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China's nitrogen and methanol industries

Urea to melamine

Formaldehyde-free urea

Urea incident analysis

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Cover: *Neon signs at night in downtown Shanghai.*
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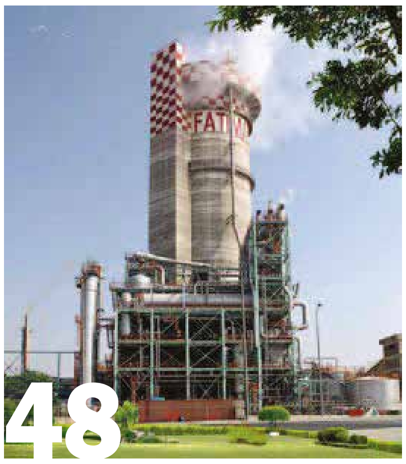
Ammonia process safety

Strategies for mitigating risk.



Urea incident analysis

Fifty years of lessons learned.

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Published by:
BCInsight

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Ammonia as an energy carrier

> The issue is getting the ammonia back to hydrogen and nitrogen on a large scale.

As you'll see from our news story on page 14, there is once again talk of using ammonia as a way of transporting hydrogen, and hence energy – this time solar energy 'harvested' in the northern deserts of Australia. The use of ammonia as an energy carrier has been a 'hardy perennial' story during my tenure as editor of *Nitrogen+Syngas*, recurring every few years or so – most recently in 2013. Sometimes it has even been proposed as a fuel for direct combustion – proponents tend to be attracted by the prospect of a vehicle fuel which burns to form only water and nitrogen, although combustion conditions have to be very carefully controlled to avoid producing nitrogen oxides, and ammonia does not burn anywhere near as readily or with as much intensity as other competing vehicle fuels. Other proposals have talked about using ammonia in fuel cell vehicles, avoiding the nitrogen oxide issues but complicating matters in other ways, as few fuel cells can work directly on ammonia, and so would require it to be 'cracked' back to hydrogen and nitrogen in the vehicle, using ammonia in effect purely as a hydrogen carrier.

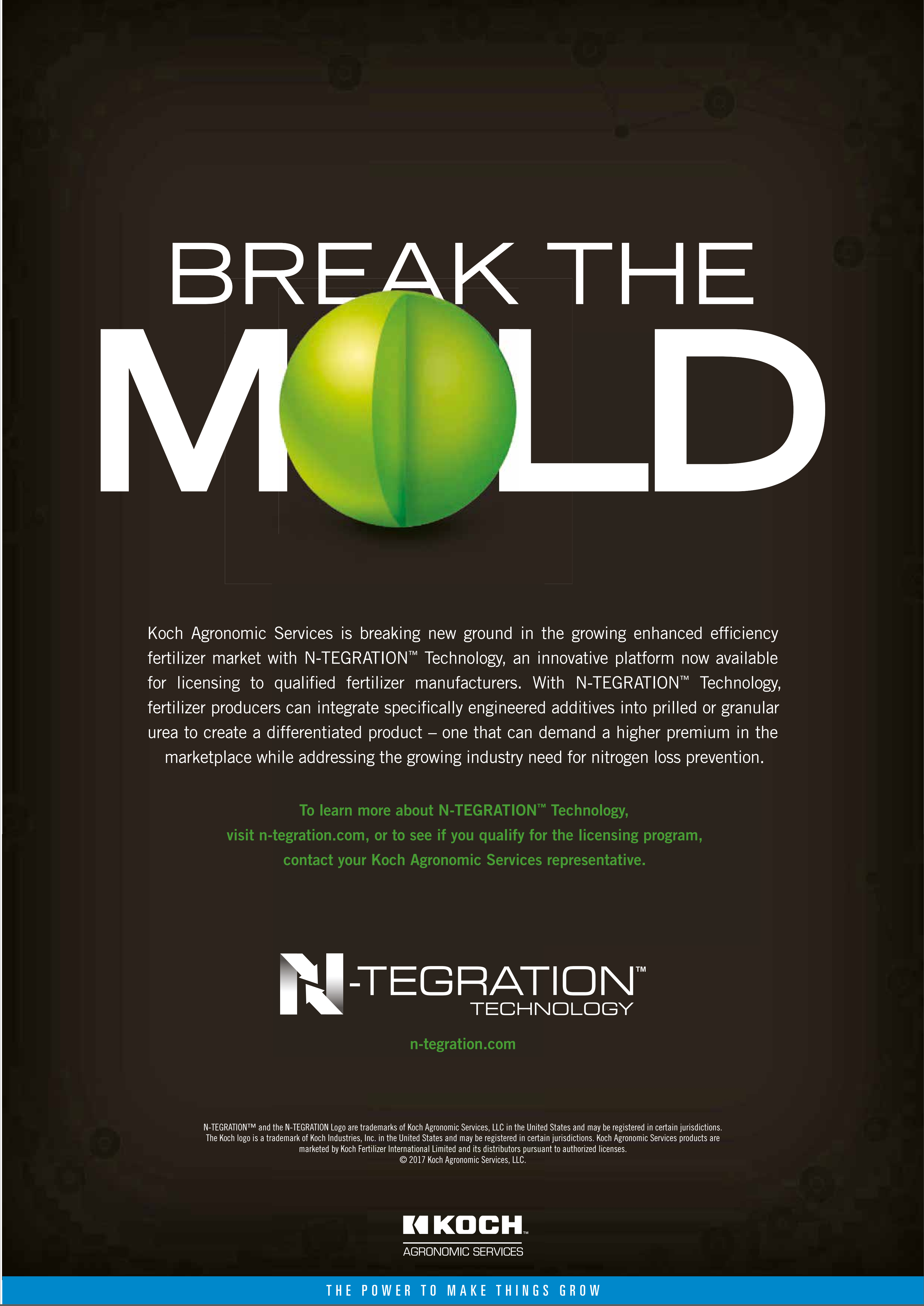
The problems with large scale use of ammonia by the general public are of course manifold, and mainly revolve around its storage, transport and handling. It must be transported as a liquid to achieve any kind of energy density, and this requires keeping it below -33°C, increasing costs. It is also corrosive when in the presence of water, and it is an irritant in low concentrations and poisonous in large concentrations. For this reason, the idea of filling up a vehicle – even a fuel cell vehicle – with ammonia at a gas station seems to be too big a hurdle to cross.

But the current proposal is taking a slightly more sensible approach, using the existing large scale global ammonia distribution infrastructure to use ammonia as a way of transporting hydrogen over long distances, allowing remote areas where renewable energy is readily available to be linked to centres of demand. The problem with hydrogen, and hence the 'hydrogen economy', is that it is almost impossible to liquefy (its boiling point is only 20 degrees above absolute zero), and so it must be transported as the lightest and least dense gas that exists, meaning huge volumes are required to contain it, even in compressed form. Other ideas for ways of transporting and storing hydrogen try to bind it to other elements, but metal hydride systems are less than 2% hydrogen by weight. Ammonia is 17% hydrogen by weight, and thus offers a potentially far more efficient way of transporting it.

The issue is getting the ammonia back to hydrogen and nitrogen on a large scale, and this is where Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO) has been putting its research effort. The plan is a scaled up version of the semi-permeable membrane which was used in ammonia fuel cell vehicles, allowing hydrogen to pass but keeping ammonia in, coupled with a catalytic coating which drives the ammonia to hydrogen decomposition.

At the moment it is of course very early days, and as chemical engineers will know all too well, the devil can be in the details when it comes to scaling up from laboratory scale experiments to industrial scale facilities. Nevertheless, the use of ammonia as a 'bridge' between renewable electricity production and hydrogen consuming urban centres sounds at least on paper far more plausible than any other I have yet seen for the 'hydrogen economy'. ■

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

Falling domestic urea sales in India over the last 18 months reduced Indian urea imports from 10.0 million tonnes in 2015 to just under 7.0 million tonnes in 2016. This figure looks set to fall further for the full year 2017. Annualised data for the year-to-April shows that the import requirement has collapsed to just 5.0 million tonnes, presenting a stunning reversal of India's role as the world's largest urea import market.

What has driven this collapse in Indian urea sales? The government has loudly proclaimed that its switch to 100% production of neem-coated urea in 2015 has been a driver of this sales reduction, through greater use efficiency. However, we believe that a more likely reason for the fall in sales is that the record imports in 2015 merged with poor monsoons that lowered farm-level consumption, allowing significant inventories to build up throughout the supply chain. This carried inventory continues to overhang real consumption, limiting sales activity amongst co-ops and wholesalers.

Indian production appears relatively stable at just under 24.5 million t/a, so consumption will be the key decider this year. Integer assumes that annual sales will be flat at around 30.0 million tonnes. Accounting for volumes already secured in the three tenders so far this year, and assuming stable production from Omifco, it looks like the government only needs to secure around another 1.5-1.6 million tonnes of urea this year.

The major demand-side risk to this outlook is that record grain production in 2016/17 has destocked the supply chain more than we are anticipating (the data does not indicate this). While on the supply-side, the uncommissioned (but mechanically complete) Matix plant remains a concern; its 1.4 million t/a capacity could lower imports by around 500,000 tonnes this year if it were to start this summer.

Looking to the urea price setter, ambitious coal mining capacity rationalisation measures are underway in China. The country has already eliminated around 560 million tonnes of coal capacity and closed 7,250 coal mines in 2011-2015. In 2016, China removed 290 million t/a of coal capacity and is expecting to close 150 million t/a in 2017. The Chinese National Development and Reform Commission says it plans to close around 4,300 coal mines, remove outdated capacity totalling 50 million t/a and redeploy around 1 million workers by 2019.

Government measures introduced to the coal sector in 2016 to deal with the structural overcapacity in coal production led to a recovery in coal prices in the second half of the year, with prices having fallen almost uninterrupted prior to this. The primary measure put in place to shorten the market was a directive to reduce the number of days per year that coal mines can operate, from 330 to 276, driving up the price of coking coal in particular.

The increase in coal costs squeezed coal-based nitrogen producer margins, leading operators to further idle capacity, and effectively raised the urea export price floor. However, following the removal of the coal production day limits – implemented when the rapid increase in coal prices was deemed to have put too much pressure on consumers – coal prices began to flatten out. This reinforces the view that the Chinese government will continue to exercise its power to intervene in the market, although this effect has become less influential.

With a more rational approach, the Chinese coal market is forecast to become increasingly driven by production economics, and in turn prices are expected to become more closely aligned with international levels, providing the government stays on the path towards exposing commodity industries to market forces.

Another area of interest on the supply side is the changing competitiveness of European nitrogen producers. These producers have traditionally been among the highest cost globally, however gas prices to industry in Europe have been overhauled since 2015 due to the collapse in oil prices coupled with increased LNG supply in Europe and reduced state intervention in energy pricing. Recent developments suggest that there could be further shifts away from oil-indexation in Europe, which would make the market far more competitive both in terms of gas price and nitrogen production costs.

In March, Russian gas giant Gazprom agreed to a draft compromise with the EU to end an investigation into alleged abuse of market power in Eastern Europe, beginning a seven-week feedback window before any finalisation begins. The agreement would allow for the company to resolve the ongoing investigation without incurring a fine.

The biggest impact of the proposed deal would be to link contracted gas prices to benchmark natural gas hubs in Western Europe, effectively stopping the existing structure of oil-indexing in Bulgaria, Estonia, Latvia, Lithuania and Poland. This will allow customers in these regions to have more frequent and effective price reviews and allow gas pricing to based more closely on gas-on-gas competition.

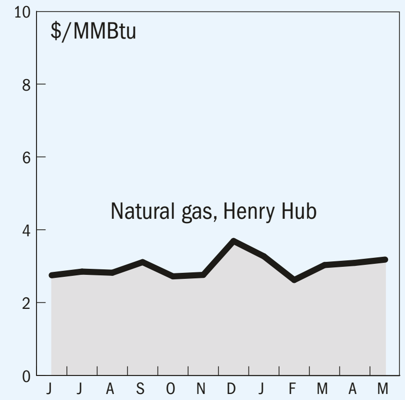
Table 1: **Price indications**

Cash equivalent	mid-May	mid-Mar	mid-Jan	mid-Nov
Ammonia ($/t)				
f.o.b. Caribbean	285	295	215	175
f.o.b. Arab Gulf	295	350	195-221	175
c.fr N.W. Europe	325	365	345	245
c.fr India	340	360	230	187
Urea ($/t)				
f.o.b. bulk Black Sea	175	237	251	219
f.o.b. bulk Arab Gulf*	176	211	260	238
f.o.b. bulk Caribbean (granular)	210	218	243	213
f.o.b. bagged China	210	231	265	236
DAP ($/t)				
f.o.b. bulk US Gulf	355	375	329	323
UAN (€/tonne)				
f.o.t. ex-tank Rouen, 30%N	157	169	169	145

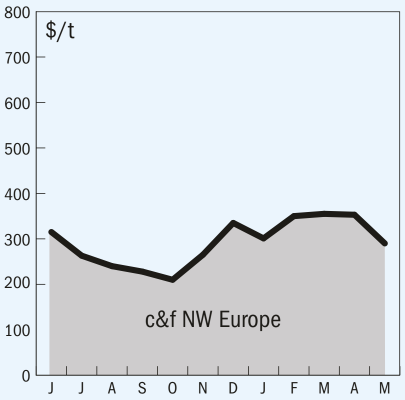
Notes: n.a. price not available at time of going to press
*n.m. no market   * high-end granular*
Source: Fertilizer Week

END OF MONTH SPOT PRICES

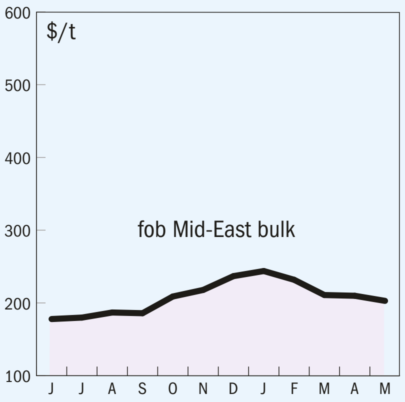
natural gas



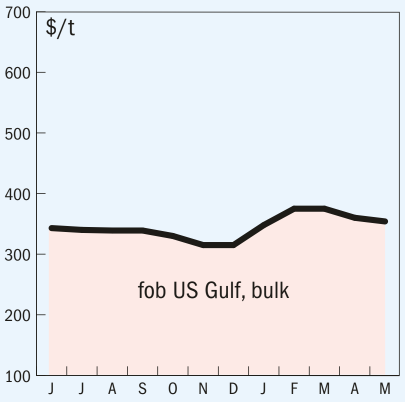
ammonia



urea



diammonium phosphate



MARKET INSIGHT

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

METHANOL

The official, posted reference prices from the two main US producers for June were $1.16/gal for Methanex (a decrease of 7 cents from May) and $1.11/gal for Southern Chemical Co. (down 6 cents from); equivalent to $386 and $369/t respectively. Month-on-month weighted average spot prices in the US Gulf for May increased by 2.5 cents/gallon from April to $0.915/gal ($304/t). IHS Chemical's contract net transaction price for June was officially posted at $1.137/gal ($378/t).

In the Americas, Methanex's 840,000 t/a Chilean unit is estimated to have run at an increased level of around 76% of capacity in May. Methanex has secured additional natural gas supply through April of 2018 via a tolling agreement with Argentina. On the demand side, the MMA market remained extremely snug following an unexpected outage last year and turnarounds and an unplanned outage this year. MTBE units ran steadily, but biodiesel demand in the US remained near two year lows with a great deal of uncertainty due to policies around tax incentives as well as pressure from South American imports. The site-wide outage at Celanese's Clear Lake facility continued into May, reducing methanol demand into acetic acid.

Liquidity improved in the European market in the second half of May. Rhine water levels at Kaub decreased from around 2.1 m at the beginning of May to around 1.65 m by the end of May; at this level, barges had to be short-loaded, increasing unit transport costs. Formaldehyde demand was steady, with operating rates estimated at 90-95% across Europe, supported by summer demand for resins. Biodiesel production was around 60% of capacity; low oil prices have resulted in some margin erosion for some alternative/renewable fuels. Acetic acid demand was stable.

On the supply side, Zagros in Iran experienced a short outage in early May. In Saudi Arabia, Ar Razi V was offline all month for a planned maintenance outage. AzMeCo in Azerbaijan restarted in April and was offering methanol for export, and in Russia, Eurochem's Nevinnomyssk facility re-started in early May after a turnaround on its methanol and acetic acid units. European spot prices (T2 f.o.b. Rotterdam) for May averaged €278/t over the month, down €30 over April. Methanex posted its 2Q 2017 West European Contract Price at €450/t, f.o.b. Rotterdam T2, up €80 on the previous quarter. The 2Q 2017 West European Contract Price was settled at €405/t f.o.b. Rotterdam T2, up €50/t from 1Q 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.

In India, port prices started the month at an average of $250/t c.fr T1 and finished the month $17.50 lower at $232.50/t; domestic prices decreased from 20.5 Rs/kg to 17.75 Rs/kg during the month, as Indian prices reacted to lower China prices and good supply from Iran.

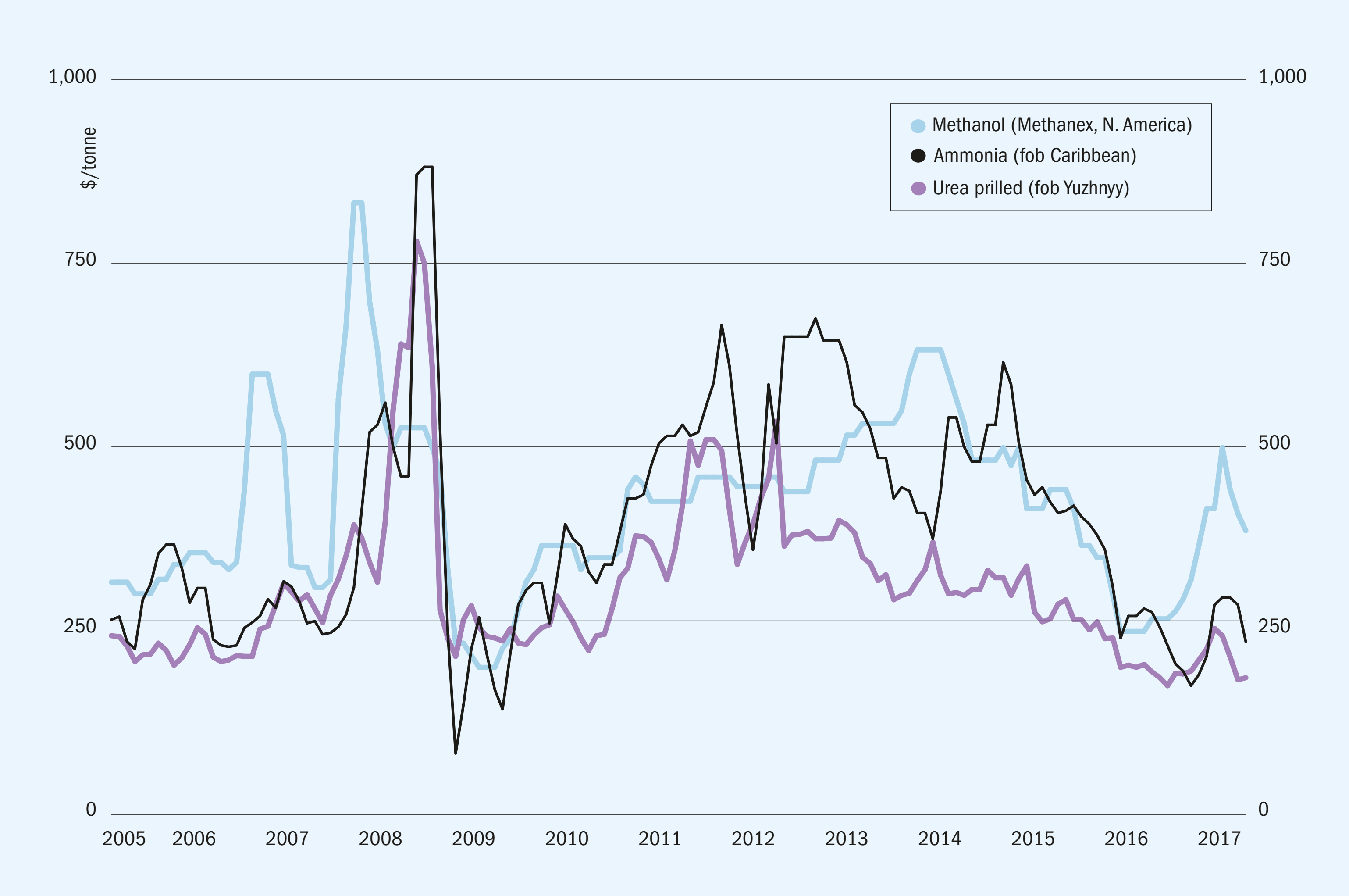
Asian prices in May traded down in an average range of $273-289/t, c.fr; China average prices fell $30/t in a range of $261-270/t c.fr. Methanex's posted APCP for June is $320/t, a decrease of $40/t from May.

In China, overall capacity utilisation was higher at around 55% of nameplate capacity, or around 71% of effective capacity. Shaanxi Yulin Natural Gas Chemical's natural gas-based unit and Boyuan Unichem remained offline for the whole month. Kingboard/CNOOC's no. 1 unit restarted in mid-May after a turnaround; the company's no. 2 unit is expected to go down for maintenance soon.

Methanol consumption into the MTO sector increased in May after the re-start of Jiangsu Sailboat's MTO facility (consuming 2.3 million t/a of methanol), although the company's methanol inventory is thought to be sufficient to support MTO production for a further month. The entire facility of Shandong Yangmei Hengtong shut down on 7 May for a 3-week turnaround and the MTO section of Fund Energy Changzhou remains offline, with no re-start date yet announced, although the facility's polypropylene section restarted in the second half of May with purchased propylene. Overall, MTO units ran at an average of around 79% in May. Formaldehyde in China weakened slightly, as the arrival of the summer season impacted demand into man-made boards. ■

Market outlook

Historical price trends $/tonne



Source: BCInsight

AMMONIA

- Ammonia prices have continued their downward trend into June, due to the usual fall in seasonal demand at this time of year.
- The late settlement of the Tampa contract price was indicative of the confused sentiment in the market, with negotiations taking longer than usual due to differing opinions between the key parties of the scale of the price decrease.
- The final agreement on the Tampa price for June was US$260/tonne c.fr, a noteworthy reduction of $65/tonne from the May contract price.
- In Yuzhny, OPZ is understood to have decided to focus on domestic commitments only for the month of June, meaning no ammonia or urea will load at Yuzhnyy for export.
- Middle Eastern producers have ample availability through June, however, there is limited demand on the horizon for spot business.

UREA

- Urea prices experienced an uptick in May ahead of the IPL India tender for 500,000 tonnes of urea, however price ideas soon weakened as the demand shortfall grows wider for June and July. India's import requirements have been falling steadily over the past couple of years, due to poor weather conditions and the move to neem-coated urea.
- In China, operating rates for urea plants were reported to be higher, at around 56-58% going into June, following the closure of several loss-making plants, as well as reduced output at some marginal plants.
- Given the low operating rates and high local prices, traders have begun exploring whether there are opportunities to import urea cargoes into China, although this seems unlikely.
- The price difference between Chinese domestic and global prices would need to be at least $40/tonne for this to be workable.

METHANOL

- The buoyant MTO sector in China continues to support demand there, aided by the re-start of the 2.3 million t/a (in terms of methanol consumption) Jiangsu Sailboat facility, offsetting weaker summer demand into formaldehyde markets. However, there is still no re-start in sight as yet for the Fund Energy MTO plant, which has been shut down since December 2016. Overall ample stocks and supply, including higher domestic production, have kept prices lower. China's methanol imports were reported to be up 5% year on year in June.
- European demand is at its peak in 2Q 2017, and prices seem more stable after the rollercoaster ride of the first part of the year, although falling Chinese prices have fed through into contract price discussions.
- US prices seem balanced, with some outages and seasonal demand increases helping stabilise prices.

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Nitrogen Industry News

POLAND

New nitric acid plant for Grupa Azoty

Grupa Azoty Puławy has signed a contract with thyssenkrupp Industrial Solutions AG to licence nitric acid production technology, including the delivery of process documentation and key equipment, and supervision of plant installation and start-up. Grupa Azoty says that the new nitric acid unit is a key element of the company's strategy to develop its fertilizer production, which also covers the construction of new neutralisation and fertilizer production units. The company's existing four nitric acid production lines will also be modernised as part of the $190 million plan. As well as increasing nitric acid production scale and efficiency, the project will also improve the efficiency of downstream nitric acid-based fertilizer production. A part of the output of the new (fifth) nitric acid unit will be processed on a new line for the production of speciality liquid and solid fertilizers: magnesium nitrate, calcium nitrate and potassium nitrate, with a target capacity of 600 t/d. Grupa Azoty says it intends to invest more than $270 million into nitrate fertilizer production by 2021, including the construction of two granulation plants. Over the next four years the company will expand its product range by six new fertilizers, which will serve as the base for blended fertilizers manufactured at the Dobre Miasto plant.

Jacek Janiszek, president of Grupa Azoty Puławy said: "this is currently the largest investment project under way in the Grupa Azoty Group's fertilizer segment and the Puławy plant's largest in more than a decade. The fertilizer segment is particularly important for the entire Grupa Azoty Group as it generates about 60% of its revenue. The steps that Grupa Azoty Puławy is taking are to prepare a base for the manufacture of modern fertilizers, thus filling the gap in our offering," he added.

UNITED STATES

Clariant and Huntsman to merge

The boards of Clariant and Huntsman Corporation have unanimously approved a definitive agreement to combine in a merger of equals through an all-stock transaction. The merged company will be named HuntsmanClariant. On a pro forma 2016 basis, the combination of both companies will create a leading global specialty chemical company with sales of approximately $13.2 billion, an adjusted EBITDA of $2.3 billion and a combined value of approximately $20 billion at the time of the announcement.

Clariant shareholders will own 52% of the new company and Huntsman shareholders 48%. Huntsman shareholders will receive 1.2196 shares in HuntsmanClariant for each Huntsman share, while Clariant shares will be exchanged on a 1 for 1 basis. The merged board will have equal representation from both companies, and will be headquartered in Pratteln, Switzerland.

The new company aims to create value for shareholders "through a more robust combination of technology, products and talent". The combined company expects to realize more than $3.5 billion of value creation from approximately $400 million in annual cost synergies, to be achieved within two years of the merger, which will be realised by reducing operational costs and improving procurement. The targeted synergies represent roughly 3% percent of total combined 2016 revenue with one-time costs up to $500 million. There will also be additional cash-tax savings.

"This is the perfect deal at the right time. Clariant and Huntsman are joining forces to gain much broader global reach, create more sustained innovation power and achieve new growth opportunities," said Hariolf Kottmann, CEO of Clariant. "This is in the best interest of all of our stakeholders. Peter Huntsman and I share the same strategic vision and I look forward to working with him."

The transaction is targeted to close by year end 2017, subject to Clariant and Huntsman shareholder approvals, regulatory approvals etc.

Land sale approved for fertilizer plant

Longview City Council in Washington State has approved a $1.78 million sale of 17 acres of city lands to Pacific Coast Fertilizer LP, which is aiming to develop a $1 billion ammonia plant at the Mint Farm Industrial Park. The company is also separately buying 36 acres of private land from PNW Recycling at Mint Farm. Pacific Coast Fertilizer is a joint venture backed by Texas-based Saturn-Ferrostaal Chemicals LLC, Ferrostaal, Haldor Topsoe, and Canada-based Pacific Fertilizer, and hopes to have the plant up and running by 2021. Saipem and local firm J. H. Kelly have been slated to construct the facility, which will tap into an existing natural gas pipeline near the Mint Farm Industrial Park, which connects to the main Northwest Williams natural gas pipeline at Ostrander.

Total capacity for the plant has not yet been divulged, but Pacific Coast says it would ship the ammonia as liquid to agricultural retailers throughout the Northwest by truck and ships, as well as by pipeline to nearby docks owned by Millennium Bulk Terminals' or Weyerhaeuser Co, and aims to produce the equivalent of 11 semi-truck loads of liquid fertilizer – which would represent perhaps around 660 t/d or 220,000 t/a.

GERMANY

Shell and Sandvil launch sulphur enhanced urea

Shell and Sandvik have launched a granulated urea variant incorporating elemental sulphur fertilizer produced with Shell *Urea-ES* technology, using Sandvik's Rotoform granulation system. The combined technology was tested during a series of continuous plant trials at Sandvik's productivity centre in Fellbach (Germany). Shell's unique technology and the versatility of the Sandvik equipment enables the production of Shell *Urea-ES* granules containing up to 70% of finely dispersed elemental sulphur in a urea matrix. The homogeneous Shell *Urea-ES* emulsion is fed to the Sandvik Rotoform unit and deposited in the form of drops (diameter of 2-4 mm) across a steel belt cooler. Water is sprayed against the underside of the solid steel belt, ensuring no cross-contamination either to product or to water. As the product moves along the steel belt, the liquid droplets are converted into solid pastilles. The final solid product is collected at the end of the belt and sent to the downstream handling system (conveying, storage silo, bagging, etc.).

"We are pleased to collaborate with Sandvik to granulate our new Shell Urea-ES technology products on their robust Rotoform equipment. With this success, more and more fertilizer producers can granulate our urea + elemental sulphur fertilizer to potentially unlock better crop yields and improve soil health," said Michael Lumley, vice president of Shell Sulphur Solutions.

Shell has collaborated with key players in granulation technologies in order to develop solutions for owners of small to medium-sized granulation plants and believes Sandvik's standalone Rotoform granulation equipment provides a fully fit for purpose system to undertake product diversification at fertilizer production sites.

"We believe specialty fertilizers are the future, as they promise not only a win-win situation for both farmers and fertilizer producers, but also contribute to a better environment through effective fertilizer applications. Sandvik offers versatile Rotoform system to manage various formulations. Our collaboration with Shell for the Urea Elemental Sulphur has been a rewarding partnership," said Johan Sjögren, managing director of Sandvik Process Systems

MOROCCO

Focus on Africa at IFA conference

The Moroccan Secretary of State to the Minister of Agriculture, Hammou Ouhelli, opened this year's Annual Conference of the International Fertilizer Association with an emphasis on the important role of nutrients for sustainable agricultural development. Speaking to an audience of over 1,300 representatives of companies throughout the fertilizer value chain and other groups from over 75 countries, he referring to the AAA initiative (Adapting African Agriculture) as a concrete and innovative response to the challenges of climate change, and praised the industry by saying: "with your presence, here today, in Marrakech, you are contributing to the vision of a world without hunger."

His remarks were followed by keynote speeches from Sunny Verghese (CEO of Olam), Christian Witt (senior program officer on Soil Health at the Bill & Melinda Gates Foundation), Rebbie Harawa (Head of Soil and Fertilizer Systems at AGRA) and Dyborn Chibonga (executive director at the National Farmers' Association of Malawi), who addressed the opportunities and challenges for ensuring greater access to fertilizers for African farmers, and the need to ensure more crop- and site specific, balanced and sustainable fertilizer application.

According to the UN FAO, sub-Saharan Africa (SSA) alone is expected to experience a population growth of 180% until 2050, which will require an estimated 170% increase in food production. With an average fertilizer application rate of approximately only 12 kg/ha in 2016 (compared to 110 kg/ha in the rest of the world), there is a vast opportunity to grow the market. Indeed, IFADATA shows that SSA is the region with the fastest growing fertilizer demand: 17-18 kg/ha are expected to be reached in 2021, with regional demand expected to reach over 4.8 million t/a by 2021 (including South Africa) compared to 3.3 million t/a in 2015. Although this would bring the application rate to 17 kg/ha within the next two years, it is still far below the 50 kg/ha recommended by the Abuja Conference in 2006: soil mining, large yield gaps and wide-spread hunger remain key problems for the continent.

The fertilizer industry, committed to doing its part towards the implementation of the Sustainable Development Goals, focuses in particular on bringing the goals of food security and climate change together with market development objectives. "While infrastructure, availability and access are key prerequisites to drive fertilizer consumption in SSA," said Charlotte Hebebrand, Director General of IFA, increased fertilizer application must entail "the efficient and effective use of nutrient inputs and be combined with good agronomic practices to assure that higher yields are not increasing environmental impact and greenhouse gas emissions."

This was also the key message of Ibrahim Thiaw, deputy executive director and assistant secretary general at UN Environment, who, speaking to IFA members in a video address, recognized the critical role of fertilizers for the future of our planet, but does not shy away from a strong call for action on environmental stewardship. Mr Thiaw acknowledged explicitly the already existing good cooperation between IFA and UN Environment and invited also IFA members to reach out directly to UNEP.

RUSSIA

KBR wins two more contracts for EuroChem Kingisepp

KBR has been awarded an operator training simulator (OTS) and reliability based maintenance (RBM) services contract by JSC EuroChem Northwest for the ammonia plant currently under construction in Kingisepp. KBR says that the OTS will provide a cost effective solution for training operators for safe and efficient plant start-up and continued on-going operational training, while the RBM contract will enable proactive monitoring of assets and formulation of appropriate reliability strategies leading to continuous improvement of performance, improved safety and higher productivity. The new Kingisepp ammonia plant has a design capacity of 2,890 t/d, or 1.0 million t/a, and is being constructed using KBR's *Purifier*™ ammonia technology.

"KBR is pleased to have the opportunity to provide OTS and RBM for JSC EuroChem Northwest," said John Derbyshire, president, KBR Technology and Consulting. "KBR is committed to providing state-of-the-art solutions for safe plant start-up and operations and providing an environment to achieve preventative and predictive maintenance activities of the ammonia plant. "This project is indicative of KBR's strategic commitment to growing our presence in Russia," Derbyshire continued.

BELGIUM

Proposals sought for waste to urea plant

Antwerp Port has put out a request for proposals (RFP) for an additional investor to help develop an 88 hectare site at the Churchill dock after a waste treatment facility investor cancelled its option. Saudi Arabian firm Energy Recovery Systems (ERS) and the port mutually decided to cancel ERS's option on the Churchill site, which it has held since May 2016, as ERS had not reached the milestones imposed by the Port Authority. However, ERS will continue some development work on the $4 billion waste-to-chemicals (WtC) plant designed to produce 'green' ammonia and urea, to be managed by a Belgian subsidiary which is due to be set up and with new emphasis on mitigating CO_2 from waste and recycling.

The plant was the subject of an analysis by consultancy PricewaterhouseCoopers (PwC) at the request of the Port Authority, based on the concept of the "circular economy" as it would use waste from other industries as raw material for production. PwC confirmed the intrinsic value of such a circular economy project for the Port of Antwerp, but also called attention to a number of important conditions for it to be successful, including clarity about the technical partners in the project, the financing of the project, its technical feasibility, the quality of the non-recyclable waste and the impact on an existing waste processing industry. The Port Authority therefore decided to make the option dependent on these points being cleared up by establishing deadlines, which were subsequently not met.

JAPAN

New catalyst for small-scale ammonia production

Ajinomoto, a Japanese food and chemical company, has formed a joint venture – Tsubame BHB with partners including the Tokyo Institute of Technology to commercialise a new catalyst for small-scale ammonia production. The catalyst, described in a research paper as including ruthenium nanoparticles deposited on a calcium aluminate substrate, has been developed by Dr Hideo Hosono of the Tokyo Institute of Technology, and aims to be effective at conversion to ammonia at small scales using lower temperatures and pressures than the conventional Haber-Bosch process. Ajinomoto uses small quantities of ammonia in amino acid production. The project's backers say that they aim to install an ammonia demonstration facility at an Ajinomoto plant by 2021.

MALAYSIA

India approves investment in Malaysian urea plant

The Indian cabinet has given its approval to a $2.1 billion ammonia-urea facility to be built in Malaysia. India and Malaysia signed a memorandum of understanding on the facility on April 1st this year as part of a broad package of cooperation and development agreements between the two countries. The plant will produce 1.35 million t/a of ammonia and 2.4 million t/a of urea, and an off-take agreement will be signed for a proportion of the output (yet to be determined) to be shipped to India to supply the Indian market. The Indian government said that this would ensure a consistent supply of urea and ammonia to India at a lower price than available on international markets.

INDIA

Zuari Agro Chemicals approves revamp

The board of Zuari Agro Chemicals Ltd has approved a $210 million revamp of its ammonia-urea plant in Goa, making it more energy efficient and increasing the production of urea from 1,350 t/d to 1,800 t/d. Specific energy consumption will fall from 6.67 Gcal/t to 5.39 Gcal/t. The revamp is expected to take around 25-30 months. The 2015 New Urea Policy promulgated by India's Department of Fertilizers, mandates that all 'vintage' plants must bring down their energy consumption, and Zuari Agro Chemicals' plant falls into this 'vintage' category as defined by the Department of Fertilizers. Zuari has a manufacturing facility at Goa, with four plants producing urea, DAP and NPK-based fertilizers.

Tata Chemicals to sell urea business to Yara

Tata Chemicals Ltd has agreed to sell its urea business to Yara Fertilisers India Private Ltd, the Indian arm of Norwegian fertilizer firm Yara International AS, for $430 million. It forms part of a strategic plan by Tata Chemicals to focus on higher margin value-added products and nutritional supplements to strengthen its "living essentials" consumer segment and move away from its fertilizers business.

"We are exiting the fertilizers business, which has led to savings across the board, including in interest income," commented managing director and chief executive R. Mukundan. The deal is expected to be finalised over the next quarter, pending approval from the Indian National Company Law Tribunal. "With this, we will not be in the fertilizer business in North India any longer. We will remain in the Eastern region, in certain markets, with the intent to maximise cash generation," Mukundan said.

Urea bag sizes cut in a bid to reduce consumption

The Indian government is moving to a new standard size for bags of urea, from the present 50kg size down to a new standard of 45kg bags. The government hopes that this will encourage farmers to use less urea, helping to reduce the ever-increasing subsidy budget, which has been set at 700 billion rupees ($11.2 billion) for the 2017-18 financial year. This includes $2.2 billion set aside for urea imports during the year. The fertilizer ministry believes that the move to smaller bags will result in farmers using two bags weighing 90kg for one acre against the current practice of using two 50kg bags, which weigh 100 kg, and hopefully therefore reduce consumption by up to 10%.

A recent analysis done by the agriculture ministry has indicated that use of urea per acre has already fallen by 4-6% since the switch to 100% neem-coated urea. In spite of this, and India's record production of 24.2 million t/a of urea in the 2016-17 financial year, the country still needed to import 8 million tonnes to meet domestic demand. The government has also started work on reviving closed urea manufacturing plants to ramp up production by 2022 to reduce imports.

BOLIVIA

Agreement on gas and urea sales

Bolivian Hydrocarbons Minister Luis Sanchez has signed two memoranda with the governors of the Brazilian states of Mato Grosso and Mato Grosso do Sul for gas and urea exports from Bolivia. The signing, in the presence of Bolivian president Evo Morales, would see the import of 10-12 million cubic metres per day of natural gas from 2019, when the existing contract between Bolivia and Petrobras expires. Brazil is also interested in securing urea from the new plant being built at Bulo Bulo in Bolivia. The 2,100 t/d (700,000 t/a) urea plant, owned by Bolivian state petrochemical company Yacimientos Petrolíferos Fiscales de Bolivia (YPFB), is due to start up in the next few months, and has already secured off-take contracts with Brazilian and Argentinian firms for up to 80% of its production.

UKRAINE

OPZ facing bankruptcy

Odessa Port Plant (OPZ) has had its appeal against an arbitration ruling thrown out by a local appeals court. The ruling paves the way for Ostchem Holding, controlled by Ukrainian gas and fertilizer mogul Dmitry Firtash, to collect $193 million in debts owed by state-owned OPZ to the Ostchem Group, as was ruled previously by the Arbitration Institute of the Stockholm Chamber of Commerce. Dmytro Parfenenko, acting head of Ukraine's State Property Fund (SPF), said that this would probably mean the bankruptcy of OPZ. The government has previous failed to privatise the plant, as no buyers were interested in taking on the company's huge debts, not to mention paying another $100 million in costs for re-starting and modernising plant operations. There is also another potential legal case hanging over the company, courtesy of the Nortima company, whose owner Ohor Kolomoisky claims that it should have won a 2009 tender to buy the plant for $600 million. OPZ has 17% of Ukraine's ammonium nitrate capacity and 19% of urea capacity.


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AUSTRALIA

Australia looking to export hydrogen as ammonia

Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO) has developed a metal membrane which it hopes will be able to separate high purity hydrogen from ammonia on an industrial scale, allowing for the transport of hydrogen as ammonia. CSIRO principal research scientist Michael Dolan says the technology, now being trialled on a small scale in Australia, is "the missing link" allowing hydrogen to be transported and used as an energy source. The membrane is a molecular sieve which allows the passage of hydrogen but keeps out larger molecules, coupled with a catalyst that catalyses the decomposition of ammonia to hydrogen and nitrogen. The aim is to overcome the inherent problem with transporting such a low density gas as hydrogen over long distances. Coupled with renewable energy based ammonia production, it could become an alternative energy carrier for the future, and there are hopes of trialling the system during the 2020 Tokyo Olympics, which are aiming to run entirely on hydrogen to showcase the "hydrogen society" of the future, especially as Japan pivots away from its previous reliance on nuclear energy in the wake of the Fukushima disaster. However, the initial trial will produce only 5kg/day of hydrogen from ammonia as proof of concept.

Yara is also forming part of the ammonia as an energy carrier project, installing a 2.5 MW solar array at its Dampier ammonia plant in sun-drenched Western Australia to generate 0.2 t/d of hydrogen by electrolysis for ammonia production. This forms only the first phase however, which would next be scaled up to 400MW of distributed solar generation, with high voltage hookup to a large electrolysis unit at Yara Pilbara Fertilizers, generating 32 t/d of hydrogen and 200 t/d (70,000 t/a) of ammonia. Ultimately, several renewable ammonia plants based on solar power would be built, exporting ammonia to Korea and Japan for use in hydrogen vehicles. ■

INDIA

Work begins on Assam methanol plant

State-owned Assam Petrochemicals Ltd (APL) says that it has begun work on construction of its new 500 t/d (165,000 t/a) methanol plant and associated 200 t/d (66,000 t/a) formaldehyde plant at its Namrup site. The new development, for which pile driving work began on May 7th following a vedic ritual, also includes a 7MW captive power plant. The whole expansion is costed at $215 million, with equity participation from the state government of Assam and MS Oil India Ltd (OIL). The ground breaking ceremony was attended by APL's managing director Ratul Bordoloi, chairman Jagadish Bhuyan, local Member of the Legistlative Assembly Noren Sonowal, APL vice chairman Bipul Deka and the company's senior management team, to mark the formal starting of construction work.

OMAN

MTO forms part of major Chinese investment

The China-Oman Industrial Park at Oman's Duqm Special Economic Zone has attracted major investment from Chinese companies, with land leasing agreements signed in April with 10 Chinese firms. Up to $11 billion of investment is slated for the port area, including a new 230,000 bbl/d oil refinery, a coal-fired power project, a solar panel manufacturing plant, a desalination plant, and a major methanol to olefins (MTO) facility. Many of the projects will be based on new gas being produced from BP's Khazzan tight gas project, which is expected to add 1 bcf/d of gas from the end of 2017. Work on a 221km pipeline to connect Duqm with Omani gas production has begun under the auspices of the Oman Gas Company. Also under construction are new roads and a 350km rail line to connect Duqm and Al Shuwaymiyah. The Industrial Park forms part of China's 'One Belt, One Road' initiative, also known as the 'new Silk Road', aiming to spread Chinese investment along a corridor across Asia.

The $2.3 billion MTO plant is being developed by Chinese petrochemicals corporation Mingyuan Holdings Group Co. In its first phase it will include 1.8 million t/a of gas-based methanol capacity with downstream olefins production of several hundred thousand tonnes per year.

UNITED STATES

Loan approved for West Virginia methanol plant

The West Virginia Economic Development Authority has approved a $10 million loan to US Methanol, which is aiming to develop its Liberty One Methanol project west of Charleston. Liberty One will be a second hand methanol plant which is currently being disassembled in Brazil for onward transport and reassembly in the United States. US Methanol say that the plant should be operational by early 2018 at the Dow Chemical facility in Institute, West Virginia, and will produce 150,000 t/a of methanol from local shale gas.

US Methanol chief commercial officer Brad Gunn told local press that the loan "fits our overall strategy to get the plant in operation soon. It doesn't finance the development of the plant itself, but it goes toward the equipment we'll use. Getting it is a big part of the process."

CHINA

Boost to Chinese shale gas production

The Unconventional Oil & Gas Monitor (UOGM) reports that Chinese shale gas production rose by 50% last year, reaching 1.15 bcm for March 2017. Shale gas output for 1Q 2017 was 2.67 bcm. Beijing is aiming to increase shale gas output to 30 bcm per year by 2020 as part of a major push on unconventional gas resources – sour gas, tight gas and coalbed methane included. China's shale gas production still lags far behind the US, and has been hampered by limited infrastructure and complicated geology. Many of China's shale plays are located at considerably greater depths than those found in North America, and access to stable supplies of water for hydraulic fracturing is also a challenge in a country regularly facing droughts. However, progress does now seem to be accelerating. China's largest shale gas producer, Sinopec, is set to begin production from its Nanchuan shale gas block in June. This comprises the second phase of Sinopec's

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Fuling project, which is estimated to hold 380.6 bcm of proven and probable shale gas reserves. Sinopec says that it has also managed to cut its well costs from 100 million yuan ($14.5 million) per well to 70 million yuan ($10.2 million) per well owing to improvements in efficiency and technology, as well as economies of scale.

Hydrogen for refinery complex

Honeywell UOP says that Zhejiang Petrochemical Co. Ltd will use four of its *Polybed*™ pressure swing adsorption (PSA) units to supply high-purity hydrogen for its new integrated refining and petrochemical complex in Zhoushan, Zhejian Province. The complex will also use Honeywell *Experion*™ distributed control systems, and the PSA units will be integrated with the *Experion* system. When completed, the new plant will be the largest crude-to-chemicals complex in China and one of the largest in the world, manufacturing petrochemicals to make plastic resins, films and fibres, as well as fuels.

John Gugel, Vice-President and general manager, Gas Processing and Hydrogen at Honeywell UOP, said, “Our customers in China are selecting UOP’s PSA technology as an extremely competitive and reliable source of high purity H_2. This is critical because H_2 is essential to the operation of any refinery or petrochemical plant, and the quality of that H_2 helps determine the efficiency of the entire complex,” Gugel added.

The PSA process uses proprietary adsorbents to remove impurities at high pressure from H_2-containing process streams, allowing it to be recovered and upgraded to more than 99.9% purity to meet refining needs. In addition to recovering and purifying hydrogen from steam reformers and refinery off-gases, the Polybed system can be used to produce hydrogen from other sources such as ethylene off-gas, methanol off-gas and partial-oxidation synthesis gas.

UZBEKISTAN

Topsoe syngas technology chosen for GTL project

Haldor Topsoe’s syngas technology has been chosen for Oltin Yo’l GTL, a 38,000 bbl/d gas-to-liquids (GTL) plant in Uzbekistan. Topsoe will deliver proprietary equipment for two synthesis-gas trains, including autothermal reformers (ATRs), waste heat boilers, steam drums, CTS burners, refractory materials, and HTZR zirconium target tiles. Oltin Yo’l GTL, owned by state gas company Uzbekneftegaz, will produce synthetic diesel, jet fuel, and naphtha based on local natural gas. Sasol is providing the technology license for the Fischer-Tropsch gas to liquids section using its Sasol Slurry Phase Distillate (SSPD) process. Sasol has been appointed single point licensor, and Hyundai Engineering Co. is the engineering, procurement, and construction (EPC) partner.

Fakhriddin Abdurasulov, Oltin Yo’l’s general director said: “in English, Oltin Yo’l means ‘golden road’ and this project will help set Uzbekistan on a golden road of development. We will produce some of the cleanest and most advanced transport fuels in the world, and we will add one of the world’s most advanced technologies to Uzbekistan’s already impressive energy industry. Topsoe’s syngas process is a very welcome contribution.”

“We are very proud to be part of this technologically advanced project and the development of Uzbekistan’s industry, added Per Bakkerud, executive vice president, Topsoe.

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People

At its most recent annual conference in Marrakesh, the International Fertilizer Industry Association (IFA) elected **Rakesh Kapur** as its new chairman. Mr Kapur is joint managing director of the Indian Farmers Fertilizer Cooperative (IFFCO), one of the largest fertilizer cooperatives in the world, and currently celebrating its 50 year anniversary of continuous support to Indian farmers. Mr Kapur is also currently completing his term as chairman of the Fertilizer Association of India (FAI), and sits on a number of international boards. An ex-Indian Revenue Service officer, he has held various senior positions in government, including as director of the Ministry of Chemicals & Fertilizers, the Telecommunications Regulatory Authority of India and, prior to joining IFFCO, as additional assessor and collector at Municipal Corporation of India. Rakesh Kapur has previously served as chairman of IFA's Production and International Trade Committee, and joined IFA's Executive Board in 2015, when he was also elected as vice chairman and chairman of IFA's Finance Committee.

In his speech to the conference, Mr Kapur said: "I am honoured and delighted to assume IFA's Presidency and will continue to further advance and expand IFA's strategic role in promoting product and nutrient stewardship initiatives around the world and delivering added value through its programs on statistics and market analysis. Under his leadership, my predecessor, Dr.Jawahery, has already accomplished major advances in driving the industry's commitment to the Sustainable Development Goals. I pledge to continue this engagement in my new role, and ensure that IFA supports the industry to contribute to the important Agenda 2030 Goals. I am also delighted to oversee the development of a strategic, future oriented outlook for plant nutrition and our industry during my two year Chairmanship." **Mostafa Terrab**, CEO of OCP, Morocco, and longstanding Executive Board Member of IFA, haa been nominated as vice-chair.

Uhde Fertilizer Technology bv (UFT) has had a change of identity, and will now be known as thyssenkrupp Fertilizer Technology GmbH. UFT has been a global market leader in fluid bed urea granulation technology, with more than 30 years of experience in developing and licensing fluid bed urea granulation technology and practical experience from more than 60 plants in operation all over the world. UFT was established in 2005 as a subsidiary of ThyssenKrupp Nederland BV, based at Roermond in the Netherlands, with the worldwide, exclusive license rights for the fluid bed urea granulation technology developed by Yara Fertilizer Technology. As part of the change in identity, UFT will be moving its home base to Dortmund, Germany, and in line with thyssenkrupp's brand strategy the company name will assume a group identity as thyssenkrupp Fertilizer Technology GmbH.

Following the proposed merger between Clariant and Huntsman (see Industry News), the combined company, incorporated in Switzerland, has announced the new board line-up, with equal representation from Clariant and Huntsman, and following Swiss Corporate Governance standards. **Hariolf Kottmann**, current Clariant CEO, will become chairman of the board of HuntsmanClariant. **Peter Huntsman**, current Huntsman President and CEO, will become CEO of HuntsmanClariant. **Jon Huntsman**, founder and chairman of Huntsman, will become chairman emeritus and board member of HuntsmanClariant. ■

Calendar 2017/18

JUNE

26-30

Nitrogen Fertilizer: Advances in Technology, Products, Safety and Global Impact, LONDON, UK
Contact: International Fertilizer Development Center, PO Box 2040 Muscle Shoals, Alabama 35662, USA.
Tel: +1 256 381-6600
Email: training@ifdc.org
Web: www.ifdc.org

29-30

International Fertiliser Society Technical Conference, LONDON, UK
Contact: International Fertiliser Society, PO Box 12220, Colchester, CO1 9PR, UK.
Tel: +44 1206 851819
Email: secretary@fertiliser-society.org

JULY

9-12

IMTOF 2017, LONDON, UK
Contact: Sue Appleton, Johnson Matthey Plc, PO Box 1, Belasis Avenue, Billingham, Cleveland, TS23 1LB, UK.
Email: sue.appleton@matthey.com

SEPTEMBER

10-14

62nd AIChE Annual Safety in Ammonia Plants and Related Facilities Symposium, NEW YORK, USA
Contact: AIChE Customer Service
Tel: +1 800 242 4363/+1 212 591 8100
Fax: +1 212 591 8888
Email: xpress@aiche.org

30

35th World Methanol Conference, BERLIN, Germany
Contact: Lynn Urban, IHS Markit
Tel: +1 303 397 2801
Email: Lynn.urban@ihsmarkit.com

OCTOBER

1-6

Ammonium Nitrate/Nitric Acid Conference, AUSTIN, Texas, USA
Contact: Hans Reuvers, BASF, Karl Hohenwarter, Borealis
Email: johannes.reuvers@basf.com
karl.hohenwarter@borealisgroup.com

15-18

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

24-26

IFA Crossroads Asia-Pacific Conference, SHANGHAI, China
Contact: IFA Conference Service, 28 rue Marbeuf, 75008 Paris, France.
Tel: +33 1 53 93 05 00
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Plant Manager+

Problem No. 43 Increased dust content of urea granules

Dust formation in the granulator can adverslely affect stream time. There are several reasons for increased dust in the fluid bed granulator. No formaldehyde or less formaldehyde injection, lower bed level in the granulator, lower concentration of urea melt to the granulator, a higher pressure in atomisation (sprayer) air and a higher pressure in the urea melt header are all factors which can play a role. This roundtable discusses increased dust level and its causes.

Fateme Ahangarani from Razi Petrochemical Company, Iran starts the discussion: These days we have a problem in our urea granulation plant and the amount of product urea dust has increased. Which parameters are important for decreasing the dust content? We try to control the concentration of urea formaldehyde at about 0.5 wt-% but the problem still persists.

Naceem Kashif from SABIC, Saudi Arabia replies: Dust can increase due to the following factors:

- high ammonia content in product;
- higher moisture content;
- higher temperature;
- low strength.

Mark Brouwer from UreaKnowHow.com, The Netherlands asks some questions: Do you see an increase in the temperature of the product granules leaving the granulation section? If yes, from what temperature to what temperature? Has the inlet urea melt concentration changed?

Majid Mohammadian from PIDEMCO, Iran shares his ideas: If the amount of dust is greater than normal check for the following items:

- low content or poor quality of urea formaldehyde;
- low level in the beds;
- low concentration of urea melt feed.

Chandra Mohan from Nagarjuna Fertilizers and Chemicals Ltd, India offers some advice: You could try contacting GPIC, Kingdom of Bahrain for more details/advice. As far as I know, the GPIC granulation unit is the world's best running unit.

Abbas Noureldeen from Petrochemicals Industries Company, Kuwait makes some suggestions: If the dust increase is in the final product, you may need to check the air flow and levels in your first and second bed coolers. When the level in the final bed cooler is high and the air flow is reduced, dust will be carried over with the final product. You need to increase the air flow a little and decrease the bed level. If the dust is high in the granulator scrubber then you need to check the temperature and urea melt concentration as it might be high.

By the way, increasing the urea formaldehyde concentration to more than 0.45 wt-% will not help much in decreasing the dust formation.

Mark Brouwer from UreaKnowHow.com, The Netherlands asks for more information: When you talk about a dust problem, what do you mean? Is the fines (<1 mm) content in the product high? Are there any caking problems? Does the product show caking behaviour?

Mohammad Farooq from SABIC-SAFCO, Saudi Arabia shares his opinion on this subject: By dust we typically mean fines which are less than 1 mm in urea product. In my opinion, if the amount of fines (<1mm) increases to more than 1.5 wt-% of the product at the exit of the prilling tower and the product is to be stored there is an increased possibility of caking. Caking will start within a few days and the situation will get worse with the passage of time. However if the product is packed directly, the problem can be minimised.

Reza Keyhani from Kermanshah complex, Iran asks a new question: What is the effect of the granule temperature on this?

Jeremy Feser from Agrium, Canada asks for clarification: Are we talking about granulation or prilling?

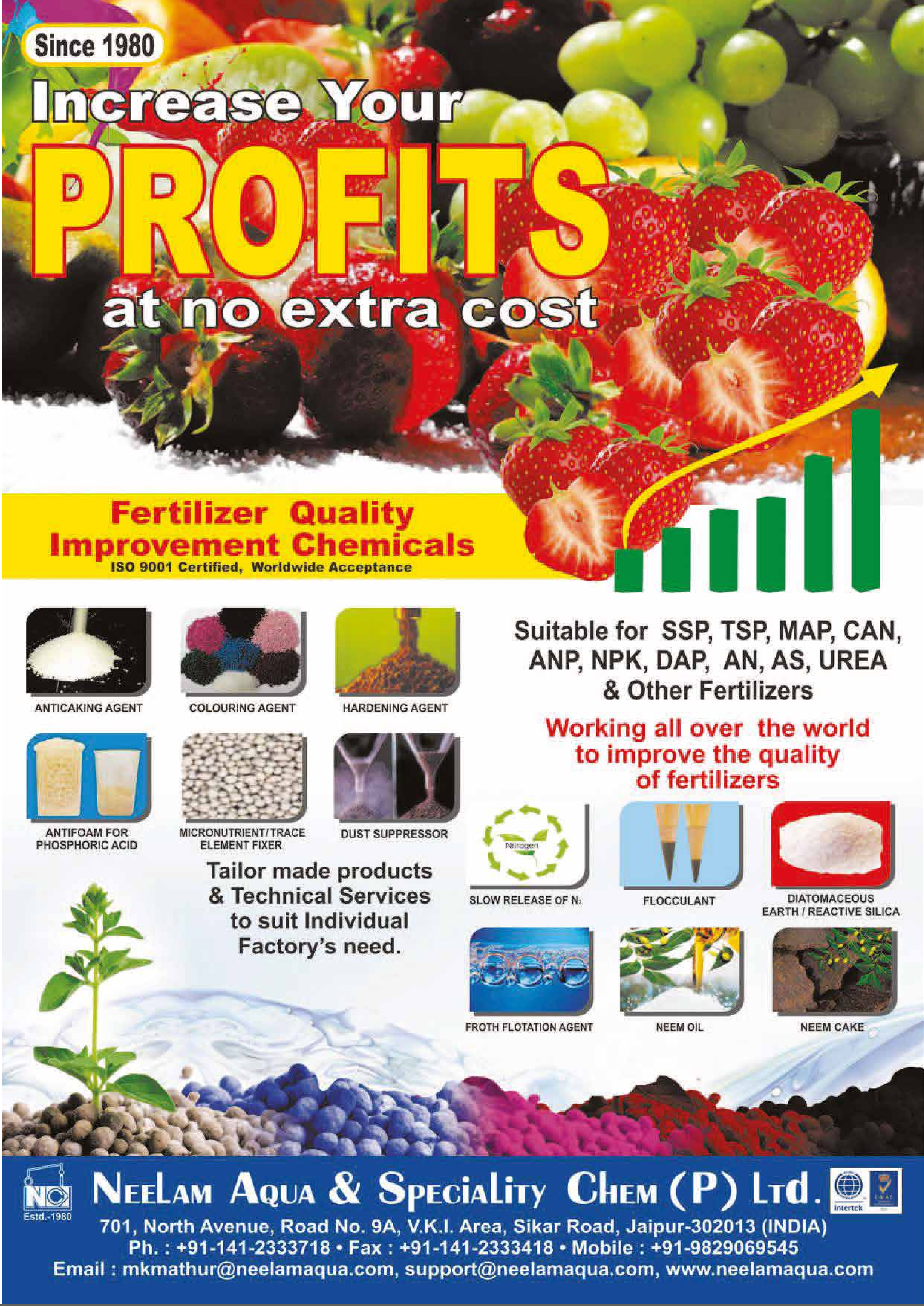
Mark Brouwer from UreaKnowHow.com, The Netherlands replies and provides more information about drum granulation: We are talking here about fluid bed granulation. I believe you are talking about drum granulation. In a fluid bed granulation unit a high bed temperature leads to a softer product and thus more dust formation and a shorter run length.

Dusty urea product often leads to uncomfortable discussions between a urea producer and their clients. It also leads to caking and causes unpleasant and even hazardous working conditions for any employee working with such a product. Additionally, dusty urea can cause damage to crops, leading to reduced yields in the agricultural sector.

Dusty urea product is typically caused by operation parameters of the evaporation section in the urea melt plant, operation parameters of the granulation section, storage conditions and logistic procedures. In most of these cases an end-of-pipe solution is the most efficient and cost-effective solution to improve the product quality and produce premium-grade urea. The Van Bommel Dedusting Technology (VBDT) offers such a solution.

The VBDT was developed in 1992, and has been in continuous operation ever since at a modern fluid bed urea granulation plant in North America. The original VBDT design was a one-line unit with a design capacity of 200 t/h. It was capable of breaking up soft lumps with a diameter larger than 8 mm, taking out fines and broken product (90 μm-1.0 mm), and removing dust and ultra-fines (1 μm-90 μm). The design made it possible to guarantee an "on-spec" premium-grade urea granular product of between 1.0 mm and 4.0 mm at variable feed rates.

The line was expanded in 1994 to 500 t/h. The VBDT has also been implemented at various DAP & MAP plants and has the option to perform cooling of the product and refresh warehouse air to improve visibility during unloading and loading operations. ■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China's nitrogen and methanol industries

The Wison MTO plant in Nanjing.

PHOTO: UOP

China is the world's largest producer of both ammonia and methanol, but while China's nitrogen industry faces overcapacity and rationalisation, methanol continues to be imported in large quantities to feed olefins production.

China has come to define most bulk commodity markets, including nitrogen (mainly urea) and methanol, but its position in both markets shows considerable difference as well as similarities. On the nitrogen side, over-production, over-application, and a variety of environmental issues are forcing a consolidation of the sector which will bring major change to China's nitrogen industry, probably leading to the large volumes of exports seen in recent years falling, while on the methanol side, the ability of methanol to act as an intermediate for the production of fuels and plastics from coal is leading to production and demand continuing to increase at a rapid rate, and probably higher volumes of imports in future.

Nitrogen

China is the world's largest ammonia and urea consumer and producer. The country has an estimated 80 million t/a of ammonia production capacity, almost one third of the global total, although some of this is either intermittently or permanently closed, and operating rates average only 50-60%. Much of this is legacy form capacity from China's long-term policy of maintaining self-sufficiency in nitrogen fertilizer production over several decades, in order to avoid the terrible famines of the Mao era, and continue to feed a population in excess of 1.3 billion – 20% of the world's total – with only 8% of the world's arable land.

Initially this was achieved by ammonium bicarbonate (ABC) production, using fixed bad gasifiers to gasify coal to make ammonia, and then passing carbon dioxide through an ammonia solution. This simple process was superseded in the 1970s with the introduction of more advanced ammonia and urea technology, although a significant number of old ABC plants do still remain.

China pushed ahead during the 1970s and 80s with ammonia-urea capacity, mainly using coal gasification, although during the late 1980s and 1990s there was also some gas-based urea capacity developed in China, but shortages of gas because of it being required for power production forced a focus back onto coal gasification as a feedstock. Clariant estimated in 2015 that 81% of Chinese ammonia capacity was based on coal feedstock, with the rest mainly natural gas as well as a scattering of coke oven gas-based plants. This mix is unlikely to change going forward – China has little domestic gas reserves and, while it is making a concerted effort to develop unconventional gas reserves – coalbed methane, shale gas, sour gas and tight gas – these again are mainly destined for power production. Indeed, since 2012, government regulations have actually forbidden using natural gas as a feedstock for new ammonia projects.

Another broad thrust of policy over the past couple of decades has been to replace older, smaller and less advanced ammonia plants with newer, larger plants based on advanced gasification technologies which are often considerably more energy efficient. These allow the use of lower quality, bituminous coal rather than more expensive anthracite, which can then be preferentially used for power production and home heating.

More recently, a minimum plant size of 300,000 t/a for new plants has also been set, in order to encourage economies of scale and cheaper production. There is also a policy to develop more capacity in the coal-rich northwest of China and try to shut down production too close to urban centres.

Emerging policy areas

As mentioned above, China has concentrated on producing enough urea for its farmers at a subsidised price in order to produce sufficient food to feed its growing population, and China has indeed been successful in raising grain yields as well as moving to more nitrogen-hungry crops such as fruit and vegetables and achieving food security over the decades. However, China has done this by having the highest nitrogen application rates in the world, and since the 1990s there has been growing recognition that high levels of nitrogen fertilizer use in China are contributing to local, regional, and global environmental problems, including deteriorating water quality through leaching and nitrification, soil acidification, and rising greenhouse gas (GHG) emissions. While there is room for more application of some nutrients, such as potash, the Chinese government has recognised that it must now focus on nutrient use efficiency in order to get the best out of the nitrogen it produces and applies. The slowing growth of China's population as the 'One Child Policy' adopted in 1979 makes itself felt has also removed some of the urgency from simply producing more food.

Two trends have emerged from this. One is a switch away from relying so heavily on urea as a source of nitrogen nutrient towards other, more complex compound fertilizers. More animal rearing for a more protein rich diet is also leading to more manure being available for farmers. Another trend is an attempt to cap nitrogen applications to fields. The Chinese government decided in the most recent five year plan (2016-2020) to let nitrogen fertilizer demand rise only 1% per year to 2020, at which point it will be capped nationally, with future productivity gains will coming from more efficient application.

At the same time, government controls on internal markets for all manner of items are starting to be withdrawn as China moves towards market pricing. This is affecting fertilizer and crop markets, as well as inputs into agricultural costs such as freight rates, power costs, coal and natural gas pricing, VAT etc. There is also a recognition that capacity has been overbuilt in many areas, including coal production, where the government is trying to slim down the country's bloated mining sector. The National Development and Reform Commission (NDRC) is targeting 800 million t/a of coal production for closure under the present Five Year Plan, albeit with the addition of 500 million t/a of newer, more efficient capacity. In attempting to manage coal output the government has been experimenting with restricting the number of days that coal mines are allowed to operate, leading to a coal price spike during 2016 which badly affected urea production, even those that have switched to running on cheaper, bituminous coal rather than more expensive anthracite, and significantly reduced China's exports of urea.

Another issue has been pollution in urban areas. Last winter the cities of China's northeast faced some of the worst smogs they have ever seen, even in a country used to poor air quality, and the Ministry of Environmental Protection (MEP) has begun to take drastic action to try and limit this problem, forcing major industrial plants near urban centres to close down temporarily or even permanently. This has affected many industries, from power to aluminium, but in early 2017 Yihua Group was forced to close its Yichang urea plant in Hebei, and many plants near population centres were asked to run at low operating rates. The MEP is now looking at potential seasonal closured for urea producers in Shandong, Shanxi, Hebei, Henan, Beijing and Tianjin, which could affect up to 36 million t/a of urea capacity; around 45% of China's output.

Table 1: New Chinese methanol capacity, 2017

Company	Location	Feedstock	Capacity ('000 t/a)	Start-up
Jiajing Magnesium	Inner Mongolia	Coke oven gas	300	H1 2017
Xinneng Phoenix	Shandong	Coal	200	H1 2017
Mingshui Dahua	Shandong	Coal	600	H1 2017
Hualu Hengsheng	Shandong	Coal	1,000	H2 2017
Jinshi Chemical	Hebei	Coal	100	2017
Luxi Chemical	Shandong	Coal	800	2017
Anhui Linhuan	Anhui	Coke oven gas	200	2017
Zhongtian Hechuang	Inner Mongolia	Coal	1,800	2017
Total			**5,000**	

Source: ICIS

Urea closures

This comes on top of a programme of rationalisation in the urea industry under the current Five Year Plan which has seen 9 million t/a of urea capacity close in 2014-15 and 8 million t/a in 2016. While 36 million t/a of new urea capacity has come on-stream since 2012, this has been balanced by 23 million t/a of closures over the same period, most of it smaller less efficient plants or higher cost anthracite-based or gas-based producers. New plants are often in the 600-800,000 t/a range. CRU forecast in March that another 12-14 million t/a of urea capacity will close from 2017-2021, significantly more than forecast capacity increases of around 8-9 million t/a over the period - for the first time in decades, Chinese urea capacity may actually fall, at the same time that there are production restrictions possible on plants in the northeast close to urban centres.

Falling imports

All of this is serving to reduce China's urea exports. For a while China tried to control urea exports by placing a tariff on them, as there was a period when domestic suppliers, especially near coasts, found it more profitable to sell onto a buoyant global market rather than to the domestic market where prices were controlled, and the government sought to keep urea in the country to be available for the country's farmers, with only a 4-month period in the autumn where lower tariff exports were permitted. However, as urea overcapacity mounted so worries over availability eased and export tariffs were relaxed. As a result, China's urea exports surged to a record 13.8 million t/a in 2015. However, high coal prices and rationalisation reduced exports to 8.9 million t/a in 2016, and they are estimated to fall further to 5.0-7.5 million t/a in 2017 due to low operating rates among coal-based producers. Further cutbacks and rationalisation are likely to see this fall further in future, although the prospects of any large-scale imports look slim at present.

Methanol

China has become the driver of the global methanol industry through a variety of government-backed initiatives. These have caused Chinese methanol demand to increase at an average rate of 16% year on year for the past decade, taking China from a relatively minor player on the world market to the world's largest producer, consumer and importer. China now accounts for over 50% of world methanol demand, approaching 50 million t/a in 2016. Meanwhile, Chinese methanol production reached 43 million tonnes in 2016, according to the National Statistics Bureau. Production continues to grow at around 6% year on year, and capacity increased by 7% in 2016. A further 5.4 million t/a of capacity is expected to come on-stream in 2017, including 3.2 million t/a of new capacity and 2.2 million t/a of re-started capacity.

Initially China's use of methanol was mainly for chemical applications – particularly formaldehyde, used in resins production, but also methyl methacrylate (MMA), acetic acid etc. These uses continue to grow, but as the Chinese industrial economy matures, so growth in these sectors has begun to slow. China's rise to become a methanol industry titan began with attempts to monetise Chinese coal production and to produce domestic fuels to reduce the country's increasing reliance on importing foreign oil and gasoline and other petrochemical products. This started with small-scale methanol blending into domestic gasoline in some coal-rich regions, and has now come to represent around 10% of the Chinese gasoline pool. There was also a large-scale push to develop dimethyl ether (DME) production, as a blendstock for LPG. Here, however, there was some consumer push-back as cheap, unlicensed blenders would blend in conventional containers, using rubber seals which are degraded by DME, and a series of accidents led to a government crackdown. As a result the Chinese DME market did not develop as anticipated, and there remains widespread overcapacity in this sector. Nevertheless, gasoline blending and DME blending represent almost 18 million t/a of Chinese methanol demand.

Other fuel uses of methanol have come from conversion to methyl and ethyl t-butyl ether (MTBE/ETBE), oxygenates for improving fuel octane rating, and Chinese demand continues to increase as fuel quality improves. LyondellBasell estimates that Chinese MTBE demand is around 8 million t/a, and that another 2.4 million t/a of capacity will be built from 2015-2020.

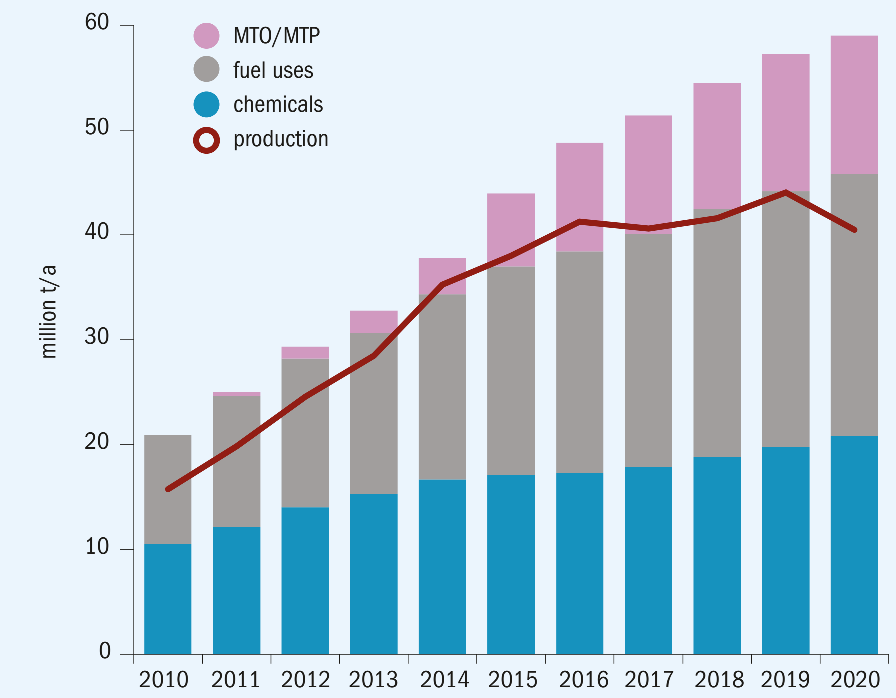
More recently, however, new processes or end uses for methanol have come to take off. Direct conversion of methanol to gasoline (MTG) has been one significant new development, using the ExxonMobil process. The first, demonstration unit came on-stream in 2010, but another 10 plants have been constructed since then. Although the fall in oil prices has reduced its cost advantage, MTG means that the product can be sold directly into the gasoline market and avoids the sometimes confusing mix of fuel methanol standards, as well as the methanol 'blend wall' issue that prevents more than 10-15% methanol being blended into gasoline before a specially adapted engine must be used.

Table 2: **New Chinese methanol to olefins and coal to olefins plants**

Producer	Location	Methanol consumption	Start-up
Current MTO production	**Various (12 plants)**	**11,160,000 t/a**	**to June 2016**
Current CTO production	**Various (7 plants)**	**12,360,000 t/a**	**to June 2016**
Shenhua Coal New Mats	Urumqi, Xinjiang	1,800,000 t/a (CTO)	Oct 2016
Zhongtian Hechaung	Ordos, Mongolia	1,800,000 t/a (CTO)	Oct 2016
Qinghai Salt Lake	Haixi, Qinghai	1,000,000 t/a (CTO)	4Q 2016
Huating Coal	Pingliang, Gansu	600,000 t/a (CTO)	4Q 2016
Changzhou Fund Energy	Changzhou, Jiangsu	990,000 t/a (MTO)	4Q 2016
Zhongtian Hechuang	Ordos, Mongolia	1,800,000 t/a(CTO)	early 2017
Shaanxi Yanchang	Yan'an, Shaanxi	1,800,000 t/a (CTO)	mid-2017
Jiangsu Sailboat	Lianyungang, Jiangsu	2,400,000 t/a (MTO)	1H 2017
Zhong'an Utd Coal	Huainan, Anhui	1,800,000 t/a (CTO)	2H 2017
Jiutai Energy	Ordos, Mongolia	800,000 t/a (MTO)	2H 2017
Shenhua Baotou	Baotou, Mongolia	1.800,000 t/a (CTO)	4Q 2017
Shanxi Qiyi Energy	Xiangyang, Shanxi	900,000 t/a (CTO)	4Q 2017
Shanxi Coking Co	Hongdong, Shanxi	1,800,000 t/a (CTO)	2018
Sinopec/Henan Coal	Hebi, Henan	1,800,000 t/a (CTO)	2018
Qinghai Mining	Golmud, Qinghai	1,800,000 t/a (CTO)	2018
China Coal Yulin Energy	Yulin, Shaanxi	1,800,000 t/a (CTO)	2018
Jilin Connell Chemicals	Jilin, Jilin	600,000 t/a (MTO)	2018
Tianjin Bohua	Tianjin	3,600,000 t/a (MTO)	2019-20
Fujian Gulei Petchem	Zhangzhou, Fujian	1,800,000 t/a (MTO)	2020
Total new MTO		**11,990,000 t/a**	
Total new CTO		**20,500,000 t/a**	

Source: Argus JJ&A

Fig 1: **Methanol consumption/production, China**



Source: Argus/JJ&A

China's two main oil companies and gasoline suppliers, Sinopec and PetroChina, do not operate their own methanol capacity and have not looked favourably at its uptake into the gasoline pool. As a result their pressure has led to a national 'M15' standard on methanol blending still not being agreed, and instead a myriad of local, provincial standards apply (13/23 provinces have some kind of methanol blending standard).

Nevertheless, fuel security continues to be an issue for China. China imports over 6 million bbl/d of oil, and with its own domestic production increasing only slowly, while gasoline and diesel demand increase rapidly, this can only increase. China is acutely aware that most (80%) of this oil comes from the Middle East and flows through the Malacca Straits in Indonesia, and could be vulnerable to being interdicted in the event of any major face-off with the United States – one reason for China's expansion of its military presence in the South China Sea. Methanol and methanol derivatives in the Chinese liquid fuel market now total over 500,000 bbl/d according to Argus DeWitt, and this is likely to continue to increase.

Methanol to olefins

While MTG is showing some significant growth in China, by far the largest driver of new methanol consumption in China has been methanol to olefins (MTO). Methanol can be converted to ethylene or propylene and then polymerised to polyethylene or polypropylene. This allows coal to be effectively used as a feedstock for plastics production rather than oil and again helps mitigate large and expensive imports of oil. Methanol to olefins capacity in China represented 25 million t/a of capacity to consume methanol in early 2016, according to Argus, and there is more than as much again planned or under construction (see Table 2).

Methanol imports

In spite of China's continuing build-up of methanol capacity domestically, the growth in MTO production and especially the growth in MTO production that does not have dedicated upstream methanol capacity at the same site – so-called 'merchant MTO' – the gap between Chinese methanol production and consumption continues to grow. Although China has a large amount of 'unused' methanol capacity, much of this is either small scale and too expensive or otherwise not likely to be able to compete with imported methanol. Nevertheless, continuing demand for methanol has led to some domestic methanol re-starts.

Total methanol imports in 2016 were around 8.8 million t/a in 2016, up nearly 60% on 2015. China remains what MMSA describes as the "importer of last resort", hoovering up any spare tonnages on the market. Imports are imports are likely to continue growing over the next few years. Demand is rising rapidly in eastern China, with two new methanol-to-olefins plants having started production at Fund Energy and Jiangsu Sailboat, with a combined requirement for 3.5 million t/a of methanol feedstock.

China's methanol imports come mostly from Iran (about 45% in 2015), and another 35% from other Gulf states – Saudi Arabia, Oman, Qatar, Bahrain and Abu Dhabi. New Zealand, Malaysia and Indonesia make up most of the rest. However, an interesting new development has been Chinese companies looking to build upstream gas-based methanol capacity outside of China, especially in the USA. Two large-scale plants are under development in Washington State, where cheap US shale gas will feed 10,000 t/d of methanol production for export to China for olefins production.

MMSA calculates that methanol imports to China could rise from 7 million t/a in 2015 to 13 million t/a in 2020 (see Figure 1), and even 19 million t/a in 2025, raising concerns about whether the country has the infrastructure to absorb such tonnages.

Driven by policy

The unifying theme of both the Chinese nitrogen and methanol sectors is their continued dependence on government policy decisions as much as market developments. On the nitrogen side, environmental and efficiency concerns are leading to rationalisation of urea capacity and a move to larger, more advanced sites, with capacity actually likely to fall over the next few years, and demand levelling out from 2020 onwards. Increases in coal prices as the country transitions to a market based economy may also increase the overall 'floor price' for China, which remains the marginal producer of urea, and exports are likely to continue to fall.

Conversely, on the methanol side, self-sufficiency concerns and the relatively cheapness of coal-based methanol compared to other ways of producing fuel or plastics will continue to see both new production and especially new demand, with imports continuing to rise steadily over the coming years. ■

Urea to melamine

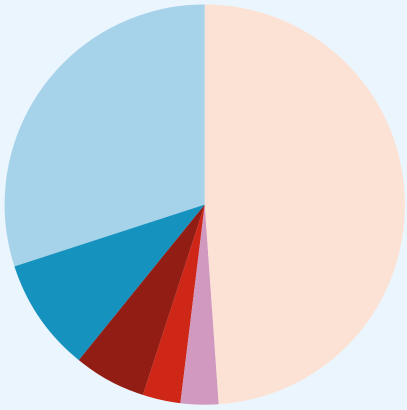
Melamine for resin production is a small but useful diversified product stream for urea producers, and melamine production can offer useful synergies for urea producers as part of an integrated plant.

Whereas most urea goes into fertilizer production, it does have a number of industrial and chemical uses as well. In general, the market for 'technical' urea is actually growing more quickly than that for agricultural purposes, in areas such as urea solutions used for catalytic reduction of vehicle exhausts ('Adblue'/DEF), urea-formaldehyde resins, health and beauty products, metal treatment and a variety of other uses. While most of these are separate from the business of producing urea itself, urea conversion into melamine – also mainly used in resins – can offer advantages to urea producers because of the way that the process can be integrated into urea production.

Most melamine is used in the wood-based fibreboard and panel industry as a starting product for the manufacture of melamine-formaldehyde (MF) and melamine-urea-formaldehyde (MUF) resins, which go into a variety of household and building uses such as surface laminates for kitchen worktops, furniture and flooring, and adhesives for board materials such as particle board (chipboard), MDF and plywood. It is also used as a binder in some paint formulations for more durable applications, and as a flame-retardant additive in polyurethane foams used in furniture and mattresses. However, laminates and wood adhesives account for a substantial proportion of melamine demand overall, and because of its broad range of uses in building and coatings, overall growth in melamine demand is generally related to general GDP growth. Figure 1 shows these end uses according to a major melamine contractor.

The overall melamine market was just over 1.6 million t/a in 2016, with demand dominated by Europe and Asia, especially China. As with many other chemical sectors, China has come to represent about 50% of global melamine consumption. However, also as with many other chemical sectors, China has overbuilt melamine capacity, to the extent that it now has almost 70% of the world's installed melamine capacity, and has not only met its own domestic demand, but has also become the world's largest exporter of melamine, responsible for around 40% of merchant melamine sales. China exports up to 300,000 t/a of melamine, and this has triggered an anti-dumping investigation in the European Union which is expected to rule later this year.

Fig 1: Major end-uses for melamine

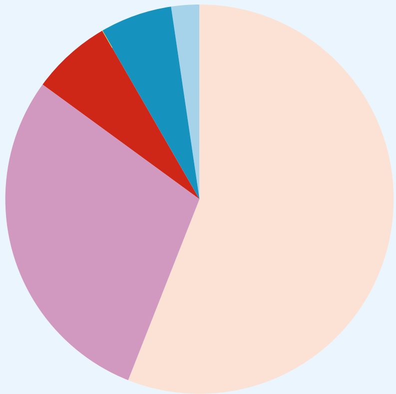


- 49% Decorative and protective laminates
- 3% Wood adhesives
- 3% Surface coatings
- 6% Moulded products
- 9% Textile and paper treating/coating
- 30% Other applications*

*concrete additives, flame retardants, special fertilizers, ion exchange resins, leather tanning agents, fluorescent pigments, glass fibres

Source: Eurotecnica

Fig 2: Melamine demand by region



- Asia Pacific
- Europe
- America
- Middle East and Africa
- Latin America

Source: IHS

Europe is the second largest consumer of melamine, with just over 25% of world consumption. Europe is also the second largest producing region, dominated by the 150,000 t/a capacity OCI facility in the Netherlands, and followed by Borealis in Germany (80,000 t/a) and Grupa Azoty in Poland (96,000 t/a). Borealis also has a 65,000 t/a plant in Austria, and BASF operates 65,000 t/a at Ludwigshaven. Outside of China and Europe, the largest producers are Russia, Japan and the USA. However, consumption is much more limited here, with the US representing only about 5% of melamine consumption (see Figure 2). The US also has a sole 75,000 t/a production plant at Cornerstone's Waggerman facility.

In spite of the relative slowdown in the Chinese economy, Chinese consumption has continued to grow at a rate of around 6% year on year due to continuing demand for wood panels and laminates for flooring and furniture in the Chinese property market. However, growth has been even stronger in other parts of Asia, with India, South Korea, Malaysia and Indonesia all seeing steady growth for wood panels. The Asia-Pacific market as a whole is forecast to continue to see 5% increases in demand year on year to 2020. Western European demand by contrast is increasing at a relatively more modest 1-2% per year, increasing to 3-4% in Eastern Europe and around 3% overall in Europe. The US figure is around 2% growth, with construction and car production the main areas of demand. Overall global demand is expected to increase to 1.9 million t/a by 2020.

The recent run of low urea prices has been beneficial for melamine producers, as each tonne of melamine produced requires up to 3 tonnes of urea as feedstock (this can be lower, depending on how

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

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the recycle works). For this reason, melamine consumes in effect up to 4.8 million t/a of urea – relatively modest compared to a global urea market of 190 million t/a, but still representing a respectable 2.5% of global urea demand. Moreover, as melamine prices can run at $900-1,900/tonne – far higher than urea's average of $250-400/t (or $750-1,200/tonne of melamine equivalent), it makes melamine a significant value-added product.

Major technologies

The reaction from urea to melamine can generally be thought of as a two-step process. In the first step, urea decomposes into cyanic acid and ammonia in an endothermic reaction:

$$6CO(NH_2)_2 \rightarrow 6HCNO + 6NH_3 \quad (1)$$

In the second step, cyanic acid polymerises to form cyanuric acid, which condenses with the liberated ammonia forming melamine. This releases water which then reacts with cyanic acid present (which helps to drive the reaction) generating carbon dioxide and ammonia.

$$6HCNO \rightarrow \underset{\text{(melamine)}}{C_3H_6N_6} + 3CO_2 \quad (2)$$

Reaction (2) is exothermic but the overall process is endothermic. The overall reaction is thus:

$$6CO(NH_2)_2 \rightarrow C_3H_6N_6 + 6NH_3 + 3CO_2 \quad (3)$$

There are essentially two broad ways to produce melamine – a high pressure non-catalytic process first developed by Allied Chemicals in the 1960s, with similar versions soon emerging from Nissan and Montedison, and a low-pressure gas-phase catalytic process developed by BASF and later variants from DSM (with a liquid quench) and Chemie Linz. Although companies and licensors have changed hands over the years, the broad processes remain essentially the same, although with various improvements along the way. Chemie Linz became AgroLinz (who also bought the Montedison technology), then Borealis, and now those melamine licenses have been bought by Casale, while DSM's melamine technology is now owned by OCI. Other entrants include Eurotecnica, with a process based on the Allied technology, and Lurgi, now owned by Air Liquide. The various technologies are shown in Table 1.

The low pressure process in vapour phase is a catalytic process in which the decomposition of molten urea and the synthesis of melamine takes place in a fluidised or fixed bed catalytic reactor. The effluent is quenched with water (recovering the product in a slurry) or with cold gas, and the off gas is sent to the recovery and treatment unit. The slurry (in the case of liquid quenching) is driven though a filter (to remove catalyst fines) and finally to a crystallisation section, where the final product is obtained after centrifuging and drying.

While both low and high pressure processes operate at around 370-400°C, the low pressure processes require only around 1-10 bar of pressure, and hence do not require special grades and thicknesses of steel, making for lower capital expenditure, but catalyst and utility requirements can make for higher operating costs. The high pressure processes operate in a liquid phase at 80-150 bar, and generate a coarser product, meaning that the low pressure process is preferred for finer, paint and coating applications. The LP process, which uses a fluidised bed reactor, also tends to lend itself better to larger scale applications.

Table 1: **Melamine technologies comparison**

	High pressure	Low pressure
Liquid quench	Casale Eurotecnica Nissan	OCI (SLP) Casale
Gaseous quench	OCI (GPH)	Lurgi/Air Liquide BASF

Casale

Casale acquired Borealis' high pressure melamine technology in 2013. As a urea licensor, Casale have both before and since worked to realise synergies between the urea and melamine processes – the off-gases generated in the melamine plant can be recycled back to the urea plant where they will be converted again into urea, making a melamine plant neatly integrated within a larger fertilizer complex.

In Casale's *LEM*™ (Low Energy Melamine) process, melamine synthesis and off-gas separation occur in the high-pressure section of the plant, while the melamine product is purified by separation from by-products such as oxy-amino-triazines (OATs) and polycondensates such as melam in the low-pressure (aqueous) section of the plant. Since the melamine is recovered from its aqueous solution by crystallisation, melam, which can co-precipitate along with melamine, must be removed before the solid-liquid separation is carried out. That is accomplished by hydrolysis in alkaline solution. OATs, which are formed both in the synthesis section and from melam and melamine hydrolysis occurring in the low-pressure section of the plant, are kept in solution as sodium salts at the appropriate pH during the melamine crystallisation and are subsequently purged out and treated in the waste water treatment (WWT) section of the plant. The alkaline environment needed to hydrolyse melam and form the OAT sodium salts is maintained by adding the appropriate amount of a sodium hydroxide solution. After crystallisation the melamine is dried, filtered and sent to silos for storage.

Casale *LEM* technology is currently applied in two plants owned by Borealis: a 30,000 t/a plant sited in Linz, Austria, and an 8,000 t/a plant in Piesteritz, Germany. Casale has completed a basic engineering package for a new 40,000 t/a melamine plant in 2015 and is preparing another basic engineering package for a 40,000 t/a melamine plant, awarded in 2016.

Eurotecnica

Until just over two decades ago, there had been little licensing outside of the major melamine producers themselves (DSM, Nissan, BASF, AgroLinz), via their own plants or joint ventures. The only major technology licensed outside of these was Eurotecnica's, first developed in the 1960s and commercialised in Kuwait in 1970. As a result Eurotecnica, now part of the Proman Group, has become one of the largest global licensors of melamine technology, with 21 plants worldwide using Eurotecnica's *Euromel* melamine technology, accounting for 750,000 t/a of capacity, or around one third of global production, including Qafco in Qatar, Methanol Holdings Trinidad Ltd, Hubei Yihua, Zhong Yuan Dahua and Petrochina in China, Grupa Azoty in Poland, Khorasan Petrochemical Co in Iran and Petrobras in Brazil. The company recently licensed two 60,000 t/a melamine plants to Henan XLX in Xinjiang, China.

Eurotecnica's process is a single stage liquid-phase, non-catalytic reaction. Ammonia and carbon dioxide are recycled to the upstream urea plant, and water is treated inside the process to be either recycled within the process itself or used as cooling water make-up, which produces a zero discharge process. The company claims that the process' simplicity and operability makes for a safe and reliable process generating high quality melamine. In the event of an upstream urea outage, the melamine reactor can be 'bottled in' and run at idle until urea is available again.

Lurgi/Air Liquide

Lurgi's melamine technology is a low pressure process with a gaseous quench. The company describes this as a "straightforward" process, with no water quench or drying unit, and hence no corrosion issues, no high pressure or complicated drying equipment and hence lower investment costs and low raw material consumption. The melamine produced has low water content (0.02-0.04%), small particle size and high purity (>99.9%), suitable for paint and coating applications.

The company began offering the technology in the mid-1990s, and over three generations of the technology has scaled up the process from its initial 6,000 t/d plant to offer 50,000 t/d installations. The company built 18 plants from 1995-2010 in China, with a combined capacity of 400,000 t/a, including three 50,000 t/a plants, and also designed Russia's only melamine plant, for Eurochem at Nevinnomyssk in Stavropol province, which also has a capacity of 50,000 t/a, and which was completed in 2012.

OCI

Egypt-based Orascom Construction Industries (OCI) bought DSM Agro and DSM Melamine in 2010. The company now produces 230,000 t/a of melamine at its locations in the Netherlands and China. The Dutch site is the main one, with 150,000 t/a of melamine capacity. The company has two main processes, one a high pressure gas-phase process, inherited via Melamine Chemicals, and the other DSM's original low pressure liquid phase, producing various grades of melamine accordingly. There is a larger particle size grade with 350 micron diameter produced in one of the gas phase plants, as well as a lower density 60 micron grade and a very fine 40 micron grade, all produced via the gas phase process. The shortened liquid phase plant produces a 180 micron grade.

Nissan and BASF

Nissan's higher pressure (100 bar) process operates with a liquid phase quench. The company operates a single 50,000 t/a plant at Toyama in Japan. BASF conversely has a low pressure process which it runs at its 65,000 t/a facility in Ludwigshaven, Germany. Neither company has licensed its technology for other producers.

NIIK

Russia's NIIK has inherited Soviet-era technologies for production of melamine, one using calcium cyanamide to produce dicyandiamide, which is then heated to produce melamine – this is in use at a 6,000 t/a plant in Armenia constructed in the 1970s; and the other a high pressure urea process based on the Montedison process, in operation in a 10,000 t/a at the same site at Kirovakan. Since then development work on the HP urea process has continued intermittently, leading to the launch of the company's own alkali melamine technology in 2011.

Melamine integration

With more melamine technologies becoming available for license, there has been increased interest in integration of melamine production with urea plants. The specifics of this of course depend on the type of melamine technology to be integrated into the urea process, particularly whether the process-off-gases are at high, medium or low pressure. The off-gases are generally at a lower pressure than the urea synthesis loop pressure, requiring condensation and then pressurisation to be brought up to syn-loop pressure. The condensation requires an amount of water to keep the ammonia and carbon dioxide in a liquid solution, and this can require additional water if a dry quench has been used in the melamine process.

Integration schemes have been presented in previous issues of *Nitrogen+Syngas* magazine, by Eurotechnica, Casale and urea licensor Saipem[3,4], which owns the Snamprogretti urea license. Formerly DSM's urea licensing division, Stamicarbon (now owned by Tecnimont) have also maintained the urea link with melamine technologies, and offer their own urea-melamine integration technology expertise. As part of DSM, Stamicarbon was one of the first companies to tackle the urea-melamine integration issue by developing a method of recovering the waste ammonia and CO_2 as ammonium carbamate, which could be directly reinjected back into the urea plant. These days Stamicarbon call this the *ADVANCE DESIGN*™ carbamate concentration unit (CCU).

Too much melamine?

Because the melamine market is growing faster (at about 5% per year) than the urea market (circa 2-3% per year), and because melamine prices have been higher than the relatively depressed urea market (which has seen a flood of urea on the market from Chinese producers), urea producers have been tempted to move into melamine production using the new more widely available melamine licenses. However, while the melamine market has been relatively buoyant of late, it does also suffer from some of the same issues as the urea market, which is a large glut of Chinese exports on the market.

One symptom of this has been anti-dumping action by the European Union – the second largest melamine market – against Chinese melamine. Anti-dumping tariffs of €415/tonne were imposed by the EU in 2011 and these ran for five years to 2016, at the request of Europe's largest manufacturers – OCI in the Netherlands, Borealis and Grupa Azoty. Even so, EU melamine consumption fell by 2.4% from 2010-2015, from 293,000 t/a to 286,000 t/a, and Chinese market share rebounded to 5% by 2015, while EU melamine output fell by 10% over the same period, from 311,000 to 279,000 tonnes. The EU has also faced increased imports from Russia since the start-up of the Eurochem plant in 2012. The EU is now considering whether to renew anti-dumping measures. Meanwhile, Chinese exports have also been moving in significant volumes into other markets like Turkey, Thailand and South Korea. As a result, given the significant quantities of unused Chinese melamine capacity, the scope for new melamine capacity outside of China remains an open question at present. ■

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Middle East gas and fertilizer outlook

Nelly Mikhaiel, Senior Consultant, and **Priyanka Khemka**, Consultant, Nexant, look at the Middle East's natural gas industry and its effect on nitrogen fertilizer production.

The Middle East is a robust gas consuming region, with fuel use almost doubling between 2005 and 2015 (Figure 1). Despite recent upward price adjustments in several countries in the region, energy prices are still below international levels, especially in Gulf Cooperation Council (GCC) countries, although they vary substantially across the Middle East. Historically, low domestic prices have incentivised greater gas consumption, and to that end, the Middle East is increasingly dependent on natural gas to fuel new power and desalination plants, to provide competitive feedstock for petrochemical projects and to produce metals. Regional consumption is driven not only by fast growing economies but also the wants and needs of a comparatively youthful population. According to UN (2015) data, the Middle East's population has a median age of 26.6 years, compared to an average of over 42 years in the economically-advanced Group of Seven (G7) countries. Looking ahead, Nexant expects that projected regional gas consumption will remain supported by the availability of gas at subsidised prices, despite some recent progress in phasing out subsidies in various countries, albeit from very low base prices. This sets the scene for significant gas consumption growth in the long-term.

Gas already occupies a prominent position in the regional energy mix, (just under 50% in 2015), but scope exists for additional penetration. The same trends that have governed regional gas consumption growth over the last decade remain in force: ample resource availability in several (but not all) countries; population growth; strong economic factors; urbanization; a boom in the industrial sector led by the rapidly expanding petrochemical business using gas as a feedstock; and policies that have kept end-user prices at relatively low levels. However, optimism must be tempered with the knowledge that not all Middle East countries will be willing and/or able to sustain subsidies for domestic energy prices in the long-term. The growing competitiveness of renewable energy sources in the power sector moreover poses increasing competition for natural gas, which may erode gas' share of this all-important segment.

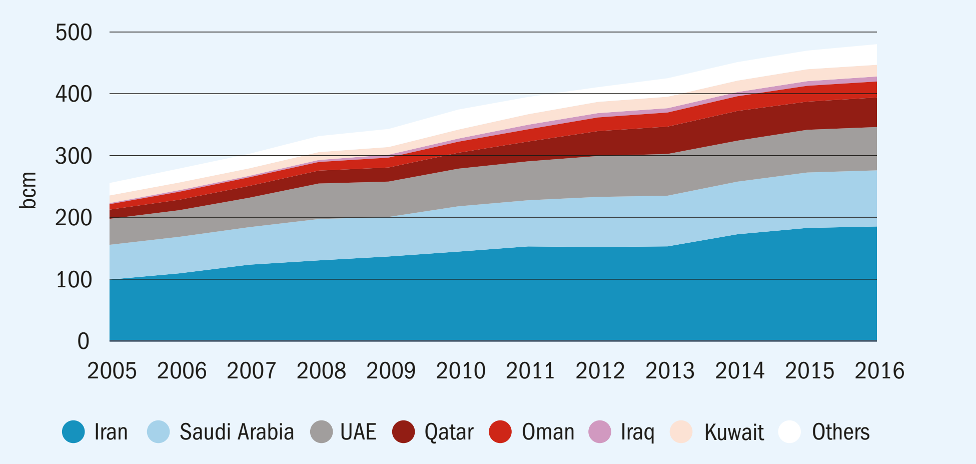
- According to Nexant's modelling, the power and industrial sectors account for a large part of forecast consumption growth by 2040. The power sector (including water desalination, where gas-fired plants combine power generation with freshwater production) almost doubles its gas use over the forecast period and accounts for almost half the region's gas consumption in 2040.
- Industrial gas use grows by almost 105 bcm per year, where switching away from oil is also a driving force.
- Middle East gas producers are conflicted between increasing gas prices to incentivise gas producers and reduce the resulting financial price subsidy burden and retaining the political support of industrial consumers whose business models are predicated on access to low-cost gas supplies. The Middle East's increased focus on natural gas is ultimately driven by the economics of oil as an export and also to some extent the use of cleaner fuel supplies.

Historic and projected gas supply

A common assumption today is that the Middle East has an abundance of readily available natural gas supplies; however, the reality is quite different. To date, the Middle East, which has 42% of the world's proved gas reserves (as of end-2015), has struggled to produce sufficient gas to meet its needs. This is attributable to several factors:

- The region's proved conventional gas reserves are unevenly distributed. While some countries in the region (e.g., Qatar, Iran, and Saudi Arabia) have significant deposits, others (e.g., Jordan) are gas-poor. Even countries with modest reserves endowments face supply problems (e.g., Bahrain and Oman): as oil-

Fig 1: **Middle East gas consumption, 2005-16**



Source: Nexant's World Gas Model. Historic data to 2015 only.

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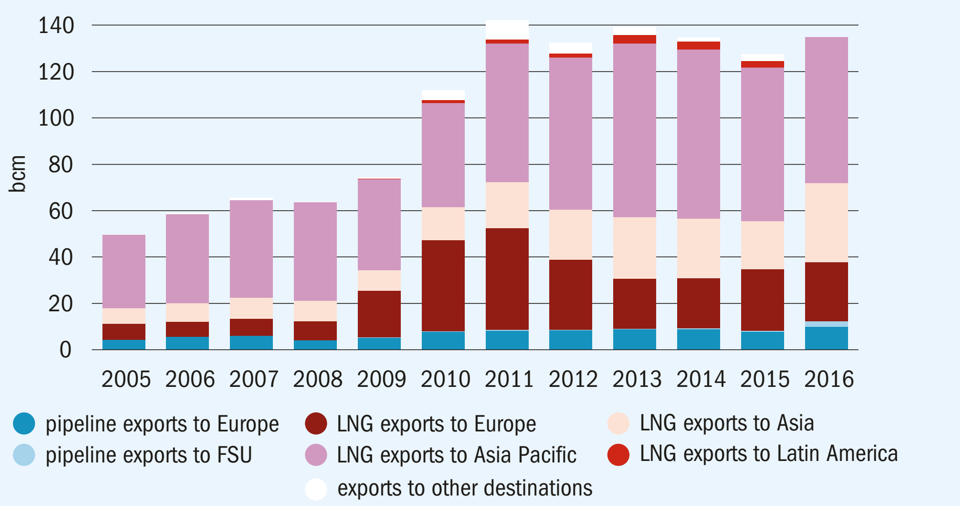
poor countries, they historically focused on gas as a means to develop their economies, and are already contending with production declines.

- Gas reserves do not translate to available gas supply, with Iran and Iraq being the most obvious examples. Iran's isolation from the global community until 2016 precluded the country from assuming the status of a large gas exporter, whereas Iraq's potential is constrained by political strife.
- Some of the region's gas supply is associated with crude oil. Reserves may not be available to supply domestic markets or export markets because production is dictated by crude oil production quotas (if applicable) and/or the need to re-inject gas to maintain current levels of crude oil production.
- Even countries with rich non-associated gas reserves are concerned about production sustainability. Qatar, which is the only Arab country not dealing with security of supply issues and is currently the world's largest exporter of LNG, imposed a moratorium on further North Field resource development in 2005, citing concerns about the effects of large-scale production on the reservoirs. This moratorium was only lifted in the summer of 2017.
- A decision taken in early June 2017 by Saudi Arabia, the United Arab Emirates, Egypt and Bahrain to impose sanctions on Qatar due to its perceived support for Islamic terrorism has not (as of June 2017) affected LNG flows from the emirate, or even Qatari pipeline exports to Oman and the UAE. Consequently, Nexant does not foresee a material long-term effect on regional gas movements.

Of the region's approximately 600 bcm of annual production in 2016, less than a quarter was exported to other global regions (Figure 2): aside from LNG export projects in Oman, Qatar, the United Arab Emirates, and Yemen, the vast majority is consumed within the region. Indeed, inter-regional gas imports have assumed increasing importance in the Middle East over the last several years. In addition to Iranian pipeline imports from the Former Soviet Union, the Middle East has assumed the status of an LNG import province, with receiving terminals operating in Israel, Jordan, Kuwait, and the UAE. The Middle East's seemingly incongruous rise as an LNG import province is testimony not only to gas' growing importance to the region, but also internal supply availability issues in certain countries. For example, Israeli and Jordanian LNG receipts were a response to unreliable and (ultimately suspended) Egyptian deliveries via the Arab Gas Pipeline, whereas a mismatch between the ramp-up of demand and new non-associated gas production ventures in Kuwait and the UAE account for the 2010 start-up of Arab Gulf LNG imports. Regional LNG deliveries totalled a provisional 8 bcm in 2016.

It is hoped that the ramp-up of new non-associated gas supply projects in Kuwait, Israel, and the UAE will eventually eliminate the need for LNG imports in these countries, but if production capacity additions fail to match demand increases, LNG imports will remain crucial to the region's supply mix. Moreover, there is scope for new LNG importers to emerge such as Bahrain, which needs LNG to compensate for declining output from mature indigenous sources. In Nexant's view, the Middle East will remain a modest but tangible import market for LNG going forward.

Fig 2: **Pipeline and LNG flows to/from the Middle East**



Source: Nexant's World Gas Model. Historic data to 2015 only.

Given the country's mounting LNG import track record over the past several years, it's unsurprising that the topic of shale gas in the Middle East has attracted considerable interest from companies operating in countries with limited conventional resources, as well as for countries with plentiful conventional resources that are costly to develop. Together, Jordan, Oman, and the UAE are estimated by Advanced Resources International (for the US Energy Information Administration) to host over 7.3 trillion cubic meters (260 trillion cubic feet) of wet technically recoverable shale gas resources, whereas third party estimates for Saudi Arabia are in the neighbourhood of almost 17 tcm (600 tcf) or more.

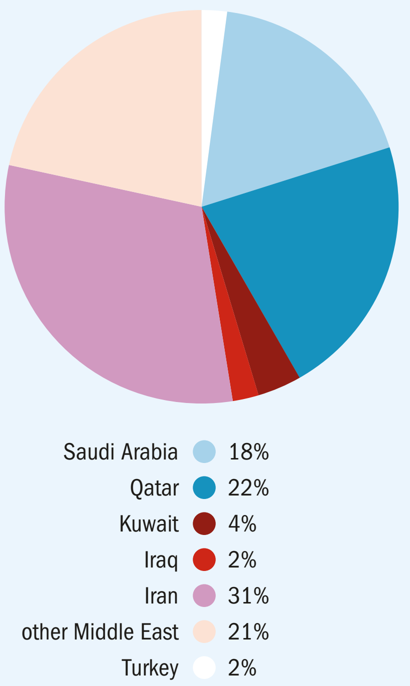
However, the costs of shale gas production must be weighed against the supply alternatives: if pipeline or LNG imports can be procured more cheaply, and promotes intra-regional trade and good-will into the bargain, this is a compelling option indeed. On the other hand, a concentrated focus on higher domestic gas output may prove more attractive in the long run. Several Middle East countries have domestic gas pricing regimes that are very attractive to consumers (owing to the presence of subsidies), which is an obstacle for gas-focused production programs. However, in the medium to long-term, gradual removal of price subsidies may provide incentives for increased gas production. This would also facilitate the imports of market-priced LNG and pipeline gas supplies.

For Middle East countries with both plentiful conventional gas reserves and high shale gas resource potential, however, the latter might not occupy a prominent role in the future gas supply mix. Producers with easily-accessible and cost-competitive conventional deposits may prefer to exploit these reserves instead of embarking on costly shale gas exploration endeavours that may or may not be successful.

Nitrogen outlook – historic production and exports

The Middle East is one of the largest producers of nitrogen fertilizers in the world, with an estimated ammonia production of close to 17 million t/a and urea production of 22 million t/a in 2016. The low cost of natural gas in the region and hence the low cost of production makes the construction

Fig 3: **Middle East nitrogen production capacity by country, 2016**



of export-orientated, integrated urea plants very attractive. Iran, Qatar and Saudi Arabia are the largest ammonia and urea producing regions within the Middle East, as shown in Figure 3. In 2016, the region exported an estimated 16 to 17 million t/a of urea; the second largest regional export volume in the world. Within the Middle East, Saudi Arabia is the largest exporter of urea followed by Iran, and Qatar.

Consumption

The region's fertilizer demand is relatively small, with an estimated consumption of about 5 million tons in 2016. The Middle East is largely an arid region, and the development of its agricultural sector has been hindered by many factors such as small farm sizes, weak infrastructure, soil deterioration, and water scarcity. Due to low precipitation levels in the much of the region, however, fertilizer use is critical to enhance agricultural production. Turkey and Iran account for more than fifty percent of urea consumption in the Middle East. Nexant believes that the Middle East's total urea demand will grow close to three percent per year up to 2025, faster than the one percent growth per year experienced in 2000 to 2016 period. The region's growing population and consequent food demand will drive regional growth for urea in the direct application segment, which accounts for about 80 percent of the total urea consumption in the Middle East. Iran's consumption, which accounts for one third of total urea consumption in the Middle East, is expected to grow close to 3.5 percent in the next decade, driven by rising export demand for various agricultural products.

Current and projected production/exports

Ammonia capacity developments in the Middle East have somewhat slowed down in recent years, from an average annual growth rate of seven percent between 2000 and 2012, to a 3% per year growth between 2012 to 2017 period. There have been no significant capacity additions in the Middle East in the past four to five years. This is attributable to various factors. For example, Qatar has not been able to expand capacity because of the moratorium on North Field development, which was just lifted in May 2017, whereas Oman is struggling with feed gas supply constraints that have even affected natural gas export volumes. The outlook for regional capacity growth is also affected by the prevailing global oversupply situation: capacity developments in other parts of the world such as coal based plants in China and shale gas based capacity developments in the United States have resulted in a global over supply situation. The incentive to invest in new Middle East production facilities in the near term is therefore not great.

On a delivered cost basis, United States Gulf Coast (USGC) producers are on par with Saudi Arabian suppliers of ammonia/urea into the USGC, thanks largely to the increased availability of competitively-priced shale gas. With the US less dependent on Middle Eastern imports, the onus is now on Middle Eastern producers to identify opportunities in other export markets – most likely in Asia, which Nexant considers to be the world's biggest demand growth market for fertilizers.

Middle Eastern exporters also face competition from North African producers in supplying the mature European market, since North African sellers enjoy a freight cost advantage due to their proximity to European outlets. However, some North African producers – chiefly Egypt – have experienced feed gas constraints of their own in recent years, necessitating supplemental LNG imports and the temporary cessation of LNG exports. This situation is not expected to persist, as Egypt brings the massive non-associated offshore Zohr field online; in addition, there have also been several new gas discoveries reported in the country in recent years, especially in the Nile Delta region. Together with the optionality of augmenting domestic production with natural gas imports from neighbouring Israel and even Cyprus, Egypt may considerably expand its fertilizer production and export base in the longer term, thereby posing additional competition for Middle East producers.

Iran poses additional competition for existing Arab fertilizer exporters in the Middle East, although its success would ultimately boost the region's profile as a source for volumes. The 2016 lifting of sanctions in Iran and various projected new capacity developments are strengthening Iran's net export position, which translates to stronger competition for current Saudi producers. In Saudi Arabia, Ma'aden is the only company that has started production at a new ammonia plant, with capacity of 1.1 million tons per year, in the recent years (in 2016) primarily to feed the Wa'ad Al Shamal phosphates complex. By contrast, some three to four million tonnes of new capacity is expected to come on-stream in Iran in 2017 to 2020 period. However, project activity may be delayed if Iran is unable to secure financing from foreign lenders. President Trump is in the process of reviewing US policy towards Iran, and the uncertainty this engenders is plainly not conducive to the financing of new ventures. Nevertheless, Iran is viewed as an attractive location by many external investors, such as Indian and Bangladeshi companies, who have indicated their interest in establishing export oriented production ventures there.

Even though the Middle East capacity is expected to grow slowly in the near term, it remains a major producer and exporter of ammonia/urea in the global market. The drop in global oil prices has reduced the returns on investments for manufacturers, but this has not eroded the Middle East's position as one of the largest urea export regions in the world. The pace of capacity development is expected to pick up post 2022 in Qatar and Saudi Arabia, as manufacturers begin to take advantage of the production from new gas fields: in addition to the lifting of the moratorium on Qatari North Field gas production, Saudi Arabia is in the process of expanding its natural gas production under the National Transformation Program (NTP 2020) that was approved by Riyadh in 2016. In Nexant's view, the Middle East will retain its position as the largest exporter of urea in the world, as regional capacity developments outpace consumption growth. ■

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

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Safety incidents

A look at recent safety incidents affecting the nitrogen industry.

PHOTO: REUTERS

The crater left by the Tianjin explosion, 2015.

In spite of its generally safe operation, the nitrogen industry continues to be plagued by accidents and safety incidents which lead to destruction of property, injury and even loss of life. Foremost among the chemicals of concern to authorities for their potential to cause risk to life are ammonia and ammonium nitrate.

Ammonia incidents

Because of the large scale of the ammonia industry and the toxic potential of ammonia vapour, ammonia incidents continue to be some of the most widespread and most serious in the chemical and other industries. According to a recent report by the US Environmental Protection Agency (EPA) District 7, 75% of all reportable chemical accidents in the four states it covers (Iowa, Kansas, Missouri, and Nebraska) involved anhydrous ammonia. As well as in agriculture, ammonia is making a comeback in refrigeration units as chlorine-based refrigerants are phased out under the Montreal Protocol and fluorinated hydrocarbons become restricted due to their global warming potential.

In spite of its familiarity with ammonia production and handling, the nitrogen industry is not immune from these kinds of accidents. For example, in August 2016, Petronas suffered an ammonia leak at its new Petronas Chemicals Fertiliser Sabah Sdn Bhd plant at Sipitang in Malaysia, leading to two fatalities and three other injuries. The contractors were carrying out maintenance work at the facility, which was still under construction at the time. The $1.9 billion Sabah Ammonia-Urea (Samur) facility has a capacity of 740,000 t/a of ammonia and 1.2 million t/a of urea. Although the full cause of the accident is not yet known, the five men were said to have been releasing gas from a pipe when there was an unexpectedly large release of ammonia at high pressure. The two dead men suffered severe burns and ammonia inhalation. Another worker was admitted to hospital; the other two men suffered minor injuries and were given outpatient treatment. The leak was brought under control within an hour.

Chittagong tank rupture

Also in August 2016, an ammonia tank explosion at the Di-Ammonium Phosphate (DAP) Fertilizer Company Ltd at Chittagong, Bangladesh led to 250 people being treated for ammonia inhalation, but fortunately without any fatalities. Fifty people were kept in hospital overnight. The facility is owned by the Bangladeshi government, via the Bangladesh Chemical Industry Corp (BCIC), and manufactured DAP in two trains with a combined capacity of 1,600 t/d. The facility has a 5,000 tonne 'mother' storage tank and two smaller 500 tonne tanks filled from this main tank which in turn feed DAP production. It appears to have been one of these smaller storage tanks where the explosion occurred, with 250 tonnes of ammonia being present in the tank at the time. Firefighters tried to dissolve the ammonia spill using water, albeit reportedly hampered by the inoperability of some fire hydrants following the accident, and it took 11 hours before the spill was completely cleared. Levels of ammonia vapour concentration in excess of the 500ppm ILDH ('Immediate Danger to Life or Health') level were recorded shortly after the beginning of the incident, and a toxic plume browned vegetation and killed fish in a pond beyond the factory perimeter. It appears that a worse disaster may have been averted by the wind direction carrying the ammonia plume away from a built-up area to the east of the factory and instead spreading it to the northwest, towards the Karnaphuli river and Patenga area in the port city. Residents of the Naval Academy, Chittagong airport, Chittagong port, Halishahar and Agrabad reported an acrid smell and were told to stay indoors.

An investigation by the local district administration found a catalogue of management and maintenance failures which contributed to the incident, according to local press reports. The two pressure indicator gauges on the tank had been inoperable for some time, and the condenser, safety valves and pressure vents were also out of order. The investigation also said that instead of skilled engineers, the reserve tank was being operated by a group of lower level employees who did not have any training. Local fire crews also lacked training and experience in dealing with such scenarios. The tank was built in 2006, by the China National Complete Plant Import and Export Corporation. It has been reported that there had been corrosion leading to significant thinning of the tank walls.

Revised EPA guidelines

In the wake of the ammonium nitrate explosion at West, Texas in 2013, president Obama ordered a review of US federal industrial safety regulations. So far, the main revision has come to the Environmental Protection Agency's (EPA's) Risk Management Program (RMP). RMP covers some 12,500 facilities that, according to EPA, reported 1,500 accidents over a 10-year period. These incidents involved nearly 60 deaths, 17,000 injuries, the evacuation of 500,000 people, and property damage of more than $2 billion.

The EPA has increased the frequency of its inspection of ammonia systems via a new National Enforcement Initiative which began in October 2016, selecting enforcement priorities based on identification of "national environmental problems where there is significant noncompliance… and where federal enforcement efforts can make a difference". Changes to the RMP include independent, third-party audits of companies after an accident or near-accident and consideration of inherently safer manufacturing approaches. There is also greater coordination with the OSHA based on a reasonable supposition that operators with poor worker safety are also likely to be breaching environmental standards. It would require regulated facilities to conduct root-cause analyses in the event of any 'near-miss' release of hazardous substances such as ammonia or chlorine. In addition, 'non-responding' facilities (i.e., those that currently rely upon local agencies to respond to releases) would face additional requirements and, in some circumstances, be required to develop their own emergency response system.

However, the rule specifies that implementation of safer approaches may only occur when 'practical', and its future under the Trump administration remains in doubt, as Trump's new head of the EPA, former Oklahoma Attorney General E. Scott Pruitt, has opposed the RMP overhaul.

Tianjin explosion

November 2016 saw court sentences handed down over the explosion which devastated the Chinese port city of Tianjin, killing 173 people in August 2015, including 80 firefighters, and injuring 800 others. Swiss Re insurers estimate that as well as the loss of life and injury to persons, the damage to property could amount to $2.5-3.5 billion, making Tianjin the largest single disaster in insurance terms in history other than the World Trade Centre terrorist attack in 2001.

The November sentencing saw jail terms imposed for 49 people, including managers and employees at Ruihai Logistics where the blast took place, and 25 government officials. The blast destroyed warehouses and nearby residential buildings and shattered windows up to 5 km away. The Tianjin No. 2 Intermediate People's Court handed a suspended death sentence to Ruihai Logistics chairman Yu Xuewei, after finding him guilty of bribing port administration officials with cash and goods worth 157,500 yuan ($23,300) for a hazardous chemicals license. Yu was convicted of illegal storage of hazardous materials, illegal business operations, causing incidents involving hazardous materials, and bribery, and also ordered to pay a fine of 700,000 yuan. His deputies and senior colleagues at Ruihai Logistics were handed jail terms ranging from 15 years to life imprisonment, while lower-ranking employees were given sentences of 3-10 years in prison. Tianjin Zhongbin Haisheng, a company that provided counterfeit safety evaluation papers to Ruihai Logistics, was also named a responsible party, and 11 of its employees jailed.

The investigation into the incident said that the explosion was due to a fire, started by nitrocellulose which had dried out due to damaged packaging and self-ignited. The fire then spread to other chemicals stored nearby, including flammable liquids and solids, and several hundred tonnes of ammonium nitrate being stored nearby, which broke down and detonated. Both chemicals were being stored without the requisite safety license.

As Tianjin and the Chittagong ammonia tank rupture have shown, promulgation of safety regulations is one thing, but effective enforcement can sometimes be another thing altogether. However, as our articles on pages 44, 48 and 51 in this issue indicate, the industry can do much to help itself by sharing experience and information on process safety incidents. ■

Formaldehyde-free urea granules

thyssenkrupp Fertilizer Technology (formerly Uhde Fertilizer Technology, UFT) has developed a new formaldehyde-free urea granulation additive with a performance that is comparable or superior to the benchmark urea formaldehyde and opens up new opportunities for extended applications for the urea product. **T. Krawczyk** of thyssenkrupp Fertilizer Technology GmbH discusses the health concerns around urea formaldehyde and reports on the development of the new alternative additive.

For more than three decades, formaldehyde has been known as a substance that can potentially cause cancer. Recent research confirms what has been suspected by most of its users. Over 80% of today's urea production, which exceeds 180 million t/a, is used as fertilizer. This fertilizer grade urea, granules and prills, is treated with formaldehyde, mostly applied as urea-formaldehyde precondensates (UF80, UF85).

An additive is needed in order to ensure certain process parameters remain stable over a long period of time, such as:

- controlled granule growth rate and limited dust formation during the production process;
- good product quality (crushing strength, dust and caking).

Although the formaldehyde is applied in the form of a precondensate in which most of the formaldehyde has already reacted with urea to form methylol urea, it still contains a substantial amount of free formaldehyde (usually more than 23 wt-%). Therefore extensive safety precautions are required in order to make handling safe.

The discussions about the toxicity of formaldehyde, its carcinogenic and mutagenic effect on humans and animals started in the early 1980s. However, the recent report on carcinogens released by the National Toxicology Program (NTP) of the US department of Health and Human Services in 2011 leaves no doubt with respect to the causal relationship between the exposure to formaldehyde and cancer in humans. A vast number of epidemiological studies have evaluated this relationship, including cohort and case-control studies of different professional groups. In particular, the National Cancer Institute (NCI) cohort of over 25,000 workers within industries producing or using formaldehyde indicates the coincidence between the occupational exposure to formaldehyde and nasopharyngea, sinonasal and lymphohematopeotic cancer risk.

While in the past formaldehyde was classified as "suspected of causing cancer", the International Agency for Research on Cancer (IARC) as part of the World Health Organisation (WHO) changed the classification of formaldehyde in 2011 to "may cause cancer".

The European Union has placed formaldehyde on the list of "substances of very high concern". These compounds have been listed in the "substitute it now" list (www.sinlist.org). The European Union wants such compounds to be replaced as soon as possible.

As a consequence of numerous studies and the evidence of coincidence of cancer and the exposure to formaldehyde, legal authorities and dedicated organisations have adapted their classification regarding the carcinogenicity of formaldehyde. Following the introduction of the GHS, the globally harmonised system of classification and labelling of chemicals, and its subsequent implementation within the American OSHA and the European CLP, there has been an even greater focus on the hazards of formaldehyde.

Although the carcinogenicity of formaldehyde is evident, different examinations also show that the carcinogenic effect depends on the level of exposure in terms of concentration and duration. In a study by the German Institute for Risk Assesment (Bundesinstitut für Risikobewertung BfR), it was concluded that at concentrations

Table 1: **Permissible exposure limits as defined by different authorities**

	Specification	mg/m³ (ppm)
USA (Occupational Safety and Health Administration – OSHA)	PEL	0.92 (0.75)
EU / Germany (TRGS 900)	PEL	0.37 (0.3)
USA (National Institute for Occupational Safety and Health – NIOSH)	REL	0.02 (0.016) *(10h-TWA)*
	IDLH	24.56 (20)
	CREL	0.12 (0.1)
USA (American Conference of Governmental Industrial Hygienists – ACGIH)	TLV-C	0.37 (0.3)

TWA: eight-hours time weighted average
REL: recommended exposure limit
CREL: ceiling recommended exposure limit
PEL: permissible exposure limit
IDLH: immediately dangerous to life and health
TLV-C: threshold limit value ceiling

Fig 1: **Reaction scheme for the formation of urea formaldehyde**

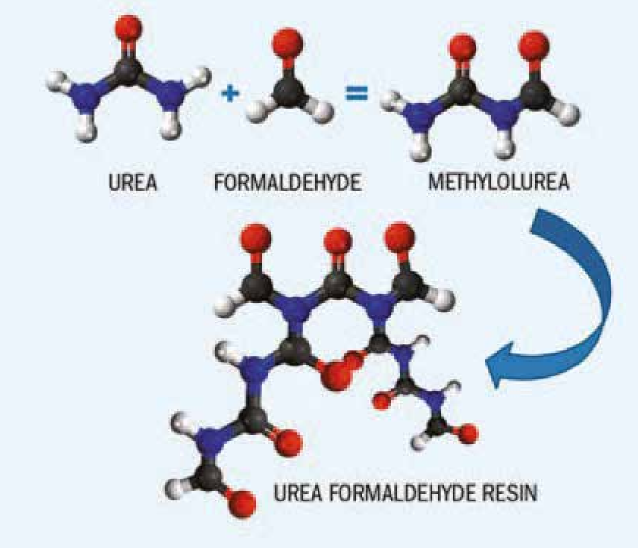


Table 2: **Comparison of product quality for urea granules treated with urea formaldehyde versus thyssenkrupp Fertilizer Technology's alternative additive**

	Treated with UFC (UF80)	Treated with alternative additive
Total nitrogen, wt-%	> 46.2	> 46.2
Biuret content, wt-%	0.7-0.8	0.7-0.8
Formaldehyde, wt-&	0.4	0
Alternative additive, wt-%	0	~ 0.2
Moisture, wt-%	0.2-0.3	0.2-0.3
Crushing strength, kg	4.1 on ∅ 3.15 mm	>4.1 on ∅ 3.15 mm
Caking tendency		same or less
Dust, %		same or less
Application	fertilizer	fertilizer, DeNOx, technical, cattle feed

below 124 mg/Nm^3 (0.1 ppm) the cancer risk is negligible. Conversely, it can be concluded, that a repeated, considerably higher or prolonged exposure to formaldehyde may potentially cause cancer.

Formaldehyde can be detected by its smell at concentrations of 0.07 to 0.12 ppm if the sensitivity for detection is not reduced as a result of prolonged exposure. This means that if formaldehyde is detected by smell then the concentration is already critical. Despite the difficulty of finding an appropriate threshold value for the exposure of a worker handling formaldehyde, the responsible authorities have adjusted the permissible exposure limits to accommodate the aforementioned findings as shown in Table 1.

In addition to the harmful nature of formaldehyde itself, there is an additional, often overlooked, limitation to the application of urea-formaldehyde precondensates for urea production. The formaldehyde is produced via the catalytic oxidation of methanol, therefore a certain amount of methanol remains in the UF solution (e.g. 0.1-0.3 wt-% methanol). Methanol is a volatile organic compound and will most likely be released during the granulation process contributing significantly to the amount of VOC emissions emitted to the atmosphere from the ammonia/urea complex. Local authorities may request these VOC emissions to be limited to very low levels.

In the past, the absence of an adequate substitute and a partially ambiguous classification of formaldehyde have limited the efforts to find a substitute for formaldehyde in the fertilizer industry, but that has now changed.

Effectiveness of a granulation additive

Before elaborating the route to such an alternative additive, it might be worthwhile to have a closer look at how formaldehyde acts as an additive within the fluidised bed urea granulation process. Formaldehyde is both a granulation aid, which plays a key role during the granulation process itself, and an additive resulting in the desired product quality parameters for transport and handling.

The mixing of urea with formaldehyde results in a eutectic mixture. Although the urea solution is completely mixable in liquid state, there is an immiscibility of the corresponding solid phases. At the eutectic point the corresponding melting point is the lowest possible within all possible mixtures of urea and the additive and its reaction products. The presence of such a eutectic point leads to a liquid film on the surface of the granule which ensures proper pickup of the sprayed material.

Furthermore formaldehyde reacts with urea to form methylol urea via polycondensation (Fig. 1). The nucleophile addition of the formaldehyde occurs at different locations which leads to a cross linking effect, that makes up the backbone of the latter granule. This gives the product the desired crushing strength and reduces the amount of abrasion dust.

Development of an alternative additive

The starting point for thyssenkrupp Fertilizer Technology's efforts to develop an alternative additive was the collaboration with a well-known and experienced specialist in the field of fertilizer additives: Holland Novochem. At first, different agents were tested on a lab scale with respect to their ability to act as a granulation additive for urea fluidised bed granulation. Only components which are not harmful to health or the environment were chosen.

After identifying the potential specific effects of the different agents with regard to the desired product properties (e.g. particle growth, dust, hardness), different components and mixtures were tested in thyssenkrupp Fertilizer Technology's batch operated pilot plant located in Leuna. With the data from the pilot plant trials it was possible to generate a database to carry out product design for the alternative additives in terms of the desired urea product quality.

Much lower dose of additive with much higher effect

In a second campaign the potential additive compositions were applied in different combinations and dosages and benchmarked against urea formaldehyde. As a result, an alternative additive has been found which is at least as effective as urea formaldehyde.

thyssenkrupp Fertilizer Technology's newly developed alternative is composed of different functional polymers in combination with a carboxylic acid. All of these agents are much less toxic (non-hazardous) and all of them have several FDA (Food and Drug Administration) approvals for direct and/or indirect food contact. The functional polymers are generally exempted from the European REACH programme due to their polymeric nature. The carboxylic acid is classified as a non-hazardous substance.

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

Table 3: **Requirements for automotive grade urea and values achieved with thyssenkrupp Fertilizer Technology's new alternative additive**

	Minimum	Maximum	Alternative additive
Urea content, wt-%	31.8	33.2	32.5
Density at 20°C, g/cm³	1.0870	1.0930	1.0903
Refracting at 20°C	1.3814	1.3843	1.3828
Alkalinity as NH_3, %		0.2	0.2
Biuret, %		0.3	<0.3
Aldehyde, mg/kg		5	<5
Insolubles, mg/kg		20	<20
Phosphate (PO_4), mg/kg		0.5	<0.5
Ca, Fe, mg/kg		0.5	<0.5
Cu, Zn, Cr, Ni, Al, mg/kg		0.2	<0.2
Mg, Na, K, mg/kg		0.5	<0.5

Fig 2: **Estimated development of future urea demand**

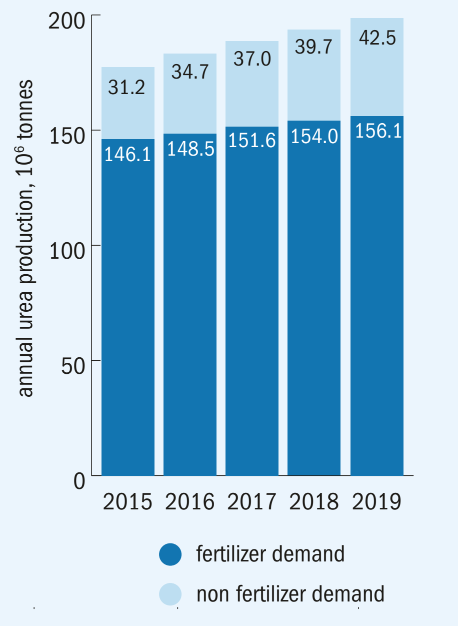
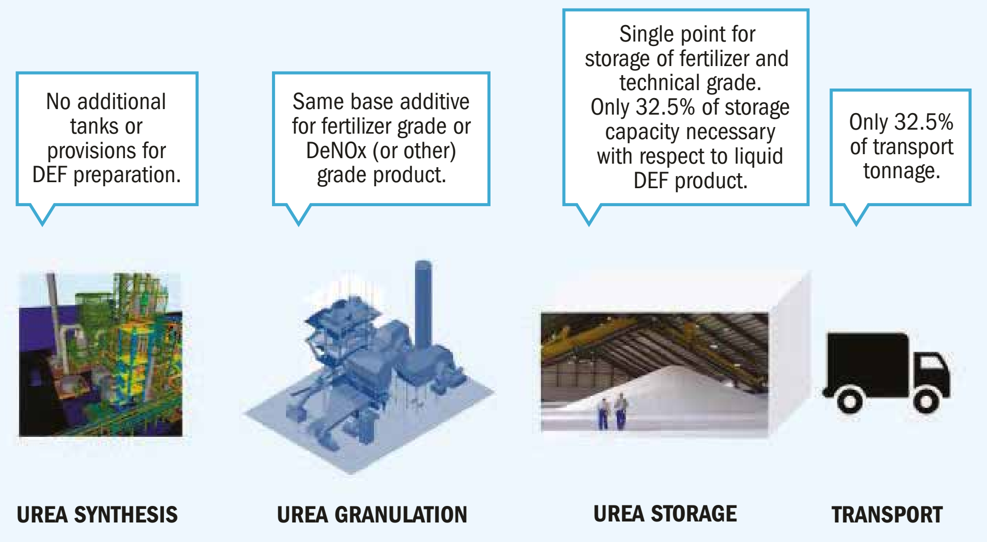


Fig 3: **Benefits of granules with extended application range**



The required dosage of the alternative additive that is necessary in order to achieve at least comparable product quality, as well as the same process parameters, is less than half that of formaldehyde. As shown in Table 2, the new alternative additive formulations are able to produce a granular urea product which shows at least the same product quality as is possible with urea formaldehyde. Furthermore, this product opens up additional fields of application not limited to fertilizer use.

Extended range of application

Fertilizer grade urea demand is steadily growing due to the fact that there is continual growth of the world's population and its standard of living (change in diet towards more meat). However, there is an even higher increase in the demand for non-fertilizer grade urea. IFA forecasts that non-fertilizer demand will account for almost half of the net increase of global urea demand, due to the increased usage for UF resins and DeNOx applications (see Fig. 2).

Due to stricter regulations concerning the emission figures for nitrogen oxides in all kinds of diesel engines the demand for diesel exhaust fluid (DEF), also known as AdBlue®, has exploded in recent years. The annual production of DEF used as a consumable for the selective catalytic reduction of nitrogen oxides accounts for approximately 2.3 million tonnes of urea. Its contribution to the global urea production in 2020 is estimated to be more than 4 million tonnes.

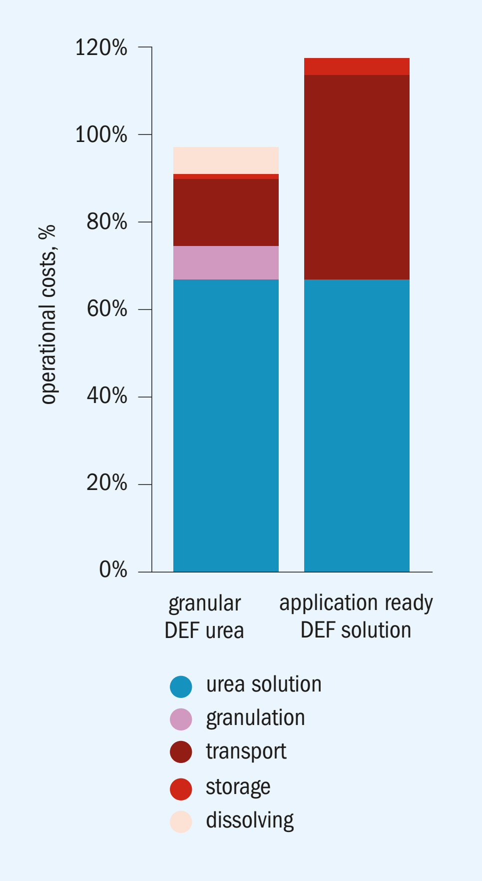
Currently the price for DEF solution on the US market is about $2.80 per gallon, which can be converted into a urea price of more than $2,000 per tonne assuming that the costs for deionised water can be neglected. In other words, the revenue for virtually the same product is ten times the revenue of a regular fertilizer product.

Product quality is the key for producers of fertilizer grade urea wishing to enter the DEF market. In order to comply with the requirements for urea as a raw material for DEF, the composition of the solid material dissolved in deionised water must fulfil the requirements of the norms ISO 22241 or DIN 70070. Ultimately all impurities or contaminants in the solid material will be present in the final DEF solution. Primarily, the main obstacle which producers have to overcome is to produce a product containing no more than 5 ppm of aldehydes. thyssenkrupp Fertilizer Technology's new alternative additive overcomes this challenge because it does not contain any aldehydes. Table 3 compares the urea product requirements for automotive grade with the results of granular urea product obtained by the application of the alternative additive.

Why deliver DEF in solid form?

Another major advantage of the production of DEF in its most reduced form, namely as a DEF compliant solid, which includes all benefits of a granular product with respect to the mechanical properties, is that the supply chain can be reduced to a minimum.

Fig 4: Production costs for DEF via granular urea and DEF solution



The application of the alternative additive is carried out by simple substitution of the content of the urea formaldehyde tank. As illustrated by Fig. 3 no additional equipment nor any other mechanical modification to an existing plant is necessary. In addition, there is no need for provisions e.g. tanks, piping, or instrumentation etc. for the production of DEF solution. In comparison to application ready DEF solution only a third of the tonnage needs to be stored and transported.

The final dissolving of the urea in deionised water poses the only minor additional step within the supply chain. During the Integer Emission Summit & DEF Forum in 2013 the feasibility of the route via a solid distribution has been evaluated and found to be the most cost effective. The costs for blending DEF from dry urea were mentioned to be very low and amounting to the range of 5 to 7 US cents per gallon.

Fig. 4 shows a comparison of the relative production costs for DEF starting from the urea synthesis normed to the cost for the preparation via DEF compliant granules. Obviously the difference in costs is directly related to the transport distance between production and final consumption.

Summary and outlook

The perception of formaldehyde has changed and the need for its substitution is stronger than ever. Producers of urea already face difficulties securing formaldehyde supplies, due to limitations caused by stricter regulations. Furthermore studies and national and global regulations unambiguously confirm that the banning of formaldehyde will turn a urea plant into a much healthier working place for operators. thyssenkrupp Fertilizer Technology's newly developed alternative additive provides urea granulation plants with an alternative to formaldehyde. In addition, it offers added value with urea product applications far beyond fertilizer applications, thus giving more flexibility to urea fertilizer producers. The envisaged next step is the industrial application of the alternative additive, which is carried out by means of a simple refill of an existing urea formaldehyde tank with the alternative additive that is harmless to humans and the environment. ■

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Introducing urea dry finishing

L. Postma and **M. Gori** of Stamicarbon present a novel finishing concept that eliminates dust and ammonia emissions, dramatically reduces utility consumption, halves the biuret content and allows flexibility in size and form of the final urea product.

Stamicarbon has an innovation programme in place that aims at facilitating the development of innovations in the field of fertilizers. Urea finishing is one of the key areas. Stamicarbon has already brought a number of innovations that boosted urea finishing operability, reduced operating expenses and cut dust and ammonia emissions down to levels that can be hardly measured, and many other ideas are in the pipeline.

Alternatives to formaldehyde: Alternatives are available but the arguments for it may sometimes be regarded as biased and subject to economical and marketing drives rather than to environmental or health concerns, the latter of which can be mitigated when taking proper care. An example may be found in the particleboard industry, where stringent regulations have pushed down the level of formaldehyde emissions to substantially lower levels than seen in common pinewood plank releases.

Dust: Emissions are a typical problem of all current urea finishing technologies. Stamicarbon is now at around 5 ppm. Do we need to do more?

Operability: Stamicarbon's granulation already features intervals between cleaning that are already three times those of the competition.

Purity: Biuret is sometimes regarded as an issue in both prilled and granulated products, but there is little that can be done, as it is brought by the chemistry of the urea reactions in the evaporation section. We know the chemistry, but we cannot change it.

So, we have to realise an important truth – prilling and granulation are mature technologies that can only be improved by small incremental innovations.

Dry finishing

Stamicarbon believes that the current urea finishing technologies have reached a situation similar to that of conventional urea melt technology back in the 1960s. Any incremental innovation will not change the essence of the technologies, nor will it dramatically reduce opex or capex. At the same time they may increase the complexity of the installations.

Stamicarbon's approach in similar situations has always been to wipe out the whiteboard and think out of the box starting from essential thermodynamics and chemistry. Stamicarbon did so in the 1960s, when it introduced the CO_2 stripping concept, a design entailing dramatic simplification of the urea process and a huge step forward in the reduction of steam consumption.

Now it is probably happening again, this time in finishing. Stamicarbon has developed a novel finishing concept that gets rid of dust and ammonia emissions, dramatically reduces utility consumption, halves the biuret content and allows flexibility in size and form of the final product by introducing the dry finishing technology.

The principle

In traditional urea finishing units (granulation and prilling), urea melt is crystallised and cooled by means of large volumes of (ambient) air. When vented, that air carries a significant amount of urea dust and ammonia. To conform to contemporary emission limits, the exhaust air must be cleaned. That requires a rather large air purification system, which consumes a large amount of power. Stamicarbon has now developed a method of producing a solid urea product which does not need these large amounts of cooling air and the corresponding cleaning systems.

The theory

The basis for the new urea solidification concept lies in the phase behaviour of the urea-water system, see Fig. 1, where: S denotes solid urea and solid water, compositions below the eutectic temperature (-11.6°C); L+S (H_2O) denotes liquid urea and solid water (ice); L+S (urea) denotes liquid water and solid urea; L denotes liquid urea and water and L+G (H_2O) denotes liquid urea and gaseous water (steam).

Fig. 2 shows how the phase diagram develops when plotted for decreasing pressures. Lowering the pressure makes the L+G – L line move down. If the pressure is decreased below a certain threshold, the diagram changes, and over a certain temperature region no liquid is present at any given composition. In this region urea

Fig 1: **Phase diagram for urea-water at 1 bar**

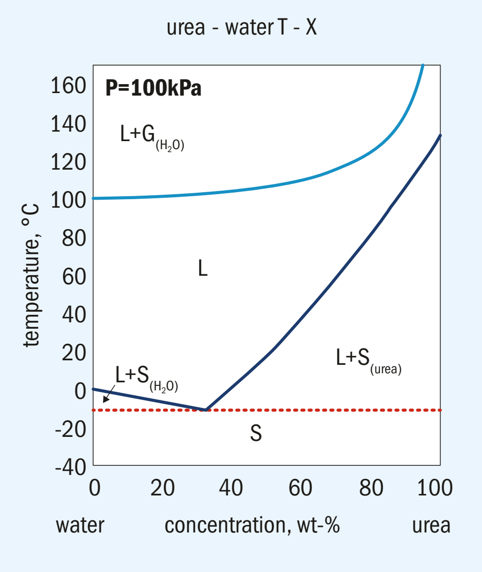
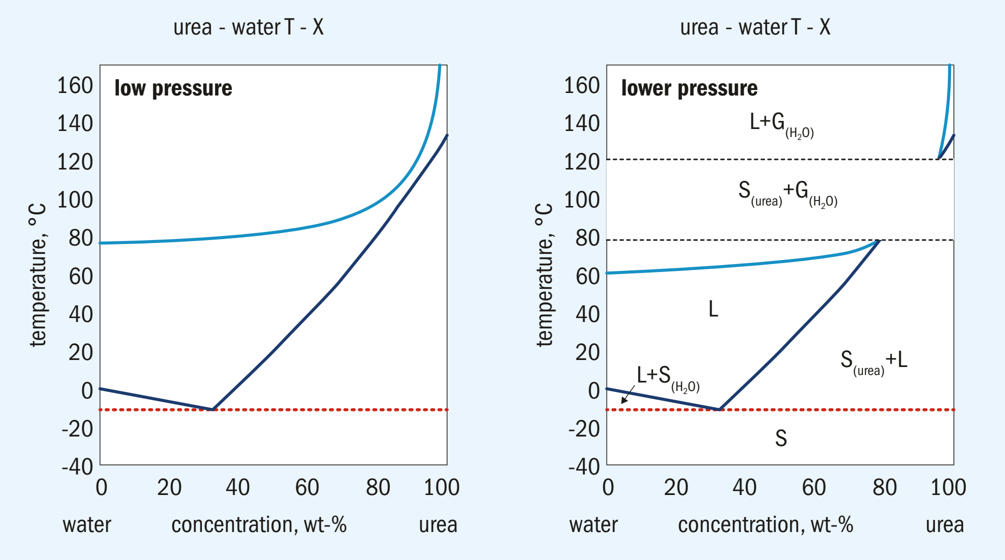


Fig 2: **Phase diagrams for urea-water at different pressures**



is present as pure solid and water as pure vapour (steam).

This behaviour of the urea water mixture can be used to separate water and urea by flashing a liquid urea-water mixture at a pressure below a certain threshold. According to the phase diagram, two phases will form: solid urea and water vapour. The lower the pressure, the wider will be the temperature range over which solid urea and water vapour occur.

If the flashing is done under adiabatic conditions, the heat balance will determine the temperature of the formed urea solid and steam at a given water concentration of the initial urea-water mixture. When a urea-water mixture is flashed at a pressure lower than the aforementioned threshold, all of its urea content will crystallise (releasing heat) and all of the water it contains will evaporate (consuming heat), whatever the initial concentration of the solution. From this it is clear that the concentration of the urea solution subjected to flashing is an important parameter controlling the process in the given S+G phase region. The heat and mass balance show that the urea solution only needs to be pre-concentrated to obtain solid urea crystals at a practical rate and thus only a mild degree of preliminary evaporation is needed.

Thus, the urea solution at the inlet of the sub-atmospheric flash will have only a low biuret content, and when the solution is flashed under reduced pressure, the crystallisation/evaporation process will take place almost instantly, so any increase in biuret content at this stage is negligible.

Could this behaviour be used in a commercial urea plant as the basis of a urea finishing technology which does not use air for cooling? Such a technology would reduce the losses from the finishing section to practically zero and would not require large and power-hungry cleaning steps such as (acidic) dust scrubbing. A further benefit would be the expected low biuret content of the solid urea product. To produce urea fertilizer using this method would necessitate a shaping step downstream of the dry flashing step to provide urea in a shape suitable for the fertilizer market.

Experiments

To develop the process, experiments were carried out to characterise the product produced by dry flashing and to determine how to control this process step. In a bench-scale setup (Fig. 3), batches of urea solution were prepared and flashed in a 100-litre vessel under controlled sub-atmospheric pressure conditions. The solution was prepared by introducing a predetermined weight of solid urea into a mixing vessel, which is heated via the jacketed vessel wall, and injecting the required amount of water. The urea solution was introduced into the flash vessel through a spraying nozzle. In this test the produced urea solid product was characterised at different process conditions (e.g. varying spraying nozzle, water concentration etc.).

The formed urea solid was analysed for water content, particle size distribution and biuret content. The particle size

Fig 3: **Schematic diagram of the experimental setup**

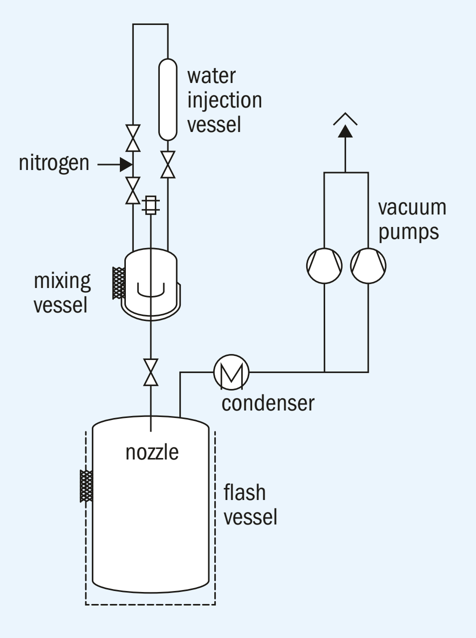


Fig 4: **Particle size distribution analysis**

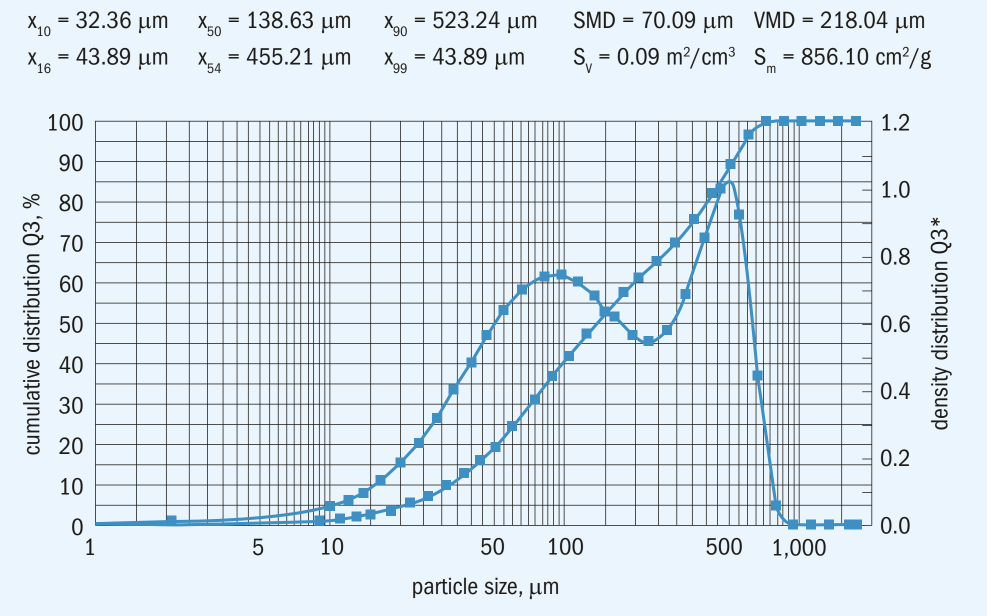


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Fig. 5: Solid urea from a flash experiment.

distribution and appearance of the solid urea produced are shown in Figs 4 and 5. The average particle size (d50) of the formed solid urea is in the order of magnitude of 100-150 µm.

The water content measured in the formed solid urea is always well below 0.3 wt-%. The inlet concentration, controlled by adjusting the pressure and temperature in the evaporator, and the pressure in the dry flash vessel determine the quality and temperature of the formed solid urea. The nozzle type and size are chosen to yield the required large average urea particle size, which is important in controlling the amount of solids entrained in the vapour leaving the flash vessel.

Process design

Based on those experiments, a design was worked up for the dry flashing process, as illustrated in Fig. 6.

In this process urea solution from the urea solution tank, containing typically about 78 wt-% water, is concentrated to the desired extent in a (classical) pressure- and temperature-controlled evaporator. The urea solution from the evaporation step is introduced into the flash vessel, where the pressure is kept at a sufficiently low sub-atmospheric pressure by means of a dedicated vacuum system. The solid urea formed is extracted from the flash vessel through a vacuum lock and is transported away for further processing.

The vacuum in the flash vessel is created by a combination of a contact condenser and ejectors and condensers (typical equipment for a urea plant). The purpose of the contact condenser is to deal with urea particles entrained in the water vapour leaving the flash vessel overhead. The overhead vapours from both vacuum systems (evaporator and dry-flash vessel) are combined and processed in the atmospheric absorber in the urea melt plant.

Fig 6: **Process flow diagram of dry flash finishing**

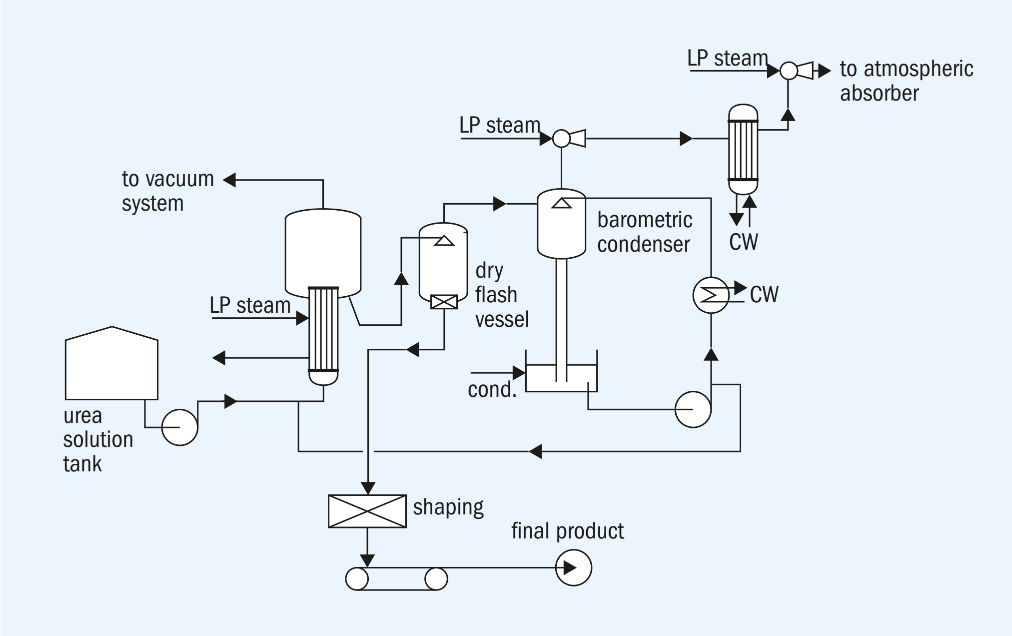
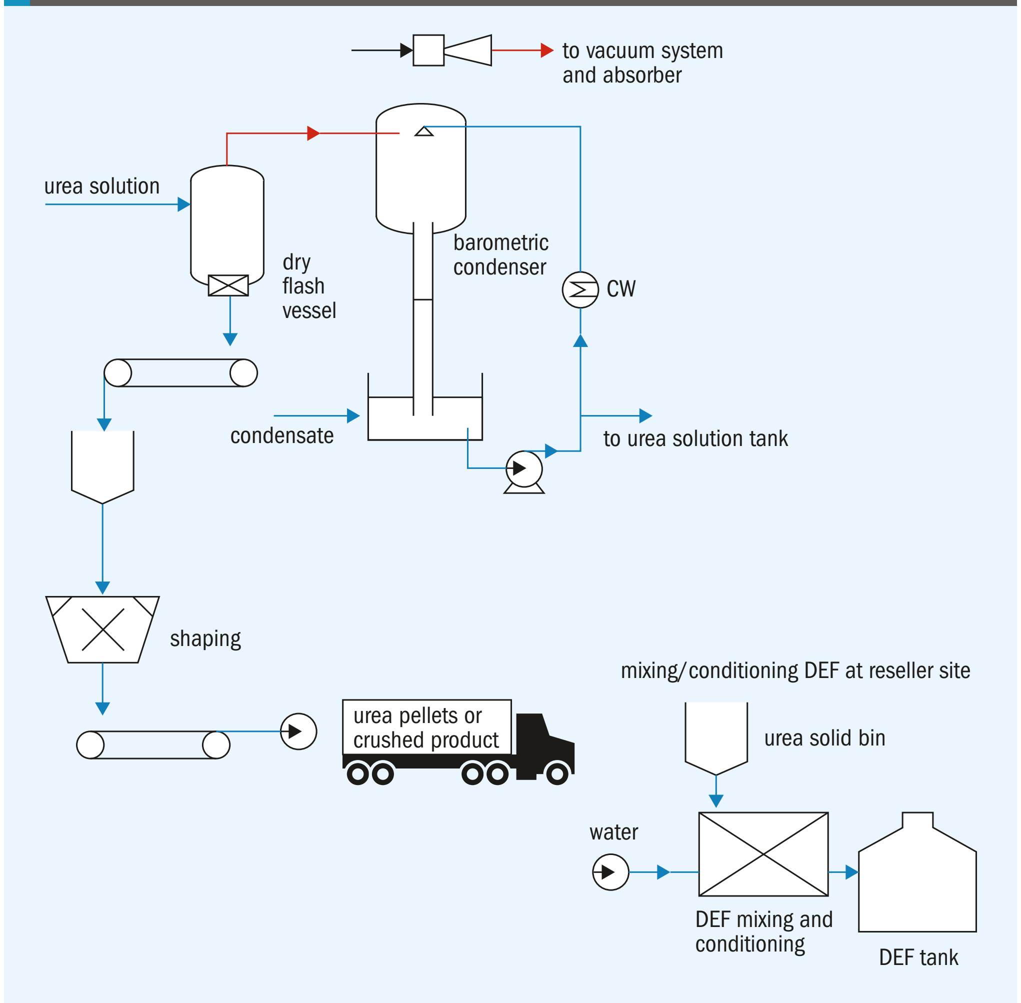


Fig 7: **Dry flash process for DEF production**



Dry flash for production of DEF (AdBlue®)

The dry flashing process produces low-biuret content urea particles that are perfect for producing diesel engine fluid (DEF), which is a 32.5 wt-% solution of urea in water, for the automotive industry. The advantage of such a process is that a solid urea product is produced which can be transported to the DEF reseller or distribution centre without transporting a huge amount of water. In the DEF distribution centre the urea is dissolved at the concentration needed to be used as DEF product. The production of solid urea product for DEF application is illustrated in Fig. 7.

Fig. 8: Urea super granules.

Dry flash for production of urea super granules (guti)

In some areas farmers use large-sized urea 'super granules' also known as guti urea (Fig. 8). These are currently produced by crushing urea prills and compacting the fragments.

The super granule has a slow release effect, which makes the urea fertilizer more efficient.

Guti production can be made more cost-effective with dry flashing, as the prilling and crushing steps are dispensed with (see Fig. 9). The super granules also have a lower biuret content than those produced from crushed prills.

The shaping unit for the super granules is a compacting machine in which urea powder is compressed into a chosen shape. A typical compactor is shown in Fig. 10.

Fig 9: **Dry flash process for production of super granules**

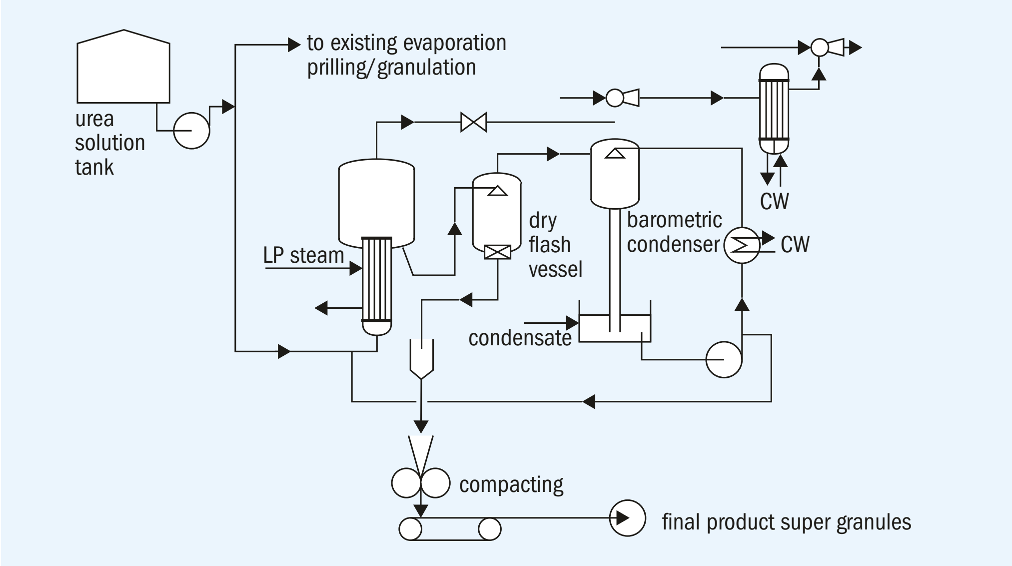


Fig. 10: Compacting equipment for production of super granules.

The future of finishing

The simple process flow diagrams presented in this article demonstrate the simplicity of the dry flashing technology with respect to conventional granulation. Low capex goes quite well with simplicity and indeed the investment for a full scale plant is expected to be just a fraction of the investment for a granulation plant. Add to this low utility consumptions, no emissions and significantly higher product quality because of low biuret, and it becomes clear why Stamicarbon believes that dry finishing may revolutionise the world of fertilizers.

Indeed, the ultimate goal is to produce fertilizer-grade urea with this dry flashing technology. The produced urea should be of comparable or superior quality with respect to the currently available granulated product in terms of caking tendency, crushing strength, composition, etc. On top of that, the fertilizer-grade urea product should be produced in sufficiently high quantities per production unit.

The urea solidification section is part of the traditional urea 'melt' plant and the solid finishing is limited to the shaping of the solid urea product into a form that is comparable to currently available prills and granules. The urea finishing process thus comprises only the shaping step and needs no cleaning steps in order to minimize emissions.

Experiments are in progress to develop a shaping process for urea product for bulk fertilizer application and it is expected that such a new urea finishing process for large industrial-scale fertilizer application will be launched to the market at the end of 2018. Stamicarbon welcomes the cooperation of fertilizer producing companies on this revolutionary advance in technology.

Conclusions

- Dry flashing opens up the possibility of a zero-emission (dust and ammonia) finishing technology for fertilizer-grade urea.
- The product of the dry flashing technology can already be used for the production of DEF (AdBlue®) and other applications such as super granules (guti).
- The dry flashing technology is perfectly suited for expanding the capacity of urea plants where the existing finishing section is loaded to its maximum or emission legislation does not allow further capacity expansion.
- Dry-flashed urea contains very low concentrations of biuret, allowing it to be used in other applications besides ordinary fertilizer.
- Dry flashing will reduce capex required to produce urea
- Dry flashing will open up new possibilities because it becomes possible to tailor the shape, size and properties of urea particles in accordance to all the specific requirements.

Rotating equipment integrity and protection

Steam turbine compressor trains represent critical process bottlenecks for the ammonia industry. **Mark Jackson** and **Stephen McGhehey** of FM Global discuss loss prevention engineering solutions as part of a successful risk management strategy to reduce the frequency and severity of a breakdown.

Rotating equipment in the ammonia industry creates critical process bottleneck exposures which impact the availability and continuity of operations. A compressor and/or driver (steam turbine, gas turbine, motor) breakdown can result in a production shutdown with extended downtime until the equipment is repaired or replaced and put back into service. This rotating equipment includes synthesis gas, ammonia, air and refrigeration compressor trains. A breakdown of these compressor trains can also result in a loss of containment and release of oil and/or process gases, resulting in a fire and/or explosion, damaging the equipment and building, including adjacent compressor trains. This exposure can be mitigated through a combination of effective asset integrity programs including: condition and performance monitoring to reduce the frequency of a breakdown; adequate safety devices to monitor equipment and alarm and/or trip to reduce the severity of operating conditions outside the equipment and process integrity operating windows; operators fully trained to standard and emergency operating procedures; viable equipment contingency planning and sparing to reduce the breakdown severity; and adequate sprinkler protection to control the fire due to loss of containment.

The effectiveness of these loss prevention solutions to reduce the impact of a breakdown to maintain plant availability, reliability and resilience is demonstrated by loss history.

Loss history

FM Global and industry loss history demonstrates that steam turbine compressor train breakdowns can result in significant business interruption with the potential for loss of containment resulting in a fire. The following loss example and loss history illustrates this trend.

A 1,600 t/d ammonia plant suffers loss production for nine months due to a mechanical breakdown of the synthesis gas steam turbine driven compressor resulting in a lube oil fire. The compressor train (22 MW) had a mechanical breakdown of a geared coupling between steam turbine stages (intermediate and high pressure) due to loss of lubrication. The geared coupling failed catastrophically, severing the lube oil lines. The intermediate steam turbine went into an overspeed condition. The overspeed protection system tripped the turbine. The released lube oil ignited after contact with the hot steam turbine surfaces, resulting in a large, three-dimensional fire that spread from the operating floor down to the basement, where a pool fire formed. The fire continued to burn out of control for 35 minutes as the lube oil pumps continued to operate, feeding fuel to the fire. By the time the pumps were manually shutdown, the entire oil holdup in the main lube oil tank (10,000 litres/2,641 gallons) was consumed in the fire. The compressor trains received lube oil from a common, single lube oil system.

Physical damage was sustained to the steam turbine, compressor, building structure and roof, electrical switchgear and associated support systems. There was no sprinkler protection on the synthesis compressor train or the adjacent trains in the compressor building. There was sprinkler protection around the lube oil skid, which had to be manually tripped as it did not operate. The critical path for restoring operations was inspection and repair of the compressor train which had to be shipped out for repairs. Adjacent compressor trains required inspections for damage.

Dedicated lube oil skids for each compressor train reduce the single point of failure exposure created by a single lube oil system for multiple trains. The ability to remotely isolate lube oil systems in the event of a fire reduces the fire exposure present by shutting off the fuel source. The gross loss was $136,000,000 (property damage and business interruption).

An analysis of FM Global's compressor loss history from a recent ten-year study showed the fertilizer industry represented 10% of the loss frequency (number of losses) and 34% of the gross loss severity (property damage and business interruption).

Mechanical breakdown was the leading loss driver with over 50% of the loss frequency. From these losses, over 32% resulted in a fire following due to the release of lube oil and/or process gas.

An analysis of FM Global's steam turbine loss history from a recent ten-year study showed the fertilizer industry represented 1% of the loss frequency and 11% of the loss severity. Mechanical breakdown was the leading loss driver according to this loss history.

Process hazards

Elements of process safety are leveraged to mitigate rotating equipment hazards. Process knowledge determines equipment design, integrity operating windows, damage mechanisms, failure modes and safety devices. Process hazard analysis is performed to identify, evaluate and control process risks, including risks from normal and emergency operating modes.

Key hazards of the steam turbine compressor train include:

- surge, vibration and thrust;
- misalignment;
- loss of lubrication/rub;

- temperature/pressure excursions;
- corrosion/erosion/fouling;
- fatigue/stress;
- overspeed.

Equipment protection

Safety devices to trip dynamic compressors based on equipment manufacturer and industry standards can include the following protective functions:

- surge;
- high differential pressure across process gas inlet filter;
- low process gas intake pressure at each stage;
- high discharge temperature from each stage and/or compressor;
- high vibration;
- high temperature in thrust bearings pads or high axial deflection (reduced thrust-bearing clearance);
- high temperature at bearing oil drain or in journal bearing metal;
- low lube-oil pressure at lubricated equipment bearing;
- high oil temperature leaving oil cooler (to bearings);
- low level for each seal-oil overhead tank or low seal oil differential pressure for each seal oil level.

Safety devices to trip steam turbines based on equipment manufacturer and industry standards include the following protective functions:

- overspeed;
- thrust and journal bearing axial/radial position;
- thrust and journal bearing high temperature;
- low oil pressure – emergency lube oil pump;
- low oil level in the tank;
- high temperature in thrust and journal bearings;
- high and high-high boiler drum water levels;
- condenser low vacuum.

Asset integrity

The asset integrity program plays a crucial role in ensuring rotating equipment integrity and reliability throughout the life cycle. Effective asset integrity programs verify that the equipment and associated systems are adequately designed, installed, operated, maintained and protected for the intended service. Damage mechanisms and failure modes the equipment can experience throughout the life cycle are identified.

The inspection, testing and maintenance program at the core of asset integrity is developed to detect and evaluate the anticipated damage mechanisms. Condition and performance monitoring combined with trended inspection data are analysed. Fitness for service and remaining life are evaluated as the equipment is service aged.

Key elements of the inspection, testing and maintenance program include but are not limited to the following:

- safety devices/protection systems;
- surge systems;
- vibration;
- instrumental/controls;
- lube oil/seal oil/control oil systems;
- stationary and rotating elements;
- shafts/couplings/bearings;
- steam turbine overspeed system;
- steam admission and extraction/non-return valves;
- intercoolers/aftercoolers;
- stator guide vanes (axial);
- control/isolation valves;
- piping systems;
- installation/mounting.

Surge protection systems, including anti-surge/control, bypass, bleed/vent valves and associated controllers are recommended for inspection and testing every two years. This time-based interval should be evaluated based on operating data including condition monitoring results, operating history, process parameters and equipment manufacturer recommended practices. Annual calibration of instrumentation, including pressure/temperature transmitters is recommended.

Lube oil system pumps are recommended for testing quarterly. Systems with a separate emergency lube oil pump should be tested in accordance with the equipment manufacturer's recommendations based on the system configuration, but at least quarterly. As part of this testing, pump operation is confirmed by checking the outlet pressure, motor amperage or other means as appropriate. Pressure sensors and low level alarms in the reservoir require testing and calibration in accordance with the equipment manufacturer's recommendations at least annually. Where a pressurised or gravity-type rundown tank(s) is used to supply emergency lube oil, tank low-level alarms should be tested at least annually.

For steam turbine overspeed protection systems, electronic systems have a higher degree of reliability as compared to mechanical bolt systems. Depending on service aging, operating conditions and maintenance history, mechanical bolt systems can be more susceptible to not functioning as designed. Part of the risk reduction strategy for this equipment includes evaluating upgrading mechanical bolt systems to electronic.

Electronic overspeed systems are recommended to be tested annually by a simulated test. For mechanical bolt overspeed systems, annual functional testing is recommended. Given the potential hazards with shutting the process down and decoupling the steam turbine from the compressor to conduct a functional overspeed test for mechanical bolt systems, including stresses on the turbine impacting remaining life, condition-based solutions are recommended to be fully implemented to reduce the risk. This includes: compressor train safety devices are installed, maintained and functioning properly; condition and performance monitoring with results trended to demonstrate operations are within the equipment/process integrity operating windows; favourable operating history, conditions and environment; asset integrity programs with acceptable inspection, testing and maintenance results trended over the equipment life cycle; trained operators to documented standard and emergency operating procedures; contingency planning and sparing for key components. Upgrading mechanical bolt systems to an electronic overspeed system based on a redundant, fail-safe 2oo3 voting logic design will improve reliability.

Exercising of steam admission valves (i.e. throttle trip valves) and non-return valves (where so equipped for exercising) verifies operational integrity of these safety devices. Weekly exercising is recommended, considering condition monitoring results.

Dismantling, inspecting and refurbishing of steam turbine emergency stop (steam shut-off) valves, governor (throttle) valves, and steam extraction line non-return valves is recommended on a five-year interval, or as necessary based on historical valve operation and operating conditions/results from the condition and performance monitoring.

Steam turbine and compressor dismantle inspections for time-based programs are as recommended by the equipment manufacturer. Time based intervals of seven years are recommended (or equivalent operating data). Condition and performance monitoring results require evaluation to fully assess dismantle inspection scope and intervals.

Condition and performance monitoring

As part of the asset integrity program, condition and performance monitoring evaluates process parameters as compared to the equipment manufacturer's guidelines. By detecting and trending deficiencies as they occur, degradation that can lead to adverse operating conditions and breakdowns can be prevented.

Monitoring typically includes operating conditions such as starts/stops, load, capacity and efficiencies. Pressures, temperatures, gas composition, power, lube oil/seal oil, steam temperature, pressure, flow and purity are trended. Flows and speeds (corrected for inlet temperature and pressure) and pressure ratios should be plotted on the compressor map with surge margins trended. Steam turbine thermal performance and steam path conditions can identify the factors contributing to deterioration. Fixed vibration instrumentation measurements at critical points on the compressor train and/or manual readings are taken and trended to develop a vibration signature for the train.

Operators

Operators with adequate system and equipment knowledge who are well-trained to established standard and emergency operating procedures can significantly reduce the frequency and severity of rotating equipment breakdowns. An effective training programme will help ensure operators are adequately trained to reduce the potential for errors to occur in response to normal and/or emergency/upset conditions. As demonstrated by loss history, operator competency and the actions they take are critical to ensuring the safe operation of equipment and processes. Operator actions can make the difference between minor and major damage to equipment resulting in the shutdown of operations and significant business interruption.

Equipment contingency planning and sparing

The ability to recover from an unplanned outage of rotating equipment and restore operations is vital to maintaining the resilience of site processes. As demonstrated by loss history, viable equipment contingency planning and sparing can reduce production downtime in the event of a breakdown. The scope of sparing as part of the plan can include complete spares, (on or off site), critical spare parts (on or off site), and/or built in redundancy. In order to be considered viable, spares require proper storage and maintenance as part of the asset integrity program to ensure viability and availability of the spares when needed.

Fire hazard analysis

Given the exposure created by loss of containment in the event of a rotating equipment breakdown and release of oil and/or flammable gases, part of the solution to mitigate this hazard is to conduct an oil fire hazard assessment (OFHA) to assess the risk. The OFHA evaluates the compressor train oil fire/flammable gas fire hazard. An OFHA is a detailed engineering review of the oil systems, building/construction features, potential release, fire scenarios, corresponding fire protection and emergency response planning to mitigate the hazard, case by case. This approach can be leveraged during initial design of new facilities as well as for the evaluation of existing installations.

Fire hazards

Several distinct fire hazards with different attributes expose compressor trains. These hazards, in combination with differences in types of equipment, construction features and potential fire areas present unique equipment damage potentials, downtime consequences and fire hazard exposure and protection challenges.

To understand the oil fire hazard and develop solutions, a comprehensive series of tests were conducted at the FM Global Research Campus. A mock turbine pedestal and lube oil tank skid were constructed. Spray, three-dimensional and pool oil fire scenario tests were performed utilising a range of sprinkler protection design options and oil flow rates to determine the best solutions for the risk.

Oil spray fire – Potential for oil spray fires from high pressure lube, control, or seal oil systems exist for most compressor trains. Although oil spray fires can develop at pressures as low as 20 to 30 psig (137 to 207 kPag), FM Global uses 50 psig (345 kPag) as the lower threshold for spray fire potential. Typically, the control oil pressure for a compressor train is well above 50 psig (345 kPag), presenting a spray fire potential. Lube oil pressures are typically lower and may not present a spray fire potential. Oil spray fires are the most intense and difficult to control of all the types of oil fires (Fig. 1).

Three-dimensional oil spill fire – Three-dimensional spill fire hazards (oil falling through the air while burning) exist from the oil piping systems. Oil not consumed in this fire can collect at the floor level forming a pool fire (Fig. 2)

Fig. 1: Oil spray fire test.

Fig. 2: Three-dimensional oil spill fire test.

Fig. 3: Oil pool fire test.

Oil pool fire – Oil leakage from piping, tanks, or compressor train collecting on the ground or operating floor presents a pool fire potential. Pool fire areas are defined by the boundaries of any containment features (Fig. 3).

This testing found that deluge sprinkler systems can be effective in controlling spray fires and in controlling or extinguishing oil pool fires.

Synthesis gas jet fire – There is a potential for this flammable gas to leak at high pressure from the process piping system and/or compressor. Ignition is relatively easy, resulting from self-ignition as well as static discharge, sparking, friction, and other low energy ignition sources. The jet flame can extend for many metres depending on the pressure and characteristics of the opening.

Synthesis gas explosion – Delayed ignition of a syngas release inside of a building can result in an explosion. Extinguishing a syngas fire without stopping the gas flow may create a building explosion.

Emergency shutdown procedure during a fire

The single most important emergency procedure during a compressor train fire is to promptly shut off the fuel source. Emergency shutdown procedures should address both syngas and all oil sources. Shut down initiating controls should be remote from the compressor train fire areas. Arrangements where controls for lube oil pumps are only located in compressor buildings is not recommended, as the buildings may not be accessible during a fire scenario.

Common rundown times for steam turbine driven compressors can be only a few minutes depending on the equipment design. Soon after oil pumps are turned off the spray fire will decrease in intensity as the oil pressure decreases. Once a spray fire dies out from lack of pressure the fire may continue as a three-dimensional spill fire. This fire can be fed from oil in piping and any rundown tank(s). A pool fire will exist after oil spillage stops until the pool burns out, is drained and/or extinguished.

The type of seals (dry vs. wet) impacts the emergency shutdown procedure. Machines with wet seals must have the system in service longer until the syngas loop is depressurised. Use of dry seals allows for quicker shutdown of the lube oil system.

Training and drills for personnel to document emergency shutdown procedures are recommended.

Detection

Heat detection is the least expensive and most reliable form of fire detection for a compressor building or train. Spot or line type detector systems are typically used. UV/IR flame detectors are also common. These detect a fire much quicker but are limited to line of sight, tend to be more expensive and have a reputation for nuisance alarms. Smoke detection is typically not used due to the harsh conditions. Highly sensitive smoke detection systems can provide extremely fast notification, detecting smouldering fires other systems may not.

Containment and emergency drainage

Emergency drainage is effective in reducing the oil fire hazard area to the minimum possible and reducing the magnitude and duration of any pool fire in the contained area. Emergency drainage should be considered for solid operating floors and ground floors where oil accumulation is possible. Floor slope should be continuous under compressor trains. Drains, which can become clogged with debris, floor low points, or sumps should not be under compressor trains as this can create an extended oil pool fire in an undesirable location. Drainage should accommodate the anticipated fire protection water application plus a safety factor.

Containment alone is inferior to emergency drainage. Although limiting the fire area, containment creates an opportunity for a longer duration pool fire. Sprinkler protection can be used in combination with containment. A foam-water sprinkler system is the recommended option when containment is present in lieu of emergency drainage.

Fixed water based protection

There is no better way to provide quicker, more accurate, effective, and reliable application of fire protection water than with an automatic sprinkler/water spray system. Manually activated fixed sprinkler/water spray systems are a less desirable alternative as they are subject to human error, resulting in delay of activation and potentially decreased effectiveness. Other forms of automatic fire protection systems are either expensive, not as reliable, and/or present personnel safety hazards and are not viable alternatives to water based systems.

A combination of directional water spray protection and conventional automatic sprinklers is the best arrangement. Directional water spray nozzles are ideal to protect bearings where an oil fire is likely to originate. Conventional automatic sprinklers are provided beneath the operating floor to protect the oil pool fire scenario below the compressor train. Another application for automatic protection are lube oil reservoirs, pumps and at the ceiling level. Directional water spray nozzles protect structural steel, both for the building and any cranes.

Water mist

Water mist systems are special protection systems for protection of enclosures for specific hazards including process equipment. Examples include combustion turbines and machinery in enclosures. The effectiveness of water mist must be proven by fire testing on the specific hazard. Water mist systems should be approved or listed for the intended application.

Foam water systems

Although not effective on spray or three-dimensional spill fires, aqueous film forming foam (AFFF) can extinguish an oil pool fire significantly quicker and more reliably than a system delivering water only. A foam water system is recommended where containment is provided in lieu of emergency drainage or where the water supply capacity is limited.

Manual firefighting capabilities

Different levels of manual firefighting capabilities are appropriate for different cases. The minimum necessary capabilities and systems include a reliable fire protection water supply satisfactory for firefighting hose streams, well-spaced fire hydrants and monitor nozzles, a properly trained and equipped firefighting team and effective pre-fire plan.

Equipment arrangement

A well-designed layout/arrangement of equipment in compressor buildings can limit fire damage. Support systems and equipment should be located as much as possible outside of defined fire areas. Adequate space separation should be provided between compressor trains so a fire affecting one will not severely affect other trains.

Water on compressor trains

Damage to hot steam turbine or compressor by properly designed automatic sprinkler or deluge sprinkler system is not considered a significant hazard. FM Global loss history shows no significant losses where fire protection water application to steam turbines or compressors has been a contributing factor. ■

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- 13-3 – Steam Turbines (2014)
- 10-8 – Operators (2016)
- 7-101 – Fire Protection for Steam Turbines and Electric Generators (2013)

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Worldwide catastrophic urea incident analysis

Fatima Fertilizer Company Limited has collected data for major incidents in urea plants worldwide for the last 50 years. The root cause for each accident has been analysed and lessons to be learned noted and used to check that suitable safeguards are in place at Fatima Fertilizer. **Syed Munawar Zaman** of Fatima Fertilizer reports on the data gathered and the excellent safety record achieved at Fatima Fertilizer.

Fatima Fertilizer is the largest fertilizer plant in Pakistan. The fertilizer complex is a fully integrated production facility located at Sadiqabad, Pakistan, with facilities to produce two intermediate products (ammonia and nitric acid) and three final products: 500,000 t/a of urea, 450,000 t/a of calcium ammonium nitrate (CAN) and 375,000 t/a of nitro phosphate (NP).

The urea plant is based on Stamicarbon Urea 2000plus® technology and has an original design capacity of 1,500 t/d. The engineering and procurement of the plant was carried out by Kawasaki Heavy Industries, formerly Kawasaki Plant Systems, from Japan, while construction was carried out by CNCEC from China. After finalisation of the contract between Kawasaki and Fatima, basic engineering was started in late 2006.

The plant was commissioned successfully on March 16, 2010 and after three months of smooth operation the plant performance tests were successfully carried out. Soon after commissioning and the performance test, the plant achieved 110% load of its design capacity. The efficiency and reliability of the plant has proved to be outstanding.

The plant has the following key features and advantages compared to conventional urea plants:

- CO_2 stripping process;
- pool reactor technology;
- no carbamate condenser;
- low NH_3 to CO_2 reaction;
- no MP section;
- hydrogen removal from CO_2;
- fewer items of equipment;
- superior corrosion resistant material (Safurex);
- flexible plant operation;
- minimum emissions;
- optimised N/C ratio.

Stamicarbon Urea 2000plus® technology employs a pool reactor operating at 145 bar pressure. The process comprises a synthesis section, a LP recirculation section, an evaporation section and a process condensate treatment section. There is no MP decomposition section.

Safety performance at Fatima Fertilizer

The safety record of Fatima Fertilizer is outstanding. The current total recordable incident rate (TRIR) of the complex is zero with 38 million safe man-hours. There have been no lost time incidents reported at the complex in the last five years.

Fatima Fertilizer has adopted the best available safety systems. HSE at Fatima Fertilizer Company is based on a sound 'safety management system'. An excellent foundation has been built based on structures (committees and sub committees), solid procedures for critical safety activities, and investment on training of management and staff and leverage of various business management processes such as performance management.

Process safety management by DuPont was initiated by Fatima Fertilizer Company in 2013. With management commitment and robust safety systems, Fatima Fertilizer was awarded a rating of 3.6 by DuPont in their external audit conducted in May 2015. This year Fatima Fertilizer is committed to achieving the excellence level (Rating 4) by DuPont in their external audit which is being planned for November 2017.

Data gathering, analysis and safeguards

Fatima Fertilizer has collected data for major accidents in urea plants worldwide for the last 50 years. The root cause for each accident has been analysed and lessons to be learned noted (see Table 1).

Of the major accidents there were: 8 incidents of explosions in the scrubber vapour line, four incidents of reactor ruptures, three incidents of HP pump failures, two incidents of HP piping failure, one incident of an explosion in an ammonia water tank and two incidents of stripper bottoms rupturing.

The extensive analysis was carried out as a means to check that suitable safeguards are in place at Fatima Fertilizer. Following a detailed evaluation it was concluded that the urea plant at Fatima Fertilizer is adequately protected and the risk of a catastrophic incident occuring at the plant has been reduced to the minimum.

Table 1: **Details of world-wide incidents and evaluation of safeguards at Fatima urea plant**

Year	Incident description	Root cause and consequence	Safeguards at Fatima urea plant
1967 1969 1971	Explosion in scrubber vapour line	Due to pure oxygen dosing, the vapour line mixture reached the explosive range and caused an explosion with hydrogen. **Consequence:** 2 people injured and serious damage to equipment.	Hydrogen convertor installed to remove hydrogen; air supply instead of pure oxygen.
1989	Release of ammonia	High pressure ammonia pump failed (fracture of crankshaft) causing a major ammonia release in a closed building. **Consequence:** 2 people killed and ammonia released to 17 km.	Preventative maintenance plans in place; remote isolation of pump available to immediately isolate pump from ammonia receiver.
1991	Rupture of high pressure heat exchanger	This was caused by improper fabrication of this heat exchanger by the manufacturer. The failure resulted in a major ammonia release. **Consequence:** 11 people killed and a major ammonia release.	Proper design and regular inspection of HP vessel available.
1992	Heavy ammonia release resulted in death of 10 people on the spot	A stand-by ammonia pump was blocked in for maintenance on the PSV of the pump. In this plant, only a single block valve was installed for isolating the ammonia pump from the rest of the plant. The plant was in normal operation mode. Whilst the PSV was removed, the suction valve of the ammonia pump was tightened because a slight leakage was suspected. As the operator tried to tighten the valve, its yoke bush gave way and the spindle became free. **Consequence:** 10 people died.	Double block and bleed protection at ammonia pump available at Fatima plant.
1992	Rupture of urea reactor	A liner leakage in a urea reactor caused severe corrosion of the carbon-steel pressure parts of the reactor. The leakage was detected by the leak detection system, however the operating personnel did not respond to these warning signs. Ultimately the reactor ruptured, causing a major ammonia release.	Leak detection system is available with blockage test frequency; standing instructions issued to operator to stop plant when indicated by LDS; leakage less likely with Safurex.
1998	Rupture of HP scrubber	Hidden weld defect in a liner of a urea scrubber caused leakage of this liner, resulting in severe corrosion of the carbon steel pressure part of this scrubber. The leakage was not detected by the leak detection system, since this system was not operational. Ultimately the scrubber ruptured, causing a major ammonia release and severe damage to the scrubber and its direct surroundings.	Leak detection system is functional; Safurex material less likely to leak; regular inspection by Stamicarbon experts.
1999	Explosion in ammonia water tank	Hydrogen containing urea synthesis off-gas inadvertently entered the ammonia-water tank via the liquid let down line of an atmospheric absorber, During flange welding at one of the control valves at the ammonia water tank outlet, the tank exploded. **Consequence:** Tank damaged and some serious injuries reported.	Zero hydrogen is ensured in syn loop; hot work permit protocol is followed to assess risks.
2000	Ammonia release	A minor leakage (pinhole) was observed on a welding point of a thermowell on a HP line, when a leakage was being inspected. The welding failed causing a major ammonia release. **Consequence:** 4 people were killed, 5 people injured.	Safurex material has better corrosion resistance; thickness monitoring regime available for HP lines.
2005	Reactor rupture	The leak detection system of a urea reactor was operated with steam as purging agent. Impurities present in the steam accumulated in the layers of the urea reactor, causing stress corrosion. The urea reactor ruptured as a result of this. **Consequence**: 4 people died, 32 people injured and major damage to plant.	Leak detection system is equipped with instrument air for purging; standing instruction issued not to use steam for purging.
2008	Ammonia release from HP ammonia pump suction line	The weld joint of the common suction line of HP ammonia feed pumps failed and caused a significant ammonia release. The leak was sealed by means of a clamp in 2007. In January 2008 it had leaked again and sealing compound was re-injected. 2 weeks later the weld fully snapped off. **Consequence:** Significant release.	Temporary repairs are avoided and, if required, must be time bound.

Continued on page 50

Table 1 continued: **Details of world-wide incidents and evaluation of safeguards at Fatima urea plant**

Year	Incident description	Root cause and consequence	Safeguards at Fatima urea plant
2009	Ammonia release	A drain line in the synthesis section ruptured. The entire content of the synthesis was released through the ruptured line into the environment. Fortunately, there were no personnel accidents. The rupture was caused by weakening of the line from erosion corrosion caused by stagnant carbamate in the drain line being present in the drain line over a longer period of time. This stagnant carbamate was present here because of a leaking valve.	Double isolation on synthesis drain line; Safurex material; flushing procedure to keep drain line packed with condensate.
2010	Rupture of ammonia pump discharge pipe	Line was in bad condition as a result of corrosion, caused by (repeated) inadvertent back-flow of corrosive fluid (ammonium carbamate solution) into the ammonia pumping system. **Consequence:** piping damage and one fatality due to ammonia suffocation.	Thickness monitoring regime implementation; NRV at ammonia inlet to scrubber to avoid back flow.
2013	Rupture of urea reactor at CF Medicine Hat Canada	During shutdown condition, ingress of CO_2 due to passing of the isolation/control valve resulted in an exothermic reaction in the reactor and a temp rise. As a result, the passivation layer was damaged and active corrosion started. The leakage was not detected by the leak detection system due to a malfunction of the analyser. Rapid corrosion resulted in the rupture of the CS portion. **Consequence:** severe damage to reactor and shutdown of plant for 2 months.	Depressurisation or stopping of CO_2 compressor during shutdown; monitoring/logging of reactor conditions during shutdown; ensuring functioning of LDS system; Safurex material requires less passivation.
Near miss incidents with high potential consequences			
2015	Leak in a liner weld resulting in severe corrosion	A leak occurred in a liner weld which was not picked up by the leak detection system (LDS). The unnoticed leak created severe corrosion in the pressure shell in a very short period of time. The observation of crystallized product on the insulation cover sheeting triggered plant management to put the plant out of service. This was just in time, since further corrosion of the carbon steel could lead to catastrophic failure of the urea reactor in a relatively short time. **Root cause:** welding defects resulted in leak, but not picked by LDS as it was not working properly.	Latest leak detection system; pressure transmitter and ammonia sensor of leak detection system to immediately report leakage; blockage test at certain frequency.
2016	Leak in an HP pool condenser resulting in a cracked weld	A leak occurred in the HP pool condensor which was noticed by the steam conductivity measurement. Poor steam quality had caused erosion and large cavities in the carbon steel tube sheet under the SS overlay weld. The overlay weld had been pushed into the cavities by the process pressure. This deformation caused the tubes of the hairpin to strongly bend close to the overlay welds and finally causing a cracked weld. The cavities which existed could have weakened the tubesheet to such extend that catastrophic failure would follow. The cavities are unrevealed failures. Fortunately a leak in the weld triggered a shut down.	Conductivity analyser available to ensure steam quality; Safurex material and regular inspection regime.
Near miss incidents with high potential consequences at Fatima urea plant			
2009	Bulging in HP stripper	During commissioning, pressure test of leak detection system was performed at 7 bar against design of 1 bar of leak detection system which resulted in bulging in HP stripper liner, There was possibility of damage to pool reactor as well, this was early detected otherwise could result in catastophic failure during plant start up.	Strict compliance of procedure not to exceed pressure of more than 1 bar in leak detection system if loop is not pressurised.
2009	Acid ingress in lube oil of CO_2 compressor	Chemical cleaning of the LP steam drum (V-904) was in progress with acetic acid. Nitrogen at 5 bar was being introduced through the bottom via a hose pipe for mixing purposes. Due to the repeated use of nitrogen, its pressure dropped to 1 bar at the utility header and acetic acid flowed back into the nitrogen utility station resulting in contamination with acetic acid. Nitrogen was being used in the compressor lube oil system so there was ingress of acetic acid into the bearings resulting in severe damage to the compressor bearings/seals.	What-if analysis is now done for any chemical cleaning.

Conclusions and major lessons learned from catastrophic incidents:
✓ Ensure prompt response of leak detection system; ✓ Install hydrogen convector and control hydrogen content; ✓ Replace pure oxygen with air in HP loop; ✓ Ensure fitness of HP equipment through inspection regimes; ✓ Ensure fitness of HP piping; ✓ Double block and bleed during maintenance intervention; ✓ Follow MOC protocol; ✓ Importance of quality of workmanship and provision of installation procedures

Stamicarbon launches HSE portal

Stamicarbon is inviting urea manufacturers to help build a urea incident database that all can benefit from. By sharing experiences the industry can learn from past incidents and near misses to gain a better understanding of the risks within urea production facilities and to improve plant safety. **H. Jorritsma** of Stamicarbon discusses the importance and potential benefits of the new incident sharing HSE portal.

Catastrophic events in process industries are categorised as "low-probability, high-consequence occurrences" and receive a lot of media attention. But history teaches us that even these major events will be forgotten with the passage of time.

Effective incident investigation, reporting and follow-up are necessary to achieve a safe operational environment. Incident investigations provide the opportunity to learn from reported incidents and to use this information to take corrective action designed to prevent them from recurring. It is essential to translate learning into design practices and operational practices.

All of the international design standards that have been developed and form the basis for Stamicarbon's current safe plant design have been derived largely from experience of incidents.

If you can use the mistakes of the past to avoid future errors, you have a good chance of staying in business.

At the moment a higher-consequence accident takes place at a facility, the majority of the plant personnel is either directly or indirectly involved. Their involvement can range from participating in an incident investigation team, implementing corrective actions or, in the worst case, being directly impacted by the accident. Especially when co-workers are severely injured or killed, the impact on the organisation is profound and everybody will understand the necessity of effective safeguards and operational practices.

It is essential to formally embed what we learn from these incidents in design practices and operational regimes to prevent similar incidents from reoccuring.

Problem statement

In the current global industrial environment new process safety challenges can be identified which are different from those of the past. These developments might introduce new risks which have not been experienced before, but also decrease the effectiveness of the learning organisation.

> **"If you can use the mistakes of the past to avoid future errors, you have a good chance of staying in business.**

The following are some of the most relevant challenges:

- When small companies consolidate into larger ones, their centralised oversight function may lack the capacity to maintain previous standards of oversight at individual sites.
- On the other hand, decentralisation of corporate functions can force sites to operate according to standards that they set themselves. This narrows the experience base and diminishes corporate memory.
- Reductions in work forces stretch the remaining manpower with much the same effect as decentralisation.
- Frequent merging and demerging of companies increases the possibility of buying assets or operations with risk exposures that are not well understood.
- The increasing age of many facilities and the extension of asset life beyond the original design intent increases maintenance needs and may lead to failure modes that were not foreseen over the expected lifetime of the asset.
- Strong emphasis on personal safety behaviour does not necessarily improve process safety performance.

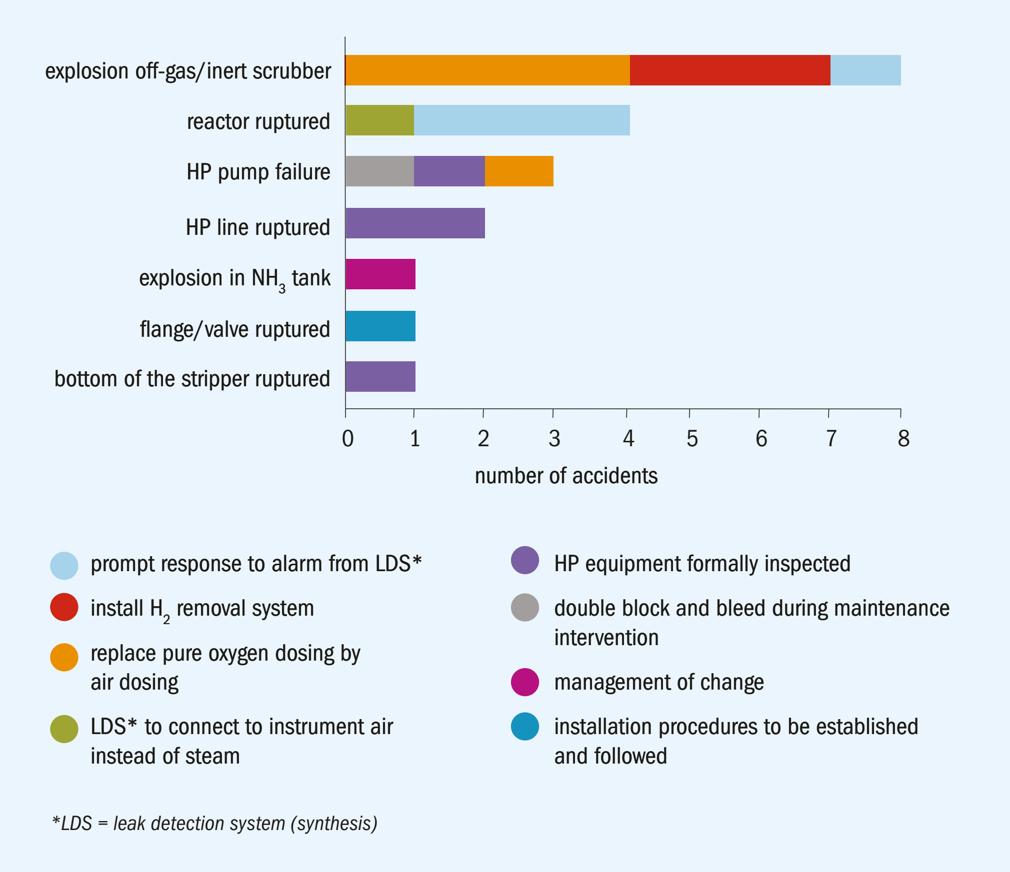
These developments cannot be stopped; they are inevitable in the globalised market in which we operate. But it is important to be constantly aware how these developments can endanger the safety performance of individual manufacturers or facilities. This emphasises the necessity for collaboration across the urea fertilizer industry to document process safety events and share these with each other.

Learning from incidents

As far back as 48 years ago, Stamicarbon realised that recording major process safety accidents in urea facilities would enable it to subsequently improve its process design. Besides capturing the data, Stamicarbon also played a leading role in the root cause analysis of the majority of these events. In Fig. 1 the major accidents, as known by Stamicarbon, are expressed in a bar chart accompanied by the relevant lessons learned.

Eight of the 20 accidents (in the period 1967 to 1981) were related to hydrogen explosions.

Fig 1: **Urea accident vs learning effect**



The lesson learned was to replace pure oxygen dosing by air dosing and to provide the CO_2 supply with a hydrogen removal unit.

In plants where both control measures have been implemented no explosion has ever taken place. Learning from past incidents does pay off!

Currently the database contains the details of 20 major accidents. The question is whether this very limited number of data points provides sufficient input to meet the objectives in Stamicarbon's mission statement. Can we identify common causes and failures of barriers (preventative measures) and correct these failings before a high-consequence incident actually takes place?

The fact is that before a severe incident happens we usually receive a lot of warnings (see Fig. 2): A barrier may have failed but the final unwanted consequence did not occur because another barrier worked in its place.

First let us start with some definitions:

- An incident can refer to any event – big or small, good or bad, intentional or unintentional.
- An accident (a sub-set of incidents) is an unintentional bad event caused by error or by chance. It occurs when a barrier (see below) is penetrated and the hazard affects the vulnerable object (people, environment, property) causing damage.
- A near miss (a sub-set of incidents) occurs when a barrier is penetrated but the vulnerable object is not present or is not affected (see schematic representation of a near miss in Fig. 3).

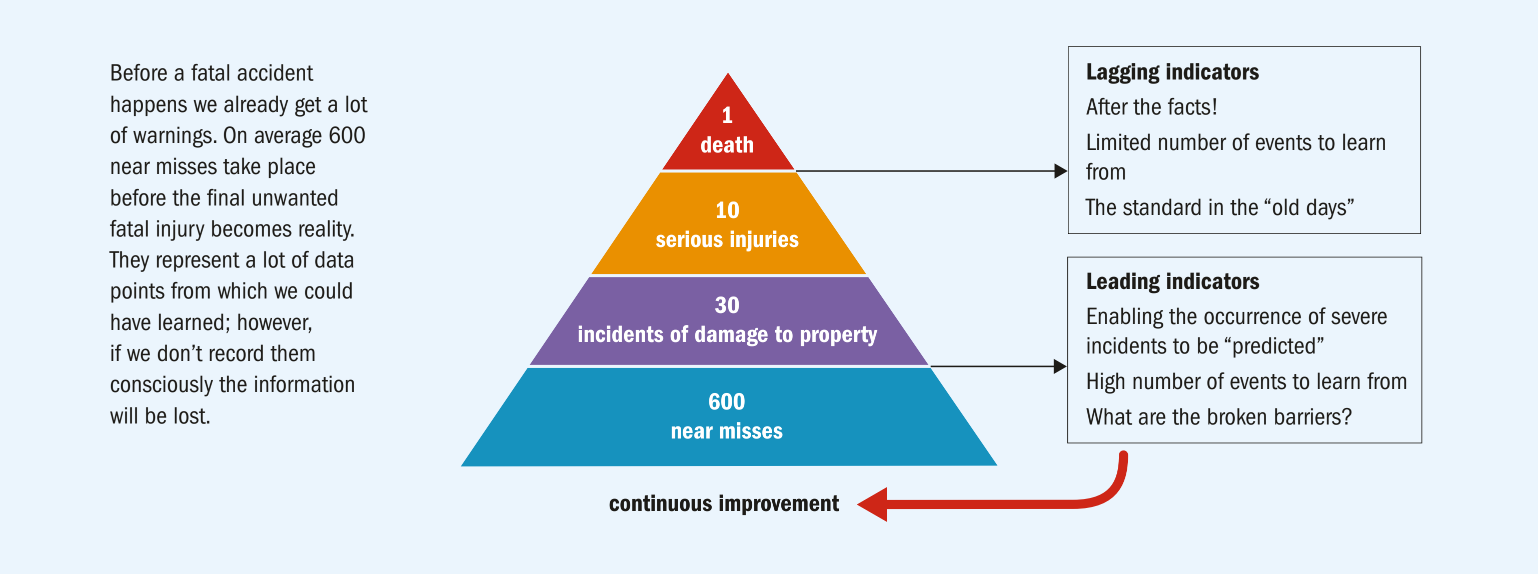
The essence of near-miss management stems from the fact that accidents typically have a history of warning signs that are leading indicators or precursors of major events (Fig. 2). For every accident there are many more near misses. Their main causes are unsafe practices and conditions resulting from at-risk behaviour. In the past, plant owners did not see the added value of investigating near misses. Everybody focused on the high-consequence events like fatal injuries, fires and explosions.

Why should we record and investigate incidents and near misses?

- To identify and strengthen key barriers between hazards and vulnerable objects which are less than adequate and have allowed the incident or near miss to happen.
- Only when we know the broken or lacking barriers can we improve!

Also, incidents with a lower consequence or even near misses, provide us with valuable information. They tell us something about the protective barriers which were broken.

Fig 2: **Incident pyramid and the importance of leading indicators**



The same broken barriers can also lead to major events in less favourable circumstances.

Investigating incidents enables us to identify and strengthen key barriers between hazards and vulnerable objects which were less than adequate and allowed the incident to occur.

Although near misses provide learning opportunities, we have to realise that there is an optimum number of investigations that can and should be conducted during the daily operation of an organisation. Companies simply do not have the resources available to investigate all incidents and near misses. Each individual company will have established criteria to decide when an incident or near miss will be investigated to the full extent.

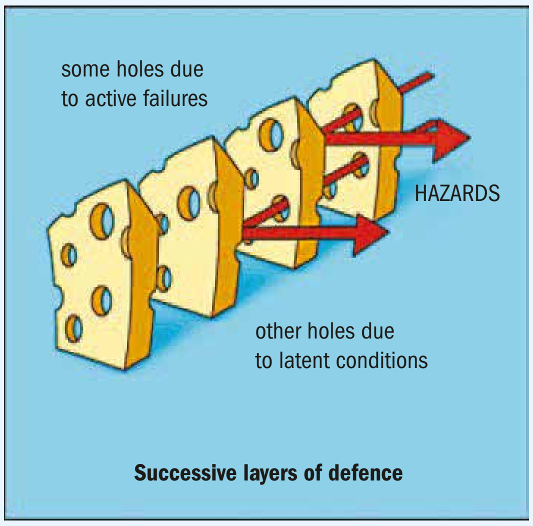
In general, three components determine which events are selected for further investigation.

- **Actual consequence:** How severe is (are) the consequence(s) of the incident?
- **Potential consequence:** How severe could the consequences have been with a different scenario/sequence of events? Sometimes near misses could have resulted in more serious consequences under slightly different circumstances.
- **Barriers that prevented or could have prevented the incident from reaching its potential consequence:** Which barriers were in place to prevent the potential consequences?
  - Where effective barriers proportionate to the potential consequence can be identified, the risk was mitigated as intended and the necessity of further investigation is relatively low.
  - Where no barriers or ineffective barriers can be identified, the vulnerable object was just lucky and in case of a near miss further investigation is strongly recommended.

In summary, an injury, loss of containment or equipment damage can be minor, but if it potentially could have been much worse and no adequate barriers were in place an investigation needs to take place.

As already mentioned, the current Stamicarbon incident database, which has been in place for 48 years, only contains the details of 20 major incidents. This low number of data points is insufficient to effectively improve the safety performance of our urea process safety design.

Fig 3: **Schematic representation of a near miss**



When a barrier is penetrated it means that energy has already been released and at least one barrier has failed. Either there is an additional effective protective barrier in place or the vulnerable object is not impacted by the hazard.
The last we call luck.

Barriers:
- human intervention (supported by training, alarm etc.);
- safety instrumented systems;
- safety relief valves and rupture discs;
- post-release mitigation (firefighting, safe haven, process sewer, flare etc.);
- personal protective equipment.

Besides this incident database, Stamicarbon has also explored other sources of incident information to populate the incident pyramid:

- Fertilizer industry associations: IFA, AIChE Ammonia Safety Committee, Fertilizers Europe
- Internet news channels
- Governmental investigation boards

However, once again, it is typically only the major events that are reported and the lower-consequence incidents are seldom mentioned. Because of this, we are left with lagging indicators instead of the so badly wanted leading indicators.

It is not only Stamicarbon's database that contains insufficient data points to reveal common causes. The same is true of incident databases at customers' individual sites. That is why urea manufacturers need to work together and build an incident database that all can benefit from.

Path forward proposal

Stamicarbon is convinced that there is a strong need to offer an incident sharing portal for the benefit of all urea producers. Initiatives in the past from Stamicarbon and other associations, workgroups, etc., often failed as there were perceived obstacles which deterred people from openly sharing information on their incidents and near misses. Companies may fear damage to their reputation or administrative burden; or they may simply not believe in the benefits of it all.

A new incident sharing portal can only succeed if it is based on trust and confidentiality. That is why Stamicarbon wants to kick off the initiative by ensuring that access can only be granted by HSE professionals. This role can be filled by an HSE officer, HSE engineer, HSE manager, QESH manager, etc.

The first step is that the HSE professional at the customer company fills in a brief notification, roughly describing the process safety incident; this demands only a limited amount of administrative effort.

The following process safety incidents are considered as incidents with a high learning potential and it is strongly recommended that they should be recorded at the HSE portal:

- High actual consequence – insufficient barriers or failed barriers;
- Low actual consequence (e.g. near miss) – high potential consequence, insufficient barriers.

The second category contains the events which were hidden until now but are more frequent than the first category and also contain the potential for learning (leading indicator).

Customers who report an accident or near miss to Stamicarbon can get support and a tailor-made recommendation under an applicable service agreement.

Each quarter, an anonymous update will be sent to all subscribing customers to inform them of relevant accidents and near misses. Common-cause analysis and new HSE insights provided by Stamicarbon will enable customers to improve their process safety performance.

Urea facility operators can subscribe to the HSE portal at www.stamicarbon.com under products/HSE portal. ■

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