shut down its old plant at Kota near Gadepan in Rajasthan state in 2015 due to unfavourable economics, is now building a new 1.3 million t/a plant at the site, with completion also set for 2019.

The government has also approved the establishment of a new brownfield ammonia/urea complex at the Brahmaputra Valley Fertilizer Corp (BVFCL) site at Namrup in Assam, where a new 860,000 t/a ammonia-urea plant will replace the two older 220,000 t/a and 270,000 t/a units, while the fertilizer ministry is also studying proposals to revive the loss-making Madras Fertilizers Ltd and Fertilisers & Chemicals Travancore plants. There have been proposals by ONGC and CFCL to build a gas-based urea plant in Tripura, by Jindal Steel and Power to build a coal gasification plant in Angul, Odisha, and by Adani Group to develop a coal to power and urea facility with a substitute natural gas (SNG) side stream. If all of these plants were to end up being built, India would be a major net exporter of urea.

A note of caution

One thing that India has never been short of is urea project proposals; over the past 20 years, governments have considered and discarded dozens of them, and a degree of cynicism regarding the current batch may well be justified. Securing financing and securing feedstock at a competitive price have always been the major hurdles. While the government has definitely become far more enthusiastic about its backing for new capacity, this has not necessarily translated into practical measures. For example, the Indian fertilizer industry suffers from a major backlog of unpaid subsidies, which rose from $2 billion in 2011-12 to $8 billion in 2015-16. The involvement of major Indian energy companies in the new project proposals may make financing easier, but does not ensure that all will be plain sailing when seeking money from major financial institutions.

In terms of feedstock, the price of natural gas currently depends on a mechanism which weights domestic gas prices against a basket of international indicators, including the US Henry Hub, the UK NBP, the Alberta Reference Price and the Russian domestic gas price. This has led to a domestic gas price as low as $2.60/MMBtu (recently increased to $3.15/MMBtu), which is below ONGC's average cost of producing gas of $3.50/MMBtu. Furthermore, imported LNG – which would be used to feed most of the new plants – is not price regulated, and so to overcome this the government introduced its Gas Pooling Policy, which averages domestic prices with imported LNG to arrive at a final price to urea producers. This, and the current relatively low costs for LNG and lower gas prices in the international hubs which set Indian domestic prices, mean that gas is currently relatively affordable.

Affordability is one thing, though, and availability is another – in theory the Indian fertilizer industry at capacity requires 46.5 million scf/d of natural gas, of which it receives a notional allocation of 31 million scf/d of gas, but in practice the actual delivered volumes have been only 22-24 million scf/d. The new pipeline and LNG import terminal projects may mean that there is more LNG available for urea producers, but this also exposes India to the peaks and troughs of the LNG market – currently oversupplied, but no surplus lasts for ever.

The prospect of coal gasification on the face of it seems a better one, but a move to coal increases capital costs and complexity. The Jindal project at Odisha and the RCF Talcher plant have both struggled along for several years and deadlines have come and gone with no earth having been turned at the sites. Talcher is looking to close financing next year via a bond issue and currently seems the more likely to make it, but there is still a long road ahead.

Still, the most likely consequence seems to be that 3 or 4 of these plants will be up and running by 2021-22, and India's net import of urea will be cut by 4-5 million t/a or so. It may not be self-sufficiency, but it is certainly a major step in that direction.


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Major investments in Russia's nitrogen production

Eugene Gerden reports on the continuing growth in Russian nitrogen fertilizer production, as SDS-Azot begins work on a new line for production of ammonium nitrate at Kemerovo.

The production of nitrogen fertilizers in Russia will significantly increase in the coming years, due to the recently begun expansion of one of country's largest facilities in the Kemerovo region. This is being carried out by the local SDS-Azot enterprise. SDS – the Russian initials for the Siberian Business Union – has a diversified holding across various industries, including one of the largest coal mining companies in Russia (SDS Coal). It is also one of the largest producers of nitrogen fertilizer in Russia, with assets in Western and Eastern Siberia, including Kemerovo Azot, the Angarsk Nitrogen Fertilizer Plant and AZOT-Service. It is a primary supplier of ammonia nitrate explosives for mining customers in Siberia and the far east of Russia, as well as Mongolia and Kazakhstan.

The new plants are being built at the site of the existing SDS-Azot facility for the production of nitrogen fertilizers and will result in a 50% increase in overall capacity at the site. Current production capacities at SDS-Azot are estimated to be 1.0 million t/a of ammonia, 1.0 million t/a of ammonium nitrate, 500,000 t/a of urea, 314,000 t/a of ammonium sulphate, and 116,000 t/a of caprolactam.

Expansion

The new project involves the construction of an ammonia plant with a capacity of 2,000 t/a, a 1,200 t/d nitric acid plant, an ammonium nitrate solutions plant with a capacity of 1,250 t/d, as well as a porous ammonium nitrate facility with a capacity of 1,000 t/d. Tecnimont, part of the Maire Tecnimont Group, has been appointed the lead contractor on the project, which is expected to be the largest project in the Russian nitrogen fertilizer industry in the past 25 years, both in terms of production capacities and investments. Those investment figures for the project stand at 1.2 billion; the majority of funds are expected to be allocated from SDS-Azot's own resources, with the remaining being provided by Russian banks.

During the second stage of the project SDS-Azot plans to invest in the building of another line for the production of urea with a daily output of 2,200 t/d, as well as a new facility for the production of ammonium nitrate sulphate. In the longer-term, SDS-Azot intends to establish a production facility for sodium cyanide at the capacities of the same plant.

Roman Trotsenko, a well-known Russian businessman and a major shareholder of SDS-Azot, said that building the new facility will allow SDS-Azot to increase its current capacities by more than 1.5 times and become one of the largest nitrogen fertilizers' producers not only in Russia, but also in Europe. The company is already one of the largest chemical enterprises in the Urals and Siberia and, together with fellow SDS subsidiary Angarskiy ATK LLC, the company controls 85% supplies of ammonium nitrate to mining enterprises in Russia's Siberia and Far East regions. In addition, both companies produce together almost 30% of the total production of caprolactam in Russia, and control up to 50% of its exports from Russia.

Roman Trotsenko said building of the plant should be completed during the next 2-3 years. "The main goal is not only to increase output of the company, but also to switch to the manufacture of new products, which will be in high demand among both domestic and foreign customers of the company", Trotsenko said. He also added the company puts big hopes on the expansion of its Kemerovo plant, the volume of investments in which has already amounted to 9 billion roubles (US$150 million) since 2010.

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Growth in nitrogen

Analysts at the Russian Ministry of Industry and Trade said the project may be attractive to its investors, as nitrogen fertilizers are perhaps the only segment of the Russian fertilizer industry, which have demonstrated good growth rates over the past few years, even during the financial crisis in Russia during the period of 2014-2016, as well as this year. A spokesman for Denis Manturov, Russia's Minister of Industry and Trade, said that this was because the majority of revenues of leading local producers are calculated in the US dollars, while devaluation of the Russian national currency in international markets has provided additional support to them on the domestic market. At present the Russian nitrogen fertilizer industry continues to be mostly export-oriented. This, in turn, ensures a regular influx of currency to producers. At the same time large reserves of natural gas in Russia priced in roubles allow local fertilizer producers to undercut foreign markets.

In recent years the production of nitrogen fertilizers in Russia has significantly increased and continues to grow, mainly due to stable demand from the domestic agricultural industry and large exports abroad. Analysts at the Russian Ministry of Agriculture predict that the demand for nitrogen fertilizers in Russia will continue to grow over the coming years, mainly due by the growth of consumption by local agriculture business, which is currently booming due to the continuing ban against food and agriculture exports from Western countries to Russia. In the case of agriculture, a spokesman of the Russian Minister of Agriculture Alexander Tkachev said that over the past few years local government has significantly increased the volume of its funding, and that a significant part of this has been allocated to the subsidies to domestic farmers for the purchases of fertilizers, including nitrogen. This has contributed to the growth of consumption of nitrogen fertilizers by the Russian farming industry in recent years.

However, where Russia produces about 20 million t/a of fertilizers, however domestic consumption accounts for only around 15% of total production, equivalent to 2.6 million t/a, and in spite of the ongoing growth of domestic consumption and exports, Russian analysts fear that further commissioning of new capacity may lead to excessive supply of some types of mineral fertilizers to the domestic market. Igor Kaluzhsky, Executive Director of the Russian Association of Mineral Fertilizer Producers (RAPU), has predicted that over the next few years the volume of production of nitrogen fertilizers in Russia will be by almost 10 times higher than the country's annual needs in these fertilizers.

While SDS Azot will be a major contributor to this growth in fertilizer production, it is not the only project which involves the establishment of a large-scale plant for the production of nitrogen fertilizers. Last year JSC Ammonium, a leading Russian producer of mineral fertilizers, officially commissioned a new plant for the production of ammonia in the city of Mendeleevsk in Tatarstan, one of Russia's most economically developed regions. The capacity of the plant is 700,000 t/a of ammonia per year and 717,500 t/a of granulated urea, while the volume of investment in its building amounted to US$1.6 billion. The company plans to build another line for the production of ammonia with the same capacity during the next several years. ■

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Ammonia market developments

A look at some of the factors shaping merchant ammonia supply, demand and patterns of trade worldwide.

In 2016, global ammonia capacity stood at around 218 million t/a, of which around 175 million tonnes of ammonia was actually produced that year. Most ammonia produced is for captive use, particularly in downstream urea, ammonium nitrate, nitric acid or ammonium phosphate plants, and the merchant market remains a small fraction of this – 18.3 million tonnes in 2016, or around 10% of total production.

On a regional basis, as shown in Table 1, it can be seen that the major net importing regions continue to be North America (mainly to feed DAP production in Florida, Western Europe (for a variety of uses, often industrial/technical), South Asia (mostly to feed Indian DAP and some urea production) and East Asia (Japan, South Korea, Thailand and Taiwan are all net importers, again often for industrial/technical uses). By nation, the largest importers are the United States (26% of all imports), India (15%), and then Morocco, Korea, Belgium, Germany, Taiwan and France.

On the export side, the major volumes come from Trinidad, which was responsible for 25% of ammonia trade in 2016, Russia (20%) and then in decreasing order Saudi Arabia, Algeria, Canada, Indonesia, Qatar, Iran, the Netherlands and Australia, which collectively represent another 40%. One notable omission from that list is Ukraine, which exported only 180,000 tonnes of ammonia in 2016, and so dropped out of the top 10 ammonia exporters. The largest exporting regions were thus South and Central America (chiefly because of Trinidad's contribution), the former Soviet Union (because of Russia) and the Middle East (because of the Saudi, Qatar and Iranian volumes).

While demand for ammonia ultimately comes mainly from fertilizer applications (about 75% of all ammonia produced), this nitrogen is mostly traded internationally as the more readily portable urea or ammonium nitrates, and so it is the rarer, non-integrated fertilizer or industrial users who represent the buying side of the market, particularly diammonium phosphate producers, as they tends to gravitate towards sources of phosphate rock, which often do not coincide with sources of gas or coal to make ammonia. Conversely, merchant ammonia production is generally from large, relatively inaccessible sources of natural gas close to waterways where export can be facilitated.

Table 1: **World ammonia production, consumption and trade, 2016, million t/a product**

Region	Production	Export	Import	Consumption	Net imports
Western Europe	11.2	1.1	4.0	14.1	2.9
Eastern Europe	5.2	0.2	0.2	5.2	0
FSU	22.6	3.9	0.5	19.2	-3.4
North America	17.4	1.4	4.8	20.8	3.4
S/Central America	9.0	5.0	1.2	5.2	-3.8
Africa	7.4	1.5	1.5	7.4	0
Middle East	16.5	3.3	0.7	13.9	-2.6
South Asia	18.9	0	2.7	21.6	2.7
East Asia	65.2	1.5	2.8	66.5	1.3
Oceania	1.7	0.4	0	1.3	-0.4
Total	**175.1**	**18.3**	**18.3**	**175.1**	

Source: IFA

Recent developments

The figures show some major changes over the past couple of years. There is higher production in the US, South Asia, Africa (mainly Algeria but also Egypt) and the Middle East (Iran and Saudi Arabia), and lower production in East Asia (due to Chinese production curtailments) and the FSU. The fall in FSU production is mainly accounted for by developments in Ukraine, which exported 1.3 million tonnes of ammonia in 2013, but less than 300,000 tonnes in 2016, as the ongoing struggle against separatists in the east and gas curtailments and price increase from Russia continue to affect the industry there.

Consumption has increased in the FSU, North America and especially Africa (mainly Morocco, as OCP continues to expand diammonium phosphate production) the Middle East (Saudi Arabia – also for DAP production) and South Asia. There has been falling consumption in Eastern Europe and East Asia.

New capacity

Ammonia capacity additions have increased sharply in the past two years and are projected to peak this year, before falling back towards 2019. Most of this capacity is integrated into downstream production, but often ammonia-urea plants are designed to operate with a slight excess of ammonia capacity, providing an additional income stream and incremental exports. In the next couple of years, major standalone ammonia capacity additions will come from EuroChem at Kingisepp in Russia in 2018 (1.0 million t/a) as well as some additional merchant ammonia from Acron at Novgorod and PhosAgro at Cherepovets.

Elsewhere, Indonesia is adding another 660,000 t/a of merchant ammonia capacity, and Saudi Arabia will have around 500,000 t/a spare from the Wa'ad Al Shamal phosphate complex. Mexico has plans to re-start two idled ammonia plants at its Cosoleacaque facility, which would reduce the country's import requirements. Although India has some new ammonia-urea units under development, as our article elsewhere this issue indicates, there would be no free ammonia from these, as they are all geared towards reducing urea imports.

However, the largest tranche of new capacity has come from the continuing development of domestic US ammonia capacity, most of it based on cheap natural gas – the product of the continuing boom in shale gas production. During the 1990s the US ammonia industry in effect decamped to Trinidad, as domestic gas prices rose in the US, to the extent that Trinidad had been exporting two thirds of US ammonia requirements. But as plants have re-started and new capacity has started to come on-stream, so US imports of ammonia have fallen. US ammonia imports fell from 6.8 million tonnes in 2010 to 3.4 million t/a in 2016, and are set to fall still further as new capacity is completed. Some 2.0 million t/a of new ammonia capacity was added in 2016 at CF industries in Donaldsonville – all of it integrated into downstream urea and UAN production – and at Dyno Nobel's Waggaman plant, eliminating imports to feed AN production. Another 2.5 million t/a is due to be commissioned in 2017-18, including CF's Port Neal plant, Iowa Fertilizers at Wever, Simplot at Rock Spring and the BASF-Yara plant at Freeport – most of these are also integrated plants, but the BASF unit will be a 750,000 t/a standalone unit.

China's changing fertilizer market

China continues to be the other major influence on nitrogen markets. While China has been a major exporter of urea, on the ammonia side exports have been small or even negative, because the producing locations, tied to major coal fields, are often some way inland. In 2016, China imported a net nearly 500,000 tonnes of ammonia, making it the 9th largest importer. Some of this was because of continuing rationalisation of Chinese ammonia and urea capacity and government environmental audits which have sought to reduce pollution near urban areas and which have forced seasonal closure of a considerable tranche of capacity. At the same time, China is attempting to move to a 'zero growth' fertilizer consumption policy by 2020, although increases continue to occur in industrial uses such as acrylonitrile and caprolactam, and scrubbing of sulphur dioxide emissions from coal-fired power plants.

Morocco

On the demand side, Morocco is currently engaged in a major expansion of its domestic phosphate production capacity and is looking towards much greater production of downstream phosphate fertilizers, mainly MAP and DAP. Out to 2021, OCP is adding a planned 6 million t/a of phosphate capacity (tonnes P_2O_5), which will require a corresponding increase in ammonia imports of about 1.9-2.4 million t/a.

A low point for prices?

Morocco seems set to provide a boost to what has been a fairly depressed market. Although the Wa'ad Al Shamal DAP plant in Saudi Arabia has eaten into that country's surplus, the new capacity in the United States will continue to displace merchant ammonia into other markets. This year should see the peak of new capacity additions, especially in the United States, and there are indications that the current seasonal low in prices may be the low point for the ammonia industry. However, demand growth for nitrogen fertilizers, accounting for 75% of ammonia demand, has slowed in recent years, and in future may only rise at around 0.7-1.2% per year, depending on China's success in capping fertilizer use. Fastest growth is now most likely in South America.

Factors to watch will be gas price availability in Trinidad, still the world's largest ammonia exporter, and the ability of producers in Ukraine and other Black Sea producers to act as swing capacity. ■

A report on papers presented at the 62nd Safety in Ammonia Plants and Related Facilities Symposium, held in September in Brooklyn, New York.

Safety in ammonia plants

The American Society of Chemical Engineers (AIChE) has been running its Safety in Ammonia Plants and Related Facilities Symposium – otherwise known as the Ammonia Safety Symposium – for over 60 years now, and it continues to be the pre-eminent forum for discussing ammonia plant incidents and trying to improve process operations. Perhaps it is a sign of the success of the Symposium that a number of papers described safe-start-ups and commissioning of plants or methods of achieving reliability. However, there is of course no place for complacency when dealing with large and complex chemical facilities.

The human element is often the root cause of process safety accidents, and so the Symposium's keynote speaker, Tony Downes of Honeywell, looked at 'abnormal situation management'. He identified 70% of process incidents as being human-related, either directly (40%) or indirectly by operating equipment out of its normal operating range (30%). Critical to making the right decisions, he said, was the display hierarchy on the operator's terminal, allowing them to move from 'big picture' to detail as the situation warrants. It is also important not to overload operators with unnecessary process alarms, and to simplify complex information by making it more visual. Tools like an alarm configuration manager can reduce the number of daily alarms by a factor of 100 and in a real world case led to one fewer plant 'trip' per year, saving hundreds of thousands of dollars.

Ammonia plant incidents

There were fewer incidents described this year, but the Fertilizer Association of India had put together the results of its most recent five-yearly surveys of safety at Indian fertilizer plants, and presented this to the Symposium. This survey, covering 2010-2015, showed an encouraging fall in the Long Term Injury Rate (LTIR) to 0.36 per million man-hours worked, compared to 0.59 for the previous survey period (2005-2010), although this average figure masked a considerable range from 0.04 for the best performing to 0.89 for the worst. There was also a 50% reduction in the 'severity rate' (man-hours working time lost per million man-hours) from the previous survey period, as well as an increase in reportable injury-free operating days. There were nevertheless still 29 fatalities during the reporting period, half of them resulting from a slip/fall from height. Road/rail vehicle accidents and electricity-related incidents covered another seven. Other causes included fire, steam scalding, and entanglement with moving equipment.

Fatima Fertilizers in Pakistan had likewise performed a study on all papers from the most recent 20 years of previous Ammonia Safety Symposia in order to try and extract key learnings for their own plants' operation. Their study shortlisted papers to identify common themes and underlying trends which would have relevance to their own site. It found that 52% of reported incidents were due to operating failure, 26% design failure, 18% mechanical or metallurgical failure, and 4% down to instrument failure. Operational failures were more common in the 'front end' of ammonia plants, design and metallurgical failures more common in the 'back end' of the plant. Fatima also highlighted the key lessons taken from the most relevant papers and how they had related it back to process improvements.

In other operating incidents, Yara Pilbara reported on a high pressure syngas compressor failure in 2015 due to reverse rotation. It appears that two synloop valves did not fully close during a trip (caused by a site electrical blackout due to a seawater piping rupture) allowing the synloop to rapidly depressurise, and a check valve remained open. The revere rotation allowed the resonant frequency to be passed five times in succession, leading to the failure.

Baker Engineering and Risk jointly presented with Koch Fertilizer on how minor failures can be precursors to larger equipment failures, and the case for more thoroughly reviewing and investigating such failures as a way of preventing the occurrence of more dangerous incidents.

Chambal Fertilizers and Chemicals Ltd had a leak of boiler feed water into the shell side of the steam generators, leading to contamination of the process gas and steam carry-over into the low temperature shift section. The plant was shut down to preserve the LTS catalyst, and so that remedial action could be taken with the waste heat boiler. A slow drying of the catalyst had to be performed to prevent breakage.

Fauji Fertilizers suffered efficiency issues with a syngas compressor, which when opened was found to be partially blocked with ammonium carbamate deposits. Fault tracing identified the interaction of leaks in the feed-effluent gas heat exchanger downstream of the methanator and the presence of ammonia in the sour gas recycle to the compressor as the cause of this previously unreported phenomenon, and their paper also described work with simulators and the corrective actions taken to ensure that it did not recur.

Technology

On the technology side, Haldor Topsoe launched their new *SynCOR Ammonia* technology for large-scale plants. This takes a leaf from their previous *SynCOR Methanol* and GTL technologies, the former of which was launched in 2014 and is now under construction at a 5,300 t/d methanol plant, while two 7,000 t/d (in terms of ammonia equivalent) GTL units are expected to be completed in 2019. Briefly, it replaces the steam reformer with an oxygen-blown autothermal reformer and fired pre-heater. Carbon dioxide and inerts are removed prior to the ammonia synthesis loop, with pure nitrogen provided from the air separation unit, allowing a single ammonia converter. Topsoe says that this flowsheet can deliver a 6,000 t/d single stream ammonia plant. There will be a full article on this new technology in our next issue, January-February 2018.

On the materials side, the Special Metals Corp. showcased the performance of their *Inconel* alloy 693 in resisting 'metal dusting' or attack by high activity carbon, typically from high concentrations of carbon monoxide in syngas. This can lead to rapid pitting and eventual disintegration of metal components into a metal and carbon powder, exposing fresh material to attack. *Inconel 693* is a nickel-chrome alloy with iron and aluminium and trace quantities of titanium and niobium. The combination of chromium and aluminium seems to be the key resistance factor, and the alloy exhibits 10,000 times the metal dusting resistance of, e.g. *Inconel 600*, which has only 0.2% Al instead of 3% Al.

Fertilizer production via the gasification route

India has abundant sources of coal which can be utilised as a raw material for producing fertilizers. **N. Mangukia** of Linde Engineering India discusses the benefits of large scale ammonia/urea plants based on the gasification of coal or petcoke for countries like India, which is currently a large importer of fertilizers.

World food demand is increasing in conjunction with the increase in world population. Some countries like India are still large importers of fertilizers. The feedstock for producing fertilizers (i.e. natural gas) is either not available in some countries or it is not economically viable to produce fertilizers from costly imported feedstock (e.g. RLNG). An alternative feedstock for producing fertilizers is coal or petroleum coke (petcoke) if available. India has abundant sources of coal which can be utilised as a raw material for producing fertilizers.

The most vital raw material for producing fertilizers is ammonia which can be produced by the following routes:

- reforming of natural gas or naphtha;
- partial oxidation of fuel oil or LSHS;
- coal or petcoke gasification.

In the case of India, due to limited availability of natural gas feedstock, high prices and ultimately marginal or no viability, there have been no major Indian fertilizer projects in recent years. The dependence on imported fertilizer continues and is directly linked to food security. Indigenous gas production from the Krishna Godavari (KG) basin has not followed original projections and hence is not encouraging for fertilizer producers. All of these factors point to sourcing of feedstock from alternative sources such as coal or petcoke.

Alternative promising feedstocks

Coal and petcoke are promising alternative feedstocks for fertilizer production due to large reserves in many countries and their cost competitiveness with other feedstocks like natural gas/ naphtha/ LSHS. Various gasification technologies have developed in recent years which helped to utilise coal/petcoke for production of not only fertilizers but also other valuable products. Some countries like China have used the gasification route to such an extent that the major share of ammonia production is produced via the gasification route. Although gasification has the highest specific energy consumption for ammonia production of all routes available, due to the relatively very low cost (in \$/million Btu) for coal/petcoke, the production costs are lower.

Production scheme

Fig. 1 shows a simplified production for the production of nitrogen fertilizer via the gasification route.

Air separation unit (ASU)

Cryogenic ASUs separate atmospheric air into pure oxygen, which is used for gasification, and pure nitrogen, which is used for ammonia synthesis. Mega capacity ASUs are built around the world with very high reliability. A standard 2,200 t/d ammonia plant requires an ASU with a capacity to produce 3,500 t/d oxygen. The main components of an ASU comprise a large main air compressor (MAC) and booster air compressor (BAC), air dryer station, cold box for cryogenic separation of air, expansion turbine for generation of required cold energy, liquid oxygen pump, and nitrogen compressor. Liquid storage for oxygen and nitrogen can be considered depending on project specific requirements.

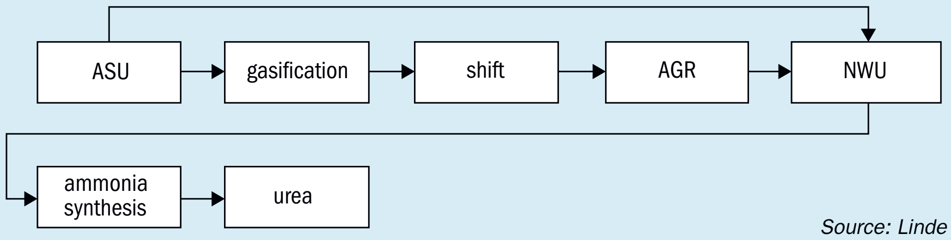
Gasification

Depending on the type of feedstock (i.e. coal with varying ash content, petcoke etc.), gasification technology needs to be selected. The gasifier converts the feedstock into syngas (a mixture of mainly carbon monoxide, hydrogen and small amounts of carbon dioxide and methane). Gasification reactions take place at medium to high pressure in the presence of oxygen and steam. After heat recovery, the syngas is routed to the shift reaction section to convert carbon monoxide and water into hydrogen and carbon dioxide by the water gas shift reaction in the presence of catalyst.

Acid gas removal (AGR)

There are two types of acid gas removal (AGR) process: physical wash or chemical

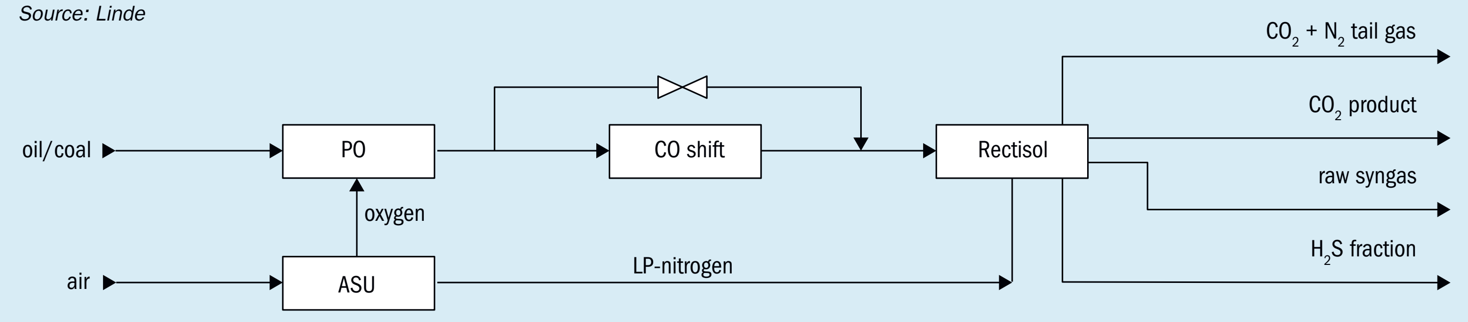
Fig. 1: **Production scheme for urea production via the gasification route**



Source: Linde

Fig. 2: **Acid gas removal scheme based on the Rectisol® process**

Source: Linde



wash. The Rectisol® process is an example of a physical wash process. It offers an excellent solution for gas treatment downstream of the gasification complex. Treated gas can be utilised for cogeneration (as fuel to existing gas turbines), fuel for existing heaters, producing value added products like hydrogen, substitute natural gas (SNG), carbon monoxide (CO), synthesis gas, etc.

Rectisol® was developed jointly by Linde and Lurgi in the late 1950s and both companies own the IP rights. The Rectisol® process uses methanol as the wash solvent. The process operates best at low temperatures and high pressures. The process can be used for the selective removal of H_2S, COS and CO_2. The handling of trace impurities like hydrogen cyanide, ammonia, metal carbonyls, chlorides etc. is essential.

Fig. 2 shows a simplified acid gas removal scheme using Rectisol.

Acid gas removal plays an important role in a gasification complex as it is located between the gasification unit and the final product processing units. The AGR removes all the undesirable components from the synthesis gas and provides valuable side streams such as an enriched H_2S fraction for the production of elemental sulphur, and pure CO_2, etc. Carbon dioxide, which is available from the AGR, is required for urea production.

AGR unit.

Nitrogen wash unit (NWU)

The liquid nitrogen wash unit is an economical and highly reliable step for ammonia syngas purification and preparation. The NWU takes high pressure nitrogen from the ASU. The two principle functions of the NWU are:

- removal of impurities such as CO, Ar and CH_4 from syngas;
- addition of required stoichiometric amount of nitrogen to the hydrogen stream to achieve the correct H_2:N_2 ratio of 3:1

Carbon monoxide will poison the ammonia synthesis catalyst, while argon and methane are inerts that will build up in the loop and slow the reaction.

The main advantages of the nitrogen wash unit are:

- high purity of ammonia syngas leading to long catalyst life in converter;
- no accumulation of inert gases in ammonia synthesis loop;
- no purge required hence losses of syngas is eliminated;
- simple operation – no moving parts like pumps and compressor.

Ammonia synthesis

Once syngas with the required stoichiometric proportion is available from the NWU, a state of the art ammonia synthesis unit can be employed for production of ammonia. Various configurations of ammonia converter are available from experienced licensors. The ammonia synthesis section of a plant utilising gasification as the route for synthesis gas preparation is no different to an ammonia plant with natural gas or naphtha as feedstock.

Challenges

The main challenges for producing fertilizers via the gasification route are:

- the coal available in certain countries has a high ash content which poses a challenge as regards the handling of large quantities of ash;
- cost competitiveness of the gasification route due to a relatively high capital cost
- reliability yet to be proven in some countries.

Summary

- Large ammonia/urea plant capacity is possible via the gasification route.
- All individual process units such as the ASU, AGR, NWU, and ammonia synthesis are available for capacities of more than 2,500 t/d ammonia.
- Although the energy consumption per tonne of ammonia would be higher, due to lower energy cost of coal/pet coke, the production cost of ammonia will be lower than conventional feedstocks like natural gas/naphtha.
- Various other products can also be produced through this route (e.g. methanol, SNG etc.)
- Sulphur is a by product.
- New gasification technologies have emerged in recent years which eliminates problems related to reliability/availability of gasifiers.
- Issues of high ash content can be mitigated by blending high ash coal with low ash coal and using petcoke from refineries.
- Environmental issues need to be addressed by using suitable methods for handling ash (lowering fly ash).

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A China first at Henan Jinkai ammonia plant

M. Rizzi of Casale and **Xu Junhong** of Henan Jinkai Group provide a short history of Casale ammonia synthesis technology for inert-free loops and its application in the design of the largest single-train inert-free ammonia synthesis loop built and operating to date: the 2,000 t/d Henan Jinkai ammonia plant in Kaifeng, China.

The operating conditions in an ammonia synthesis converter are more severe when the synthesis gas is generated by gasification than when it is generated by the more common steam reforming process. The gasification route has to be used in plants fed with heavy feedstocks such as coal.

The reason for the high operating severity is that the synthesis gas entering the synthesis loop has much lower concentrations (in the order of hundreds of ppm) of inert components (principally argon and methane) than are found in synthesis gas from steam reforming plants. Consequently the gas is more reactive, which means that operating temperatures can be significantly higher.

The parts of the synthesis section that are most critically influenced by the higher severity are the ammonia converter itself and downstream equipment items like the steam superheater, the waste heat boiler and the boiler feed water preheater. The effect on the remaining parts (standard heat exchangers, vessels, pipes, etc.) is no more critical than usual for the design and operation of the plant.

Casale ammonia converters

One of Casale's principal activities is developing new and original designs for ammonia synthesis converters and related equipment items. Over the last 30 years Casale designs have been used in about 200 new or revamped ammonia converters, i.e. almost half of all ammonia converters in operation worldwide were designed by Casale.

Recent history of Casale's inert-free converters and synthesis loop includes the revamping of existing converters as well as many new synthesis loops in new plants, most of them supplied in China, the world's most important fertilizer manufacturer using coal as feedstock. China has committed to making massive investments in the fertilizer field with the aim of becoming self-sufficient in fertilizers and, at the same time, shutting down the oldest, least efficient and sometimes polluting existing small plants.

The scope of Casale's responsibility for the synthesis loop has commonly included not only the supply of the converter internals and engineering, but also the supply of the heat recovery device (boiler, BFW preheater or steam superheater) downstream of the ammonia converter.

In these plants it is evident that it is not only the converter design that is of critical importance but also the hottest heat recovery device located just downstream of the converter outlet nozzle.

In such a position, where process conditions are very challenging (high temperature, very high ammonia concentration, hydrogen partial pressure still very high), the construction details of the converter and the heat recovery device make all the difference between long and trouble-free operation and problematic and sometimes discontinuous operation.

Casale's axial-radial converter experience with an inert-free loop dates back to the end of the 1980s, when Casale revamped an existing two-bed quench-cooled converter in a 1970s ammonia plant, in Germany. Casale chose a three-bed configuration with two quenches at the inlets of the second and third beds. This converter has been in operation since July 1989. At the beginning of the new century Casale supplied a fourth bed for this plant which increased its capacity to 2,200 t/d, at the same time achieving energy savings.

The second installation of an inerts free loop was in Araucaria, Brazil, where the existing cartridge was replaced with a new, three-bed, two interchanger Casale design. The third installation was for a new ammonia plant of 1,000 t/d for Farmland, in Coffeyville, Kansas, USA. This plant has been in operation since September 2000.

Many more installations have been implemented in subsequent years and today there are more than 40 inert-free converters/synthesis loops in the world designed by Casale (about 30 of them on stream) and another 15 are under construction or ready for start-up, most of them in China. These plants have capacities ranging from 150 to 2,000 t/d.

Casale has recently acquired other contracts in China for three new synthesis loops with capacities of 1,250, 1,800 and 1,820 t/d.

Peculiarities of inert-free synthesis loops

The inert-free synthesis loop is a feature of ammonia plants in which the synthesis gas is generated by gasification of a heavy feedstock, usually coal. Because of the way in which the synthesis gas is purified, components of the synthesis gas that are inert in the synthesis loop (noble gases, particularly argon, from the atmosphere and methane) are removed to very low levels, typically a few hundred ppm in total. That is low enough for it to be unnecessary to purge inerts from the synthesis loop, as methane and argon are sufficiently soluble in the HP liquid ammonia product for balance between the rate of introduction in the make-up gas and the rate of removal in the product to be reached at a much lower concentration in the circulating gas than is normal in the synthesis loop of a steam reforming ammonia plant with loop purge. Casale consider a synthesis loop to be 'inert-free' when the inert molar concentration (CH_4 + Ar) at the converter inlet (recycle + make-up gas) is lower than about 2 vol-%.

The design of the hottest parts of the synthesis loop is more critical for a loop using inert-free syngas than for a traditional loop in a steam reforming plant. Nonetheless, inert-free loops do have some advantages over traditional purged loops, particularly from an energy point of view.

In the absence of a continuous purge, almost the entire amount of hydrogen produced in the front end section is ultimately converted to ammonia. Because of the higher reactivity of the mixture fed to the converter, the required production can be achieved at a lower operating pressure than would be needed in the equivalent traditional synthesis loop with inerts.

For the same reason (higher partial pressure of the reactants), the circulation flow at a given production rate is lower, making it possible to use smaller size equipment and also reducing the energy consumption in the loop itself.

All in all, the result is a higher synloop energy efficiency and lower capex for a given rate of production. Their relative influence on the overall operating economics is affected by site specific factors, and the best compromise is therefore determined through a case by case analysis in which the two main parameters are energy cost and equipment cost.

In any case, since the cost of a synthesis loop can account for up to 20-25% of the total investment cost in a new coal-based ammonia plant (and up to 30% in a gas-based steam reforming plant), the economic advantage of capex reduction is significant.

It should be noted, however, that the higher reactivity of the synthesis gas entering the converter has a potential drawback. Because of the closer equilibrium approach in the ammonia synthesis reaction, on average the temperatures at each bed outlet are higher than normal for a traditional converter. This is especially true for the first bed, where the partial pressures of the reactants are at their maximum and the driving force for ammonia synthesis is consequently at its strongest.

The severe conditions at the converter bed outlets have to be properly managed to prevent untimely failures or problems with the internals. In addition it is essential to have a uniform temperature distribution of the gas at each bed inlet, that means very little temperature discrepancies. This is due to the much faster reaction rate when compared to converters fed with syngas containing inerts,and makes reaching the optimum temperature profile inside the converter more critical. The reason lies in a steeper profile of reaction rate vs temperature. This steeper profile means that the on/off transition of the synthesis reaction across the threshold temperature happens in a few degrees Celsius rather than in about ten degrees as in the inerts containing loops.

Therein lies Casale's success in inert-free synthesis loops. In the first place, in the Casale converter incoming cold gas is passed through the gap between the cartridge and the inside wall of the pressure vessel to protect it from potential damage by abnormally high temperatures and the aggressive chemical composition.

Secondly, Casale has incorporated independent temperature control at each bed inlet, which prevents overheating at the bed outlets.

In addition, the mixing device installed in Casale converters, designed with the help of a computational fluid dynamic (CFD) program, guarantees very good mixing, despite the low pressure drop required; that makes it possible to enter the beds with a practically uniform temperature profile, making possible temperature optimisation without the risk of unwanted converter shutdown.

Casale has also developed mechanical features and materials of construction that can reliably withstand the challenging environment at the outlet of each bed. Where appropriate, these advances have been implemented in the hottest parts of all Casale converters, increasing the reliability of internals generally.

Henan Jinkai plant

Henan Jinkai fertilizer complex in Kaifeng with its three single train ammonia plants of 2,000 t/d each is the biggest fertilizer installation in China.

All three plants have been designed by Casale at different times. The first two twin plants started up just a few months apart during 2013 (the first reached full capacity in March and the second in September), and the third plant is under construction.

Technical aspects

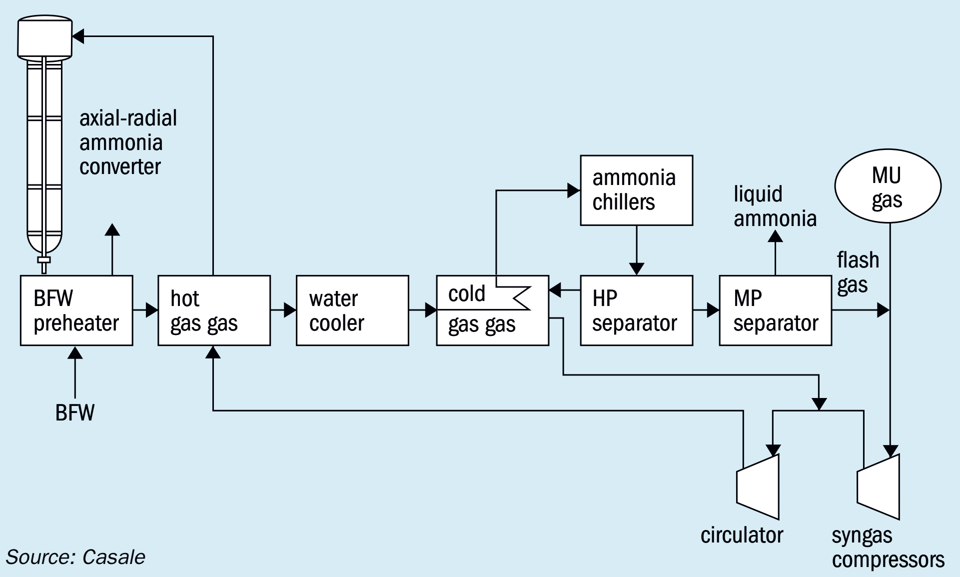
The make-up gas comes from a coal gasification unit and the pressure at compressor suction is 30 bar g.

The design operating pressure of the synthesis loop (Fig. 1) is 139 bar g and the total inerts content at the converter inlet (methane plus argon) is 1.32 mol%.

The converter configuration is a three bed two interchanger design, a typical high efficiency solution chosen for Casale new converters, since it maximises ammonia conversion per pass.

The heat recovery train consists of a high pressure BFW preheater, working at 140 bar g.

Fig. 1: **Henan Jinkai ammonia synloop (Plants I and II)**



Source: Casale

To contain investment cost, a single start-up heater common to the two lines has been installed.

The third plant, not yet in operation, has a different configuration in the heat recovery train downstream of the ammonia converter. Instead of the HI-IP BFW preheater used in trains one and two, the third train has a MPS BFW preheater, the relevant MPS boiler and the MPS superheater (placed at the converter exit nozzle).

Another difference in the two designs is the single syngas compressor in the third train compared with double twin compressors in the first two trains. In addition, the third plant has a dedicated start-up heater.

The refrigeration section is quite standard (Fig. 2). It is equipped with two chillers and its only peculiarity is that for the Rectisol unit and air separation unit (ASU) a dedicated refrigeration section has been designed (not in the Casale scope of supply). The same design will also be used in the third plant.

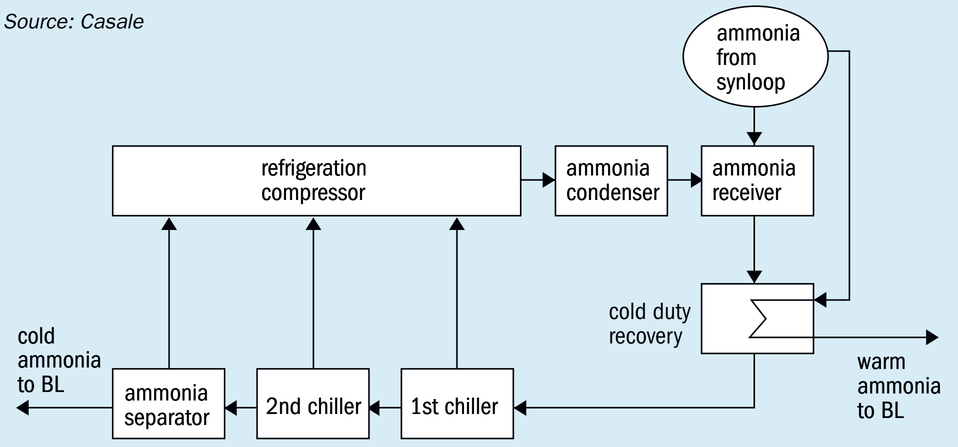
Table 1: **Main operating data: test run vs design data**

	Design conditions (SOR)	27-28 March 2013 test run
Time on stream, months	0	~4
Plant load, t/d	2,000	2,032
MUG consumption, $Nm^3/h/t$ of ammonia	2,694	2,650
Operating pressure at converter outlet, bar g	139.0	129.0
Inerts at converter inlet, mol-%	≤ 1.30	0.96
NH_3 at converter outlet, mol-% (simulated value)	20.1	19.9

Source: Casale

Fig. 2: **Henan Jinkai refrigeration section (Plants I, II and III)**

Source: Casale



Project history

The contract for the first 2,000 t/d ammonia plant in China, in Jinkai, was signed at the end of November 2009.

The Casale scope of supply consisted of the following:

- converter internals (Casale proprietary)
- BEP of the high pressure section (from compressor suction to
- the synthesis loop) and the refrigeration section
- Check of detail engineering
- Site services (installation, supervision, commissioning and start-up supervison, plant optimisation, operator training).

Casale's engineering department faced a challenging schedule for a plant with a capacity never designed before, especially for the size of machinery and equipment involved (for example to satisfy Jinkai Chemical's request to buy the two twin syngas compressors from the domestic market.

The engineering of the first ammonia train in Jinkai started in early 2010 (EDC 7 January 2010).

The BEP first issue was dispatched at the end of April 2010.

As per all Chinese projects Casale worked in collaboration with local design institutes, typically playing the role of EPC contractor of the project. For the two projects mentioned, the design institute was Beijing Aerospace Wan Yuan Coal Chemical Engineering Technology Co. It was involved in the project since the very preliminary phases, so that the design basis was agreed during contract negotiation.

BEP was provided by Casale in both English and Chinese language and according to relevant Sinopec standards.

After BEP or PDP delivery, a design review meeting was held with the participation of the client and design institute experts, in which Casale gave detailed explanations and the client reviewed and commented on all of the basic design documents, allowing the design institute to proceed with the detailed engineering work.

Henan Jinkai Group and design institute participants in this meeting comprised a delegation of about ten people including project managers and experts from all the major engineering disciplines, such as process, mechanical, piping, instrumentation, electrical, etc.

Detail engineering design was then developed by a design institute and Casale reviewed this work to check compliance with the process design requirements.

The project ended with a detail design review meeting in the offices of the design institute.

The collaboration between Casale and the client continued in the field. The installation of converter internals and the first catalyst loading was performed by the client under the supervision of field engineers.

Casale assistance continued with commissioning and start-up activities, including catalyst reduction. During this period Casale personnel also provided training to client staff operators. Final commitments for site activities were concerned with optimising parameters and the test run.

Due to the strong co-operation between all parties involved, the plant was completed and commissioned in only one and a half years after the effective start of engineering activities.

Catalyst loading in the first train was completed in October 2012, the catalyst reduction was completed at the end of November 2012 and the plant reached nominal production in March 2013, mainly due to some delays in trimming the front end section.

The successful test run certificate was signed at the end of March 2013. Full capacity and all other guarantees have been achieved with an operating pressure 10 bar lower than design.

Fig. 3: **3-Bed-2-intechanger**

Source: Casale

Fig. 4: **Direct connection with BFW preheater**

PHOTO: CASALE

Table 1 shows the main operating data for the test run compared to the design data. It should be noted that if the operating pressure had been raised to the design value, the ammonia concentration would have reached 20.6%.

Later the plant reached 105% load (i.e. 2,100 t/d) without any problem.

The second twin train was designed and erected practically in parallel with the first one.

The contract for the third 2,000 t/d train was signed on October 2014 and Casale scope of supply was also extended to the MPS superheater downstream of the converter.

This plant is under construction and is expected to be ready for start-up in 2017.

Technologies

The typical Casale design for new synthesis converters is a three bed, two interchanger design with axial-radial flow in the catalyst beds (Fig. 3).

The main advantages of the Casale converter design are:

- high conversion per pass thanks to the three bed, two interchanger design;
- easy and stable to run due to simple and well proven design of internals;
- flexibility of operation under transient conditions deriving from independent control of temperature at each bed inlet;
- easy optimisation linked to a very smooth temperature profile at the bed inlet, avoiding unexpected loss of reaction;
- reliability due to the mechanical design of the internals and choice of material of construction;
- easy catalyst replacement (loading and unloading) thanks to the full opening of upper cover and modular construction of internals.

Most of the points listed are already well known. What is worth highlighting with regard to point 4, is that the mixing devices installed in the converter, to provide uniform temperature at the bed inlets, are the result of detailed simulations developed with the help of CFD. The design requires the knowhow to achieve near perfect mixing between two stream with big differences in both flow and temperature, while maintaining a very low pressure drop across the device so that the overall pressure drop of the converter is not affected.

Thanks to these characteristics, Casale converters are highly reliable and efficient. They are able to withstand literally hundreds of start-ups and shutdowns; very high internal temperatures, for example, because of the absence of inert gases in gasification based plants; and decades of operation. Several Casale converters have been running for more than 20 years without any maintenance.

Casale also has strong experience in the design of the critical downstream equipment for process heat recovery, i.e. the steam superheaters and waste boilers, which are installed in many of its synthesis loops in gasification plants. To further improve this part of the plant, Casale has developed a direct connection between the converter outlet nozzle and the downstream exchanger, which completely eliminates the connecting pipe (Fig. 4), resulting in a less costly arrangement that is also more reliable as a pipe at this point is subject to high temperature, nitriding, hydrogen attack and mechanical stress. To withstand such severe conditions would require special and expensive materials, while in the Casale design all of these problems are eliminated.

Casale has supplied a considerable number of these special direct-coupled exchangers (superheaters, boilers and BFW preheaters) for inert-free loops: about 20 boilers, six steam superheaters and two HP BFW preheaters.

Driving methanol plant efficiency

The gas heated reformer is an alternative to the steam methane reformer in syngas plants, providing a more cost effective, compact and energy efficient unit that minimises environmental impact. **M. Janardhanan** of Johnson Matthey outlines where the technology has come from and where it is heading to, highlighting the benefits of its use in applications, particularly in Iran where water consumption is very important.

Synthesis gas from natural gas has for a long time been generated within a steam methane reformer (SMR), sometimes used in conjunction with an autothermal reformer (ATR). Gas heated reforming (GHR) has promised to revolutionise the generation of synthesis gas for ammonia, methanol and hydrogen for over 25 years by way of replacing the large and expensive reformer with a more cost effective, compact and energy efficient unit that minimises environmental impact. Recent changes, especially in the energy sector, have prompted many to relook at the benefits of gas heated reforming where electrical power is increasingly being generated by renewable energy. Similarly, where water resource is scarce, the use of a gas heated reformer can cut the raw water use by half when compared to an SMR+ATR flowsheet.

Johnson Matthey has continued to build on the work of Imperial Chemical Industries (ICI) to develop gas heated reforming technology, and is able to demonstrate that gas heated reforming is the preferred technology for synthesis gas generation for multiple applications.

Technology selection for synthesis gas generation has a significant effect on CO_2 emissions and raw water consumption in a methanol plant. The scope of this article is to look at the impact of technology choices on raw water consumption in a methanol plant based on natural gas feedstock.

The effect of CO_2 emissions on technology selection has been discussed in a paper by A. Ingham[1]. The following assumptions have been made for the comparison:

- Methanol plant is stand alone, with no power import.
- Power is generated inside battery limit (ISBL) with a steam turbine except for the advanced combined reforming (ACR) flowsheet where a gas turbine is used.
- CO_2 is imported from outside battery limit (OSBL) for flowsheet with CO_2 addition.
- The turbine condenser is cooled with cooling water.
- Where the air cooler is placed upstream of a cooling water exchanger, the intermediate process temperature is set to 60°C (140°F).

Synthesis gas generation from natural gas

A range of technologies are available for the production of synthesis gas in methanol plants. These can be broadly classified as below with each, other than advanced combined reforming, having the option to include a pre-reformer:

- conventional SMR;
- conventional SMR with CO_2 addition ($SMR+CO_2$);
- combined reforming (CR), SMR followed by ATR;
- ACR, GHR followed by ATR.

Steam methane reforming is the process of converting hydrocarbons into an appropriate synthesis gas containing carbon oxides and hydrogen. The overall reaction is strongly endothermic and requires considerable amounts of heat input. Fuel is burned to generate hot combustion gases that surrender their heat to the reacting gases through the walls of the reformer tubes. Catalyst in the reformer tubes will drive the gas to equilibrium for the water gas shift reaction (2) and close to equilibrium for the steam methane reaction (1).

Steam methane reaction

$$CH_4 + H_2O \rightleftharpoons CO + 3\,H_2 \qquad (1)$$

Water gas shift reaction

$$CO + H_2O \rightleftharpoons CO_2 + H_2 \qquad (2)$$

Overall chemical equation for methanol synthesis

$$CH_4 + H_2O \rightleftharpoons CH_3OH + H_2 \qquad (3)$$

The generation of synthesis gas using a steam methane reformer produces more hydrogen than required for methanol production in equation (3). Steam methane reforming with CO_2 addition, as in equation (4), allows this excess hydrogen to be converted into methanol equation (5), and reduces the process water requirement by a third.

SMR with CO_2 addition

$$3\,CH_4 + 2\,H_2O + CO_2 \rightleftharpoons 4\,CO + 8\,H_2 \qquad (4)$$

Overall chemical equation for methanol synthesis

$$3\,CH_4 + 2\,H_2O + CO_2 \rightleftharpoons 4\,CH_3OH \qquad (5)$$

Autothermal reforming is a process whereby oxygen is mixed with a steam/natural gas mixture in a fuel rich combustion zone. This generates high temperatures and is followed by an adiabatic catalyst bed, driving the reaction to equilibrium in both the steam methane and water gas shift reactions, combined in equation (6).

ATR

$$2\ CH_4 + O_2 \rightleftharpoons 2\ CO + 4\ H_2 \quad (6)$$

Overall chemical equation for methanol synthesis

$$2\ CH_4 + O_2 \rightleftharpoons 2\ CH_3OH \quad (7)$$

In a flowsheet with only ATR technology to generate synthesis gas, a mixture of natural gas and steam mixture is pre-heated in a fired heater. The feed gas temperature to the autothermal reformer has to be limited due to the risk of carbon formation by hydrocarbon cracking in the pre-heater tubes. To overcome the undesirable process feed conditions, the process uses excess oxygen to raise the outlet temperature to the target value of 1,020°C (1,870°F) and consequently, the synthesis gas that an autothermal reformer produces is short of hydrogen. Typically, the overall equation (8) for an ATR based process is:

Overall chemical equation for methanol synthesis

$$CH_4 + 0.65\ O_2 \rightleftharpoons 0.9\ CH_3OH + 0.2\ H_2O + 0.1\ CO_2 \quad (8)$$

To improve the carbon efficiency and achieve the stoichiometric synthesis gas, hydrogen is required. This can be achieved with a steam methane reformer or gas heated reformer installed upstream of the autothermal reformer.

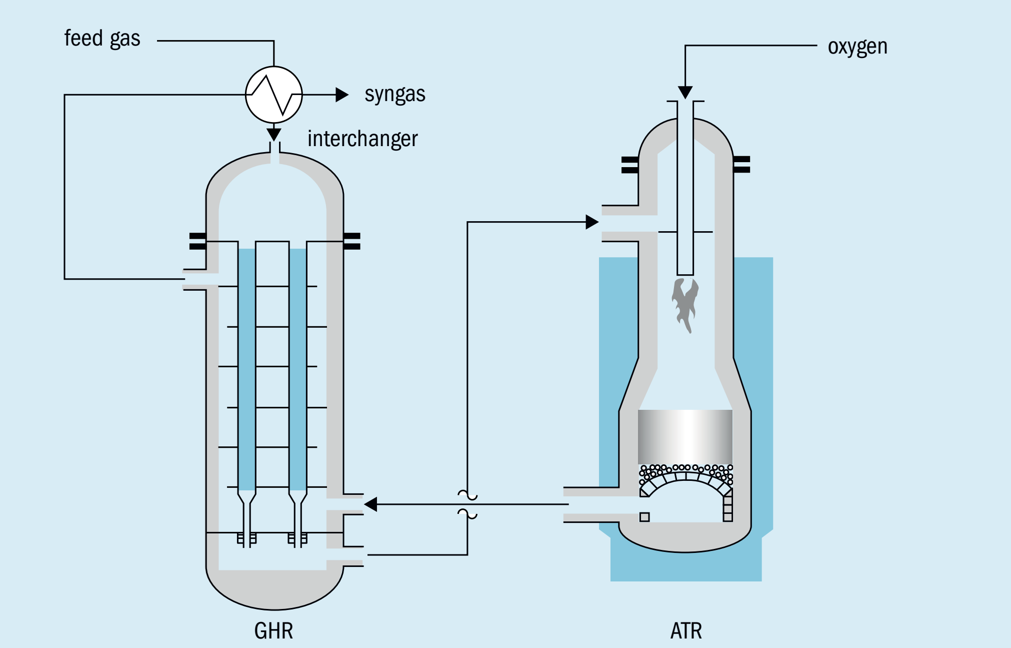
A combined reforming flowsheet avoids the limitation of the autothermal reformer feed inlet temperature by replacing the fired feed gas pre-heater with a steam methane reformer. In an advanced combined reforming flowsheet a heat-exchange reactor, the GHR, is installed upstream of the autothermal reformer. Heat is recovered from the autothermal reformer effluent stream both as sensible heat and reaction heat into the endothermic steam methane reaction. The combination of a steam methane reformer and an autothermal reformer or a gas heated reformer and an autothermal reformer in series (shown in Fig. 1) yields a synthesis gas that is stoichiometrically balanced for methanol production for a range of natural gas feedstock compositions.

Typically, the overall equation (9) for a combined reforming/advanced combined reforming based process is:

Overall chemical equation for methanol synthesis

$$CH_4 + 0.49\ O_2 + 0.02\ H_2O \rightleftharpoons CH_3OH + 0.02\ H_2 \quad (9)$$

Fig. 1: **Advanced combined reforming flowsheet**



Source: Johnson Matthey

Raw water consumption

Synthesis gas production from natural gas is a water intensive process (see Fig. 2). The primary consumers of water in a methanol plant are:

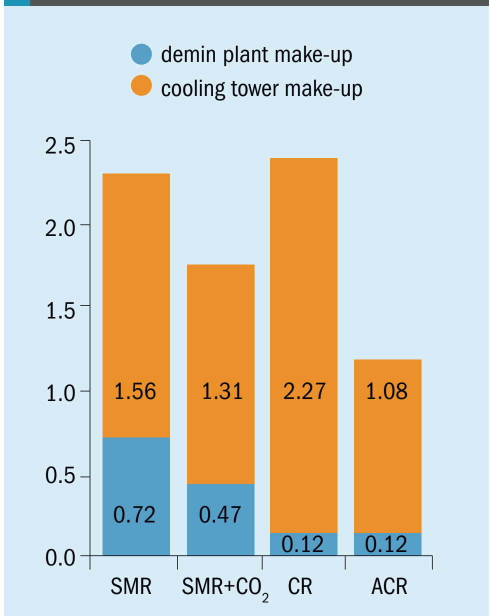
- demin water plant make-up;
- cooling tower make-up.

Demin water plant make-up

Most demin water consumption is by direct water addition to process and steam system make-up. Theoretical process water requirement is 0.57 tonne of water per tonne of methanol for the steam methane reforming only flowsheet and 0.35 tonne of water per tonne of methanol for the steam methane reforming with CO_2 addition flowsheet. With a typical 95% methanol synthesis loop carbon efficiency, the process water consumption is 0.62 and 0.37 tonne per tonne of methanol respectively for steam methane reforming and steam methane reforming with CO_2 addition flowsheets (Fig. 3).

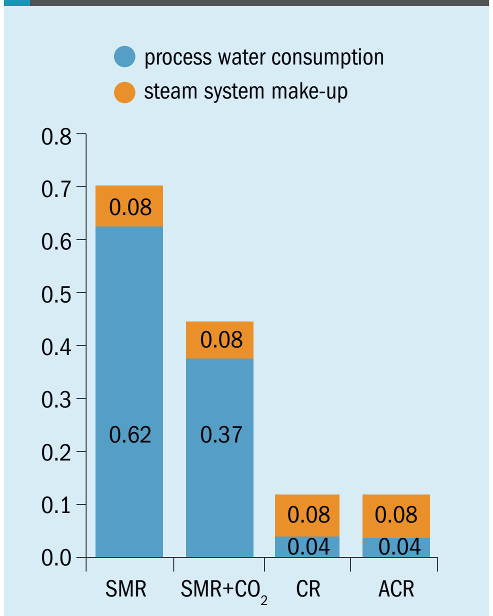
The process water make-up requirement for both the combined reforming and advanced combined reforming flowsheets

Fig. 2: **Raw water consumption (t/t of methanol)**



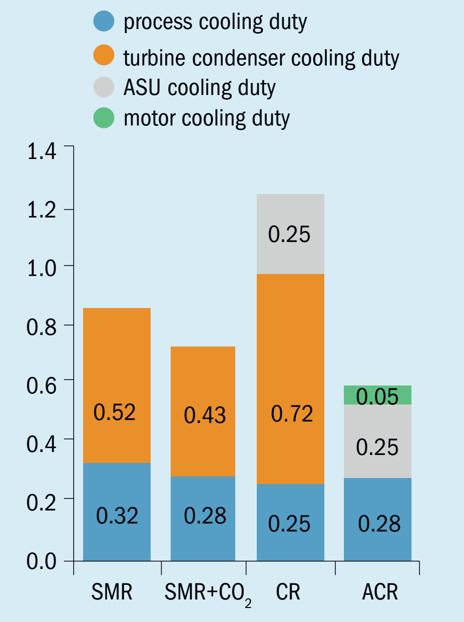
Source: Johnson Matthey

Fig. 3: **Demin water consumption (t/t of methanol)**



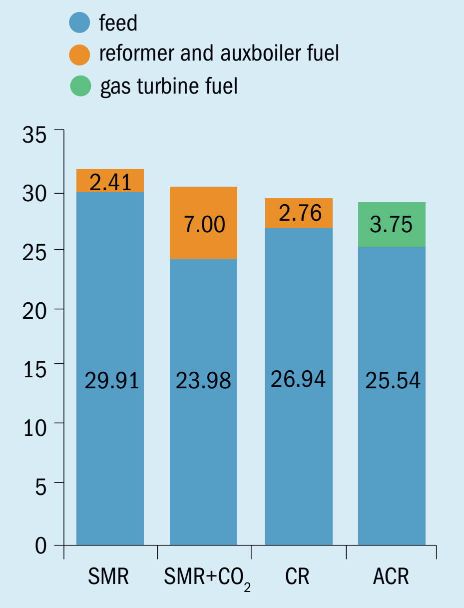
Source: Johnson Matthey

Fig. 4: **Cooling tower duty (MW/t of methanol)**



Source: Johnson Matthey

Fig. 5: **Gas efficiency LHV basis (GJ/t of methanol)**



Source: Johnson Matthey

is 0.04 tonne per tonne of methanol.

Steam system losses are approximately 0.08 tonne per tonne of methanol for all the flowsheet arrangements.

Cooling tower make-up

Cooling tower make-up is a major consumer of raw water in a methanol plant. Cooling water consumption for different flowsheet arrangements are compared in Fig. 4.

Superheated high pressure steam (HPS) is generated during synthesis gas production in methanol plants with steam methane reforming and/or autothermal reforming. The generated HPS is used for the compression of synthesis gas and /or air separation unit (ASU) turbo-machinery based on the technology selection.

In steam methane reforming, steam methane reforming with CO_2 addition and combined reforming flowsheets, more than 50% of cooling water is consumed by the turbine condensers. The advanced combined reforming flowsheet with gas heated reforming technology is unique when compared with all other flowsheets; no superheated high pressure steam is produced in the ISBL plant.

This gives the opportunity to select the optimum approach for providing power to drive the compressors in the ASU and the synthesis gas compression required in the process.

Three options are available in addition to supplying oxygen to the advanced combined reforming plant by others:

- Gas turbine power generation with distribution to electric motor drives, which eliminates the need for steam turbine driven compressors in the plant, reducing the cooling water demand.
- Power import from the grid. This is the lowest capital cost option and is a good alternative if power is reliable, cheap and readily available.
- Gas turbine drive plus heat recovery, which is the lowest energy solution.

Where oxygen is available, either by pipeline or from an ASU operated by others, the option to import power to drive the compressors is a good choice. This reduces the capital cost of the project and does not impact the overall process efficiency.

This option is not possible with a combined reforming process based on a steam methane reformer as the steam produced by the process is required to drive the ASU turbines, otherwise it would be wasted.

Table 1: **Performance comparison between flowsheets**

	SMR	SMR+CO_2	CR	ACR
Net feed and fuel (LHV basis), GJ/tonne MEOH	32.32	30.98	29.70	29.29
Net raw water makeup, tonne/tonne MEOH	2.28	1.78	2.39	1.20
CO_2 emissions, kg/tonne MeOH	428	356	286	264

Source: Johnson Matthey

Gas efficiency

In steam methane reforming, steam methane reforming with CO_2 addition and combined reforming flowsheets, fuel is burned to supply heat for the endothermic steam methane reaction. The waste heat from the reformer is generally recovered by raising high pressure steam.

The fact that heat from the autothermal reformer effluent is being recycled directly back into the process though the gas heated reformer means that there is no direct combustion of any natural gas fuel to provide heat for the endothermic steam methane reaction.

Fig. 5 compares the gas efficiency of the different technology flowsheets and Table 1 compares performance between the flowsheets.

Conclusion

The gas heated reformer recycles the high temperature process heat and decouples HPS generation and methanol; no longer a power plant making synthesis gas.

The ACR flowsheet offers the following advantages relating to energy and raw water use:

- Maximised waste heat recovery and liquid effluent recycle to the process resulting in the lowest energy consumption.
- Lowest raw water consumption.
- Where sea water is used for cooling, less heat rejection reduces the capex on a sea cooling system having expensive titanium alloys.
- Flexibility to import power and have the lowest carbon footprint.

References

1. Ingham A.: "Low carb methanol – the lighter way to produce methanol", IMTOF 2015.

Acknowledgement

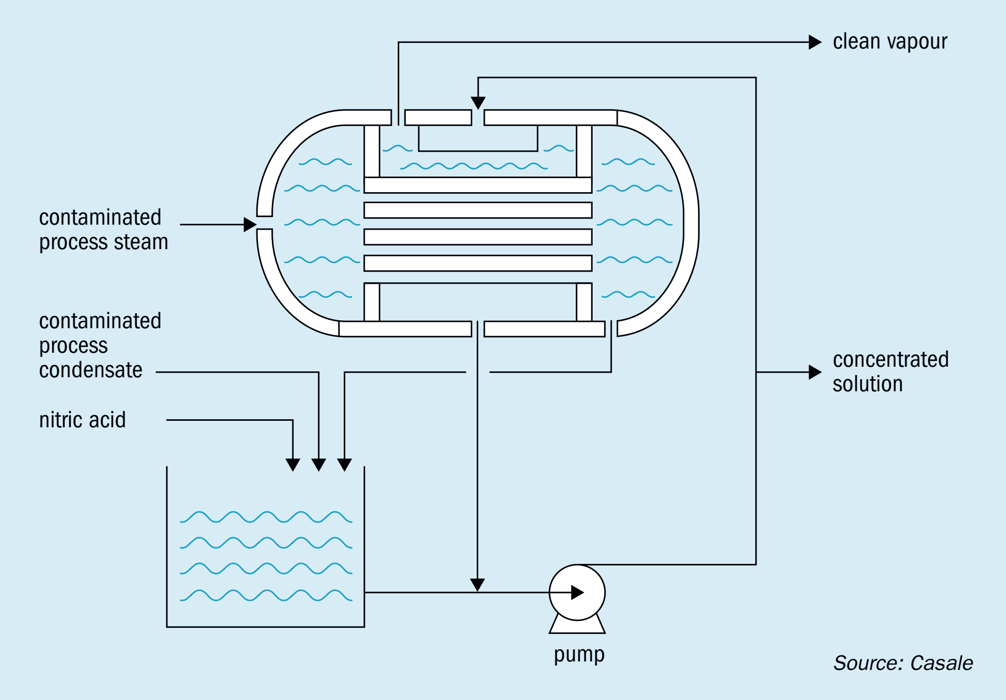
This article is based on the paper "Driving methanol plant efficiency with a focus on the environment" by M. Janardhanan of Johnson Matthey and was produced as part of the IMTOF 2017 book.

Nitrate plant debottlenecking and modernisation

Plant assets are the most valuable part of any chemical manufacturing business and should be looked after as carefully as possible. Casale has wide experience of many different types of plants thanks to its revamping activities. **J. F. Granger** of Casale discusses the latest trends for the modernisation of nitrate plants.

Casale's revamping approach can be applied to nitrates plants, regardless of the original process design. It is therefore possible to modernise existing units to improve their efficiency and increase their capacity such that the revamped plant can compete with the most modern units in terms of reliability, safety and economics of production.

Fig. 1: **Casale condensate purification system**



Source: Casale

Modernisation of ammonium nitrate solution plants

Apart from the case where equipment is at the end of its life, the main targets for modernising ammonium nitrate plants is usually to increase the capacity, improve the quality of the process condensate and decrease the energy consumption required to achieve the desired concentration.

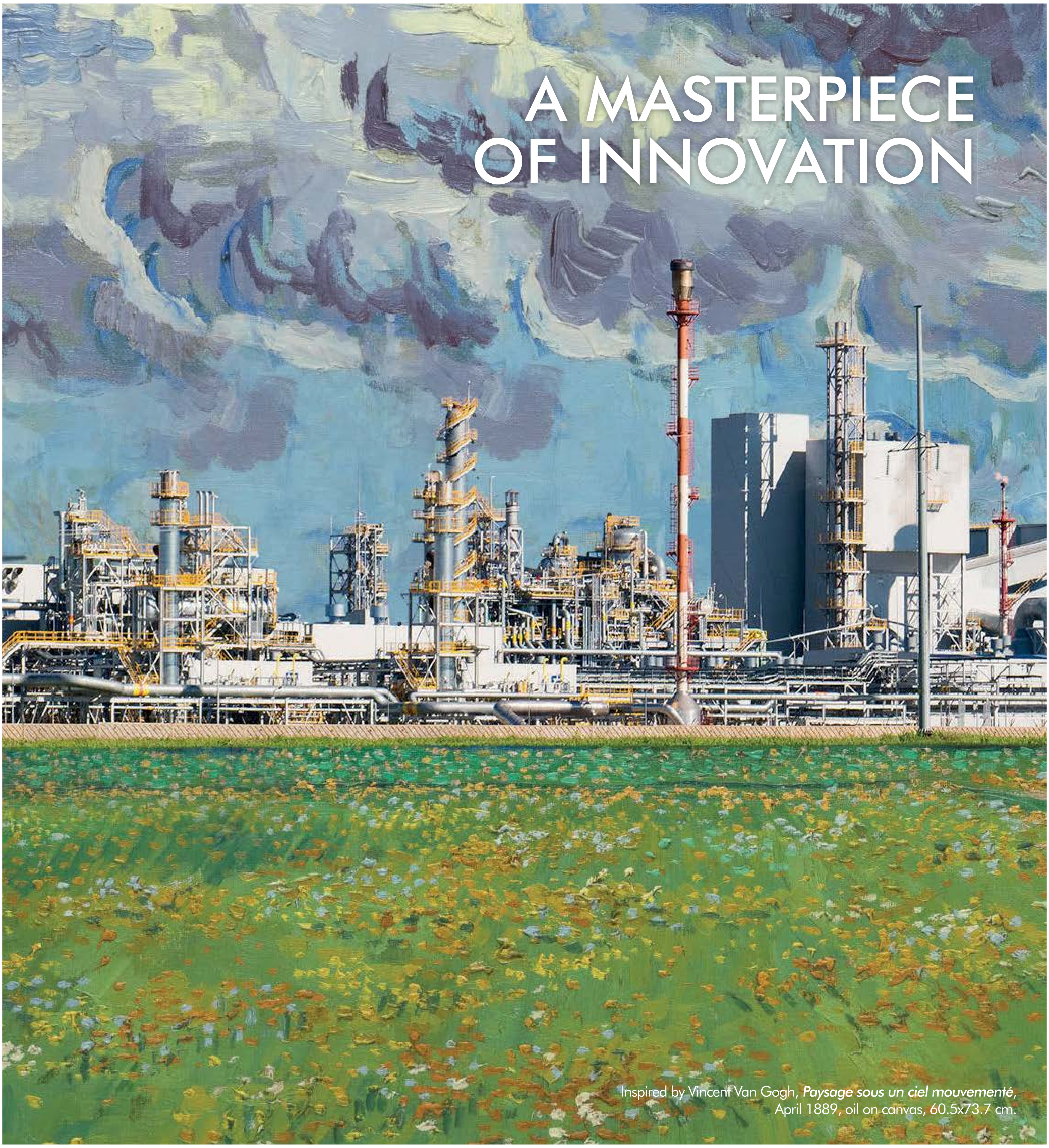
Capacity increase

At the heart of any ANS plant is the mixing of nitric acid and ammonia. Modifications made to increase capacity are usually very limited and focused mainly on the heat exchangers that preheat the raw materials and condense the additional process steam generated in the reaction. The nitric acid heat exchanger is not normally a problem as it is very small, the only consequence is to feed the acid at a lower temperature which will result in a less concentrated ANS. Apart from that, the ammonia vaporiser must be able to achieve the duty to ensure that all of the ammonia is superheated and vaporised to prevent emissions and safety risks due to the production of acidic ANS. Some minor modifications to the reactor may also be required to cope with the new load. In conventional processes, the turbulence caused by the reaction can result in strong vibrations of the entire supporting structure which can suffer severe damage. In the case of a pipe reactor process, simply changing the pipe reactor itself is sufficient to accommodate the new capacity.

Process condensate quality

To improve the quality of the process condensate may require greater modification. The easiest modification is to change the control parameter of the ratio control system from the pH of the ammonium nitrate solution to the pH of the process steam.

If that is not enough, additional process steam treatment may be required. For example, the Casale purification exchanger was installed in a conventional plant in the early 2000s to generate a stream of very pure condensate containing less than 50

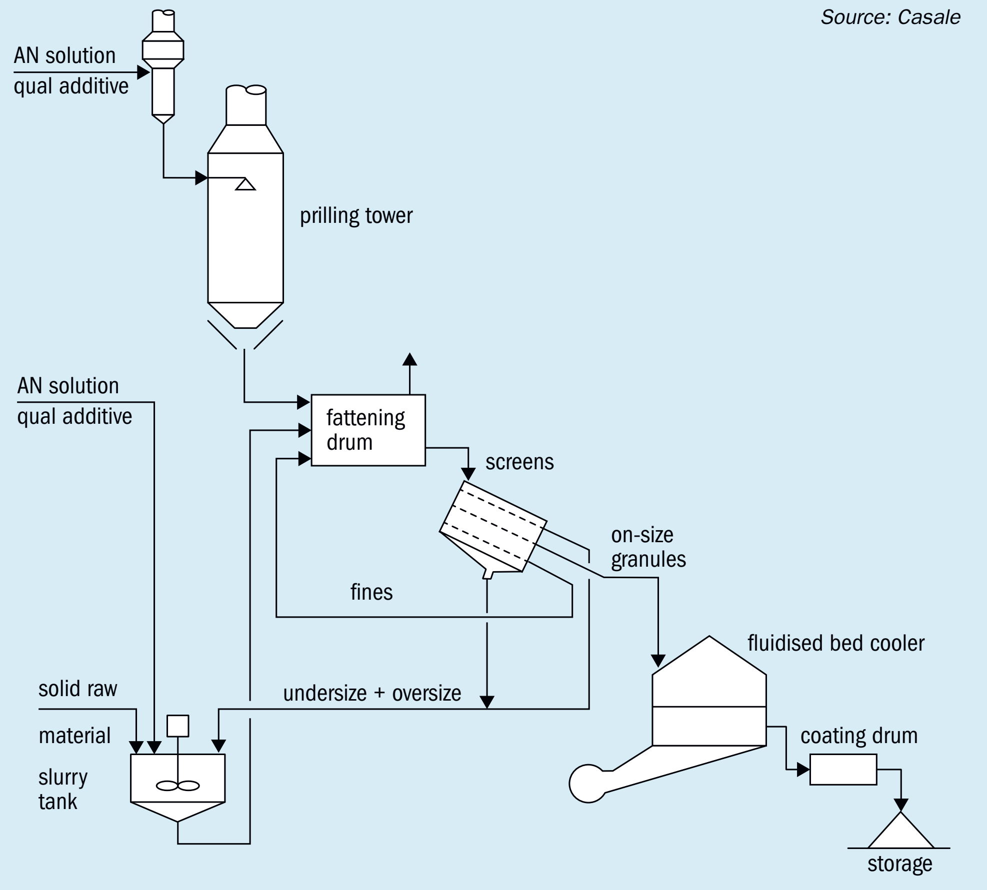


Inspired by Vincent Van Gogh, *Paysage sous un ciel mouvementé*, April 1889, oil on canvas, 60.5x73.7 cm.

MARK&THING

Fig. 2: **Modernisation of granulation processes**

Source: Casale



mg/l of AN. The system uses part of the process steam generated by the reaction to re-evaporate and purify the process condensate. Two steams are generated:

- very pure condensate (as mentioned above);
- concentrated condensate, which can be recycled to the nitric acid plant or used as make-up water for scrubbing granulation plant exhaust gases.

About two thirds of the process condensate can be generated in very pure form. A general scheme of the Casale system is shown in Fig. 1.

Emission treatment can always be improved in an existing plant by generating a smaller quantity of contaminated water. The Casale purification exchanger can be installed in a conventional process or a pipe reactor plant to limit the concentration of contaminants in the excess water to less than 50 mg/l, which is the limit for human consumption according to EU Directive 98/83/EC adopted on November 3rd 1998.

Reduced energy consumption

If it is not possible to decrease the energy consumption to achieve a defined concentration with an existing conventional process, it is generally not possible with a limited revamp of the plant. In such cases Casale recommends the most efficient and economical way is to change the technology to the pipe reactor process.

Modernisation of granulation processes

Modernisation of the granulation process is usually aimed at debottlenecking the plant or improving the quality or range of products without changing the main equipment such as the granulator and dryer in a conventional granulation loop or the prilling tower in a prilling process.

Fattening

When producing ammonium nitrate fertilizers by a prilling process, both of these objectives can be achieved by just adding a fattening system (Fig. 2). In this system, prills are fed from the bottom of the prilling tower and are enlarged with some additional slurry provided from the same source as the prilling tower or from an alternative source. It is thus possible to produce granules up to 1.5 times bigger than the prills, while multiplying the capacity by a factor of 3. In the meantime, the nitrogen content of the fertilizer can be adjusted down to 25% N by adding some filler to the slurry fed to the fattening system.

Two examples of this system were installed in France in the early 1990s. The French market for fertilizer was demanding bigger granules and the fattening system was installed to enlarge the size of the prills from about 2.2 mm to 3.3-3.4 mm.

In one plant at Grandpuits the total capacity of the plant was kept constant. In the other plant at Rouen, the capacity was trebled. In that case, the additional ANS is produced by a new plant based on Casale pipe reactor technology.

The results are shown in Table 1.

Table 1: **Material flows after installation of prill fattening at two French fertilizer plants**

	Fertilizer diameter (mm)	Prill feed (t/d)	Slurry to fattening (t/d)	Plant capacity (t/d)	Additional ANS (t/d)
Grandpuits plant					
Before	2.2	900	-	900	-
After	3.3	300	600	900	0
Rouen plant					
Before	2.2	600	-	600	-
After	3.3	600	1,200	1,800	1,200

Source: Casale

Dual pipe reactor

For granulation plants producing NPKs, Casale recommends the dual pipe reactor technology for both increasing the capacity and enlarging the range of products which can be produced. In comparison with the pre-neutraliser process, the same granulation loop can deliver more than 30% more product without major modifications to the main equipment (granulator, dryer, crushers, screens, etc.). An added benefit is a reduction in the specific fuel consumption: introducing a pipe reactor in the dryer, the heat of reaction of a part of the phosphoric acid becomes available for drying the product (Table 2).

Table 2: **Specific fuel consumption for DAP production**

	Capacity t/h	Fuel consumption kg/t
Pre neutraliser	40	12
Granulator PR	50	8.8
Dual PR	60	4

Source: Casale

Modernisation of UAN processes

Casale is in the unique position of having in-house technologies and experts for all the different processes for producing UAN from natural gas and is therefore able to optimise any type of UAN plant to get the best out of them.

The UAN process itself is quite simple, and in fact most of the work needed to improve its production lies in the upstream plants (urea, nitric acid and AN solution plants) and in improving the integration between them.

Points which have to be considered are:

- All of these processes use ammonia as a raw material but, depending on the recovery system employed, sometimes gaseous ammonia is available from the urea plant which can be reused and fed to the other plants.
- The nitric acid plant generates HP steam as a byproduct which may be usable in the urea plant.
- If the AN solution plant has proper process condensate treatment, it can generate clean condensate to be sent for disposal. That improves the water balance to the extent that liquid emissions are reduced even when the urea solution has been produced at a low concentration.

As an example, a conventional neutraliser producing 85% AN solution requires a urea solution at a concentration higher than 75% to produce 32% N UAN. The same 60% nitric acid fed to a pipe reactor AN solution plant will deliver ANS at a concentration of 92% minimum. Then the concentration of the urea solution required for the same 32% N UAN is below 70%. That means that the urea plant can be debottlenecked without modifying the concentration step; in addition, it also means that there will be some energy savings in the urea plant. ■

From low cost by-product to premium AS granules

PHOTO: tkIS

thyssenkrupp Industrial Solutions (tkIS) has developed a new fluidised bed granulation process to convert low cost by-product ammonium sulphate solutions into premium grade granules. **Jens Mathiak** of tkIS, describes the process and reports on the current status of the technology.

High-quality fertilizer for optimum plant growth

Plant growth depends on the nutrient content of the soil. A balanced distribution of primary and secondary nutrients as well as microorganisms ensures an optimum crop yield. Nitrogen is an essential nutrient, and so is sulphur.

In today's world a cleaner environment, tail gas desulphurisation and less acid rain now mean that soils especially those that are neutral or alkaline require the controlled addition of a fertilizer additive which contains sulphur: ammonium sulphate.

Ammonium sulphate feeds sulphur and nitrogen to the soil. With its colloidal components, the fertilizer binds to clay particles in the soil, ensuring a long-term supply of nutrients. Ammonium sulphate is thus perfect for plants with a long growth period and in areas with high rainfall. In addition to acting as a long-term plant nutrient, the sulphur also promotes the transfer of micronutrients, such as manganese, iron and boron, from the soil to the plants.

Ammonium sulphate solutions are a pertinent industrial by-product. In addition to sulphate, nitrogen and sulphur are key components of this fertilizer, which is mostly marketed in the form of crystals. In its state-of-the-art plants, thyssenkrupp has developed a process to convert ammonium sulphate solution to granules. The key advantages compared with liquid and crystalline solutions are improved storage as well as spreading and mixing properties.

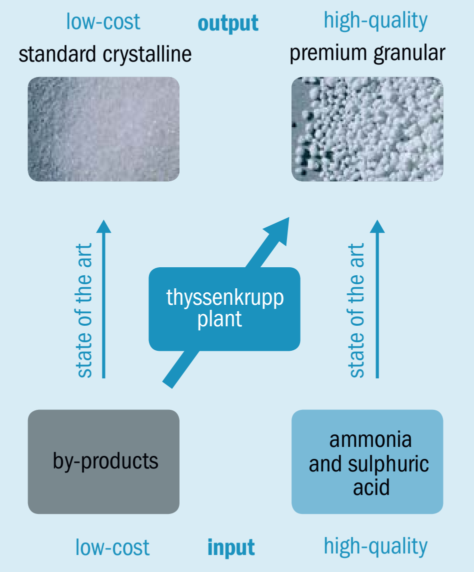
Alternative granulation plants are not able to process ammonium sulphate solutions. These plants require expensive ammonia and sulphuric acid to achieve higher-priced premium product characteristics (see Fig. 1).

Low-cost granulation – premium prices

The granular form as a unique selling point and the high profit margin are two very good reasons to choose the thyssenkrupp ammonium sulphate process. In addition, due to the large quantities produced, crystalline ammonium sulphate is

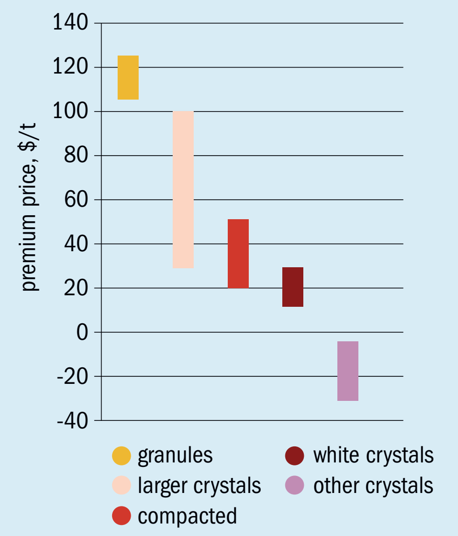
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60

Fig. 1: **Ammonium sulphate production processes**



Source: tkIS

Fig. 2: **Ammonium sulphate product prices**



Source: Integer Research

Table 1: **Product specifications**

Nitrogen content	~ 21 wt-%
Sulphur content	~ 24 wt-%
Moisture	< 0,5 wt-%
Hardness	~ 3.000 g
Bulk density	750-850 kg/m³
Diameter 2-4 mm	~ 90%

Source: tkIS

a mass-market product while granulated ammonium sulphate is produced by only a few suppliers in relatively small quantities. Demand is accordingly high and there are also sales opportunities in niche markets.

The new process developed by thyssenkrupp offers the opportunity to convert low-cost by-product into valuable premium granules. The price for premium granules is significantly above the prices of standard products at around $100 per tonne (see Fig. 2).

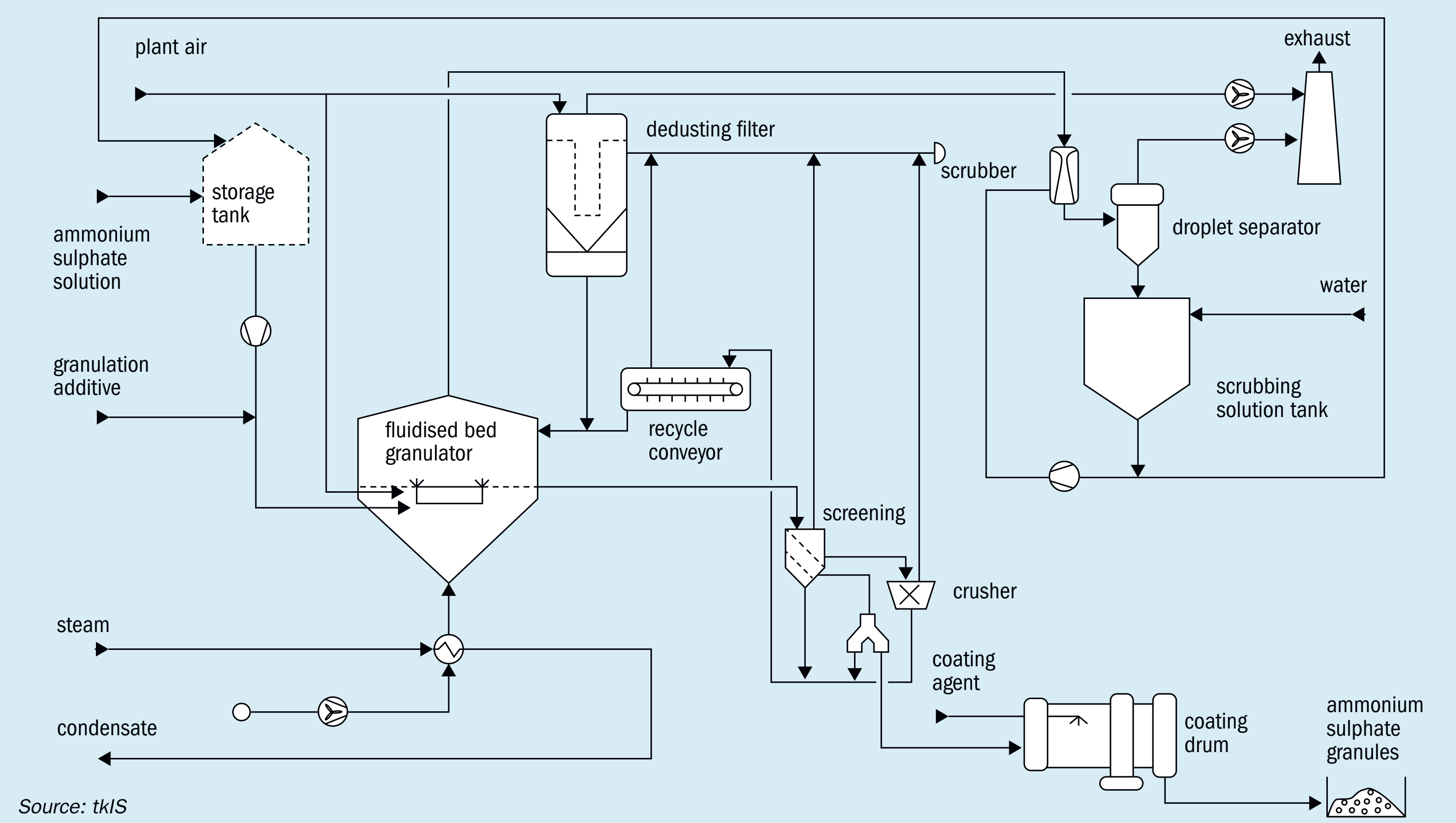
Conversion of liquid ammonium sulphate into granules

The fluidised bed granulation process can produce ammonium sulphate with a low moisture content to reduce caking tendency during storage. Long term storage tests are ongoing and results will determine the transportation, storage and coating requirements. The size of the granules is adjusted by screens in the process to be compatible with other fertilizers. This offers the opportunity for farmers to distribute the granules homogeneously and is also useful if bulk blending with other fertilizers is considered.

The chemical composition is 21 wt-% nitrogen and 24 wt-% sulphur (see Table 1). Classification as fertilizer is defined by the quality of the ammonium sulphate solution used as feedstock. The process itself (Fig. 3) does not jeopardise the classification.

The fluidised bed granulator is the centrepiece of the production plant (see Fig. 4). It is where the liquid ammonium

Fig. 3: **Fluidised bed granulation process for the production of ammonium sulphate**



Source: tkIS

Fig. 4: The fluidised bed granulator is the centrepiece of the production plant.

sulphate is turned into a solid product. The liquid ammonium sulphate solution is sprayed on the seed granules. The droplets stick to the small solid particle and the water phase is removed by applying hot air. Hence, the granules grow bigger in the fluidised bed granulator (see Fig. 5).

Downstream of the fluidised bed granulator the particles are screened in oversize, undersize and product granules. The oversize granules are crushed and returned to the inlet of the fluidised bed granulator together with the undersize particles. To maintain a stable process the particle balance has to be maintained. Therefor a partial stream of product granules can be recycled to the fluidised bed granulator as well.

The particles in the granulator are fluidised by a hot air stream. One option is to apply steam for air heating. If hot off gases are available at the production site from adjacent plants these can be used to reduce operating costs. The air from the granulator is dedusted by scrubbing and sent to the environment as clean air.

Integration of this new process into existing chemical complexes is essential for economic success. Besides the heat integration already mentioned there are also opportunities within the combination of existing crystallisers. If a fluidised bed granulation plant is installed parallel to a crystalliser the load of the crystalliser will be reduced. As a matter of fact this would lead to the production of larger crystals.

Reflecting the premium prices of larger crystals the economic benefit would be double: Higher prices for the granules produced in the new fluidised bed granulation plant and higher refund for larger crystals produced in the existing crystallisation plant.

Development of a new process

Ammonium sulphate tends to produce dust and form granules with low hardness. The toughest challenge during development of the new process was to find a suitable granulation additive. Mixing of the feedstock with the liquid additive is performed before spraying the solution onto the seed granules.

The development started with a small lab scale single nozzles test facility operating in batches. The core process parameters were identified and the granulation additive was selected. In a second phase a technical scale facility was used to demonstrate continuous operation and to identify extended process parameters like the recycle ratio. Finally upscaling was demonstrated in a pilot plant which was built to mitigate the risks and to demonstrate balance of plant. The pilot plant has a capacity of 12 t/d.

Approximately 85% of the global annual ammonium sulphate production uses solutions as by-product from upstream processes. The quality of these solutions can deviate quite significantly. On the other hand granulation can be a sensitive process for some impurities. Hence, the pilot plant was not only used during the development phase, but will also be utilised to test ammonium sulphate solutions in the feasibility phase before deciding on the investment of installing a fluidised bed granulation plant.

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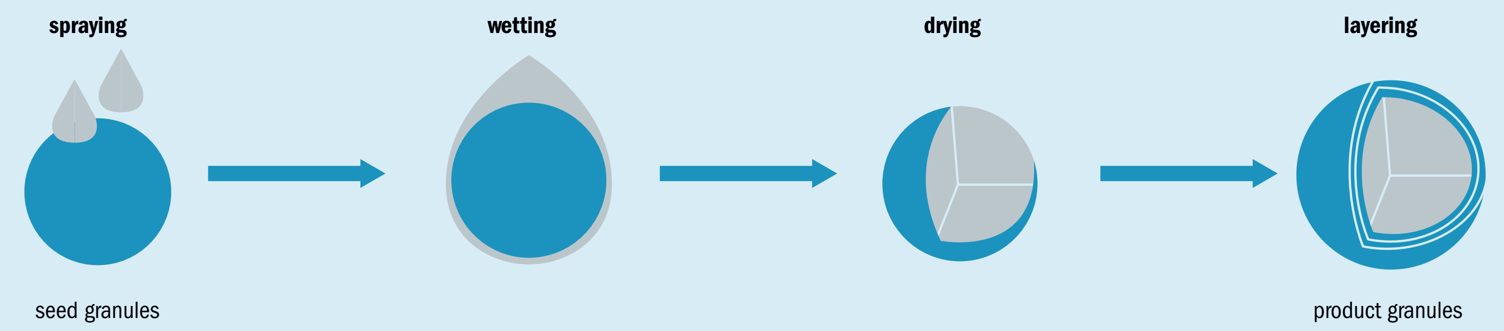
1. Integer Research Limited "The global ammonium sulphate market service", 2013.
2. Uhlemann, Hans: "Wirbelschicht-Sprühgranulation", Berlin, Springer, 2000.

Fig. 5: **Conversion of liquid ammonium sulphate solution into granules**



Source: tkIS

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