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FERTILIZER INTERNATIONAL
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BCInsight

China Works, Black Prince Road
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Tel: +44 (0)20 7793 2567
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Cover: Aerial view over Old Town in Prague with domes of churches, bell tower of the Old Town Hall. kavalenkava/Shutterstock.com

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PHOTO: IFA

Alzbeta Klein.

Fertilizers: where food and energy markets meet

Alzbeta Klein, CEO and Director General of the International Fertilizer Association (IFA), sets the scene for IFA's Annual Conference in Prague, 22-24 May.

Last year was a pivotal year for IFA and for the fertilizer industry. The importance of fertilizers in feeding the world's population was brought into sharp focus – a focus that has barely lessened this year as the war in Ukraine continues.

All of us realised that if wheat, rice, maize and soy are essential goods, none of them would be productive if mineral fertilizers were not available, as exemplified by the dramatic impact of the zero mineral fertilizer policy last year in Sri Lanka. The world realized in 2022 that fertilizers are also essential goods.

The other lesson from 2022 was that – in our interconnected world – the global production, trade and distribution of fertilizers are highly susceptible to geopolitical events and supply chain disruptions.

As last year also illustrated, food and energy are inseparable. Every part of the food system uses energy and, most obviously, fertilizer production has been heavily impacted by the shortages of gas we saw in West and Central Europe last year.

Although energy costs have stabilised from their heights in 2022, and the picture is not as severe as it was a few months ago, the need for producers to diversify their sources of energy and decarbonise production has accelerated – both for sustainability purposes and to reduce their reliance on any single source of energy. And as the global population is projected to reach 10 billion by 2050, we must all plan for a fast-evolving and increasingly complex food, energy and climate future.

In addition to feeding the world, fertilizers also have a role to play in the energy transition. The use of ammonia as a shipping fuel and as a potential material to decarbonise coal for example will have a profound impact on demand. Also, an increasing share of extracted phosphate rock will be used for producing lithium iron phosphate (LFP) batteries, a fast-emerging market. How we tackle increased demand for these vital commodities will have lasting effects on food security in the coming years.

Farm level challenges

At farm level, the challenges in meeting the growing global demand for food are many and varied. Fertilizer availability and affordability both continue to present problems across world agriculture with uneven effects and consequences.

The impacts of climate change and the need to intensify production on existing agricultural land – to prevent further deforestation, related carbon emissions and biodiversity losses – are also affecting farmers. The challenge of how farmers manage their soils and balance the need to increase crop yields and nutritional quality, while replenishing and protecting the soil for future harvests, is significant.

Mineral fertilizers clearly play an important role in addressing soil degradation and rehabilitating marginal soils. Farming systems, especially in sub-Saharan Africa, lack sufficient plant nutrients to sustain healthy soils and productive crops. Tools and technologies have been developed to make site-specific recommendations for mineral fertilizer application, which further increases its use efficiency.

Energy and fertilizer production

From the perspective of an energy producer, fertilizer is one way to export that energy through industrial transformation. From the perspective of a nitrogen fertilizer producer, it is the energy that drives a substantial part of the cost of production. On the supply side, we may have more nitrogen fertilizer production if major energy producers decide to convert energy resources into ammonia. And on the demand side, we may see increased demand for ammonia to decarbonise shipping and other industrial sectors.

Development of electric vehicles and energy storage will support further expansion of battery manufacturing. Among the latest generation of batteries are LFP batteries, which are already being adopted by some leading car manufacturers. The phosphate industry, especially in China, is responding to this market.

Where does this leave us? Fertilizer and energy are closely interlinked, and we would be foolish not to look at the dynamics of global energy markets to see the future. Beyond fossil fuel-based energy, we need to consider the trajectory of renewables, as well as the production of blue ammonia incorporating carbon capture and storage/sequestration – a key part of the business case for investing for the future.

It is very clear that one sector's decarbonisation challenge is another's opportunity. This underscores the imperative for us to take the broader view of the energy transition, to ensure we are well-prepared for the impact of other industries' decarbonisation efforts on our own future.

At this year's IFA Annual Conference in Prague, our members will come together to discuss this ever-evolving landscape and the critical juncture of the global food and energy industries.

While the challenges we face are daunting, I have confidence that the commitment, innovation, and drive of the fertilizer industry can be brought to bear to successfully meet the challenge of feeding the world sustainably – now and into the future. ■

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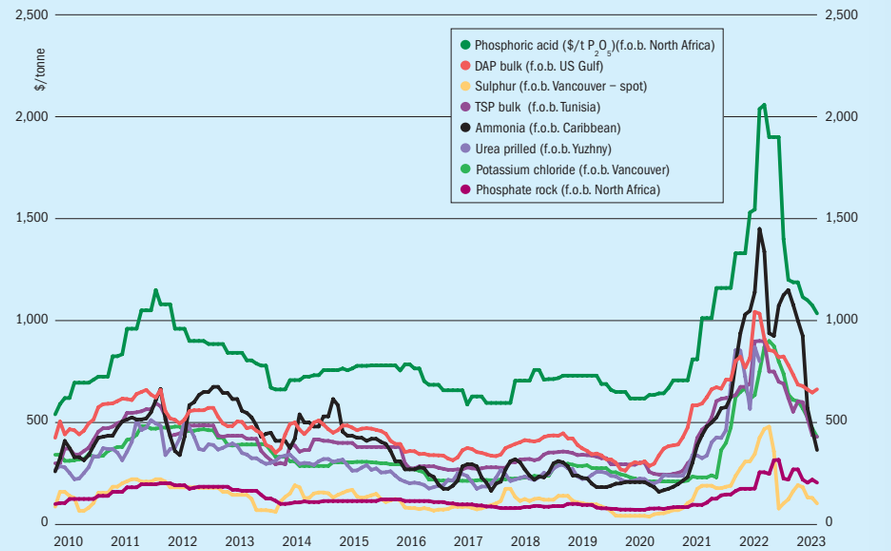
Market Insight

Historical price trends $/tonne



Source: BCInsight

Market Insight courtesy of Argus Media

PRICE TRENDS

Urea: Scarcity continued to drive urea prices higher in some markets at the end of April. The US market remains short on urea and prices spiked to reflect this. Nola barges for April were trading as high as $450/st f.o.b. ($490/t cfr), 55 percent up on this year's low point. Southeast Asia remains short on urea too, amid planned and unplanned turnarounds, with one cargo trading at around $345/t f.o.b.

Key market drivers: Although the price rally in the US continues, global markets are likely to cool when demand slows in May. The slow pick-up in spot export trade in China should put a ceiling on urea prices.

Ammonia: Prices dropped once again across several regions towards the end of April. The $55/t drop in the latest monthly Tampa contract price was indicative of an ammonia market that continues to work towards its floor. Yara agreed the Tampa ammonia price with Mosaic at $380/t cfr for May, representing a Caribbean netback of around $330-335/t f.o.b. Firmer demand from northwest Europe, meanwhile, could potentially create some stability.

Key market drivers: Fresh sales are firming northwest European demand, with an unconfirmed sale into France reported above $400/t cfr. There are curtailments in Trinidad with at least one plant being forced offline because of gas supply issues. A plant taken offline by Algerian producer Sorfert for maintenance in late April is not expected to come back online until mid-May. Ammonia storage tanks at Zhanjiang, China, are at full capacity, delaying cargoes and dampening buying interest.

Phosphates: Prices fell in major markets east and west of Suez. DAP levels in India slipped to $540-548/t cfr, with the reported sale of 30,000 tonnes of Russian DAP at the high end of this range. Two end-of-April DAP sales from a major Chinese producer for May loading were in the high $540s/t cfr and around $550/t cfr, respectively.

Elsewhere, market activity was more muted. European DAP levels slipped to $650-690/t fca Benelux. West of Suez, MAP softened to $565-580/t cfr Brazil. MAP/DAP Argentina, meanwhile, fell to $595-600/t cfr, with more trader activity emerging. In the US, MAP barge prices crumbled to $499/st f.o.b. Nola for May, down from $600/st f.o.b. in a week, while DAP also softened slightly to $646/st f.o.b. Nola.

Key market drivers: Coromandel has settled second-quarter phosphoric acid prices with Nutrien at $970/t P_2O_5 cfr India, down from $1,050/t P_2O_5 cfr in the first-quarter. The Tampa ammonia contract price was announced at $380/t cfr for May, a $55/t fall from April.

Potash: The global potash market remains slow. Granular MOP prices have continued to drift lower in Brazil, Europe and Southeast Asia, with buyers hesitant to commit to large volumes in anticipation of further price falls.

Market price summary $/tonne – Late April 2023

Nitrogen	Ammonia	Urea	Ammonium Sulphate	Phosphates	DAP	TSP	Phos Acid
f.o.b. Caribbean	300-380	270-340**	f.o.b. E. Europe 148-180	f.o.b. US Gulf	646-699	-	-
f.o.b. Yuzhny	Port closed	Port closed	-	f.o.b. N. Africa	560-635	420-440	960-1,100
f.o.b. Middle East	250-320	300-375**	-	cfr India	540-560	-	970-990*
Potash	KCl Standard	K_2SO_4	**Sulphuric Acid**		**Sulphur**		
f.o.b. Vancouver	360-450	-	cfr US Gulf	50-90	f.o.b. Vancouver	95-110	-
f.o.b. Middle East	390-540	-	-	-	f.o.b. Arab Gulf	95-115	-
f.o.b. Western Europe	-	750-935	-	-	cfr N. Africa	105-125	-
f.o.b. Baltic	350-440	-	-	-	cfr India	115-140+	-

Prices are on a bulk, spot basis, unless otherwise stated. (= contract ** = granular). Phosphoric acid is in terms of $/t P_2O_5 for merchant-grade (54% P_2O_5) product. Sulphur prices are for dry material. (+ Quotes for product ex-Arab Gulf). n.a. = not available.*

In the US, trade in the domestic market is continuing but has slowed. Prices there have also stabilised after ticking up in recent weeks. SOP prices in Europe and Asia, meanwhile, have dropped further amid weak demand and softening MOP prices. This sluggishness is likely to remain until mid-May.

Key market drivers: SQM restarted MOP production at the end of April, earlier than planned. In China, suppliers have been re-exporting standard MOP from bonded warehouses to southeast Asia due to weak domestic demand. This also confirms that China has ample supplies and is therefore unlikely to be in a hurry to sign a new MOP contract.

NPKs: Demand has remained limited across the globe and, consequently, NPK prices have continued their soft trend, led by Asian markets. A fresh sale of Russian NPK (10-26-26) to India, for example, saw a minor fall in NPK cfr prices there. In Southeast Asia, meanwhile, NPK cfr prices for 15-15-15 and 16-16-16 grades also nudged downwards.

The Kenya Tea Development Agency (KTDA) issued a tender for the supply of 12,000 tonnes of compound NPK (26-5-5) from local sources. This is separate to KTDA's outstanding request for 92,000 tonnes of the same grade. Elsewhere, market activity has been severely limited, as buyers remain cautious of purchasing larger quantities while prices look set to fall further.

Key market drivers: Ammonia prices continue to drop. The Tampa contract price dropped to $435/t cfr for April, a $155/t fall from the March settlement and its lowest price since February 2021. The price then fell again by another $55/t in May to $380/t.

Sulphur: Prices softened again at the end of April. Middle East sulphur tonnes were down on previous sales, concluding in the low-$100s/t cfr for May loading. Sulphur offers dropped to the low-to-mid $110s/t cfr India and China. Buyer bids dropped even lower, from the range $100-110/t cfr China to less than $100/t cfr.

Key market drivers: The low-priced sulphur sale to Indian fertilizer producer Coromandel (below $110/t cfr India) for May shipment from the Middle East.

OUTLOOK

Urea: The effects of increased supply from China, and the anticipated return of urea plants from turnaround in southeast and central Asia, are likely to be amplified by slow import demand in the northern hemisphere.

Ammonia: While further downward price corrections are possible, stabilising demand suggests the market floor is in sight. A series of outages and plant maintenance stoppages in the Americas and north Africa should also improve the market balance in May and June.

Phosphates: Prices will continue to drop, becoming pressured east of Suez as Indian importers continue to build DAP inventories. While affordability in Brazil is solid, buyers are still remaining on the sidelines. US barge prices are also set to move lower as spring demand subsides.

Potash: Prices are likely to erode further in coming weeks as sluggish market activity persists. More potash demand is nevertheless expected to emerge in Brazil and the US later in the second-quarter. In Europe, K+S is expected to publish its new season MOP prices in May. These are expected to be significantly down on current levels and, if accepted by the market, could prompt a pick-up in potash sales.

PHOTO: MAUINOW1/ISTOCKPHOTO.COM

Low pricing is making sulphur supply impractical from inland locations with high freight costs.

NPKs: Almost all key indicators point to a further softening of the NPK market in coming weeks. A demand surge strong enough to prevent this is unlikely to emerge in the short term. NPK buyers across the globe are awaiting price guidance before committing to purchases. This could be partly provided by the long-awaited contract settlements for standard MOP.

Sulphur: The sulphur market is quiet with downstream demand from the fertilizer industry remaining low. Low pricing is now making sulphur supply unworkable from inland locations with high freight costs, such as Turkmenistan and Russia. This is expected to lead to a reduction in sulphur export volumes from the FSU region. Lower price levels are, however, expected to spark some buying interest for late-May/early June loading, with sulphur buyers awaiting an optimal moment to buy tonnes. ■

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WORLD

IFA study confirms abundant global phosphate reserves

Haul truck at Khouribga phosphate mine, Morocco.

The first global review of phosphate rock resources since 2010 has reported that technically recoverable reserves should last for more than 300 years.

This was the headline finding of a new study by commodity experts Argus commissioned by the International Fertilizer Association (IFA). The study, published in April, provides an assessment of the world's phosphate rock resources and reserves. This was compiled from publicly available information and data from company surveys.

The study finds that – despite reports to the contrary – there is no global shortage of phosphate rock. Instead, its findings confirm there are around 189 gigatonnes (Gt) of mineable and processable phosphate reserves globally. These reserves are sufficient for about 350 years, at projected phosphate rock consumption rates and using currently available extraction and processing methods.

This figure could well be an underestimate, as it assumes no improvements beyond today's mining and beneficiation technology. Potentially, the life of phosphate reserves could be extended to more than 1,000 years, the study suggests, if emerging production technologies (e.g., Prayon's EcoPhos process and the improved hard process (IHP) from Novaphos) were combined with sustainable farming practices and the use of enhanced efficiency fertilizers.

Argus reports the following resource and reserve estimates:

- In-situ global phosphate rock resources of 342 Gt (270-420 Gt) containing 65 Gt P_2O_5 (45-88 Gt P_2O_5).
- A global reserve base of 189 Gt (148-211 Gt) containing 36 Gt P_2O_5 (26-48 Gt P_2O_5). These are in-situ ore volumes that are technically recoverable using current technology.
- The use of emerging technologies could increase the reserve base to 219 Gt (171-232 Gt) containing 39 Gt P_2O_5 (27-48 Gt P_2O_5).
- Economic reserves are estimated at 83 Gt (52-92 Gt) run-of-mine containing 21 Gt P_2O_5 (12-24 Gt P_2O_5). These are reserves which are both technically and economically viable.

Argus also provides a regional breakdown of the 189 Gt global reserve base, as follows:

- Africa: 95,700 million tonnes
- North America: 33,300 million tonnes
- West Asia: 17,700 million tonnes
- East Asia: 15,900 million tonnes
- Eastern Europe & Central Asia: 11,900 million tonnes
- West & Central Europe: 8,700 million tonnes
- Latin America: 4,500 million tonnes
- Oceania: 1,600 million tonnes
- South Asia: 110 million tonnes.

This confirms that half of global reserves are concentrated in Africa.

IFA says that the new evidence on the abundance of phosphate rock supplies should not deter companies from improving the sustainable use of this non-renewable resource. That includes improving nutrient use efficiency, recycling nutrients from waste streams, and maximizing the efficiency of the phosphate mining, mineral processing and fertilizer production processes. More efficient phosphorus use offers economic and environmental benefits, according to IFA, as it improves crop yields and farm economics, reduces aquatic pollution via runoff, as well increasing the lifespan of currently known reserves.

Evidence from the new study suggests that decarbonisation of the phosphate industry was a more worthwhile priority than a perceived global phosphate rock shortage, commented IFA.

"This study provides a balanced and insightful contribution to the debate about the future availability of phosphate rock as a source of fertilizer," said Adrian Binks, the chairman and CEO of Argus Media.

Alzbeta Klein, IFA's CEO and director general, said: "While the findings of this study are very reassuring from the perspective of the availability of global phosphate reserves, the industry recognises the need to focus on greater sustainability in the production and use of phosphates as a priority. Innovation across the supply chain is needed to ensure we extract and use the available reserves appropriately, now and into the future.

"IFA and its members are committed to both the sustainable use of phosphate reserves and to exploring opportunities to recycle by-products where possible."

Global phosphate rock production in 2021 stood at 204 million tonnes (63 Mt P_2O_5) of marketable concentrate. ■

AUSTRALIA

Construction starts on Karratha urea project

Perdaman Industries has started to construct the AUD 6 billion Karratha urea project. The company broke ground on the project, located on the Burrup Peninsula, 20 kilometres northwest of Karratha on the Western Australia coast, after making a final investment decision on 26th April.

The start of construction follows the award of the project's $2.7 billion engineering, procurement and construction (EPC) contract to a 50:50 joint venture between Saipem SpA and Clough Group in May last year. This contract covers project engineering, the supply of equipment and materials, and the construction and commissioning of the 2.14 million t/a urea production plant. The building of a water treatment plant, a 100 MW power plant are also included in the contract, as are urea storage, loading and unloading facilities.

Saipem will provide Snamprogetti™ technology for the urea plant, while Haldor Topsoe will license its SynCOR™ technology to build the world's largest single-train ammonia unit. Natural gas feedstock for the plant will be supplied by Woodside's Scarborough project.

The urea project is expected to create 2,500 construction-phase and 200 operational jobs. Australia currently imports around 2.4-million tonnes of urea annually.

"My government is proud to support… the Perdaman urea project that will deliver decades of economic benefits for Western Australia, creating local jobs and diversifying the Pilbara economy," said Western Australia's Premier Mark McGowan. "It is estimated the project will create thousands of jobs within the state and generate a total revenue of AUD 77 billion over its life."

Export Finance Australia (EFA) has provided an AUD 269 million loan to the project, alongside the Northern Australia Infrastructure Facility (NAIF) and 12 other commercial lenders.

Government lenders have also provided AUD 300 million in funding for supporting regional infrastructure. This includes two loans worth AUD 255 million granted by the NAIF to the Pilbara Ports Authority and Water Corporation.

The AUD 159 million loan to the Pilbara Ports Authority is for a new wharf and facilities at the Port of Dampier. The other AUD 96 million loan will fund the Water Corporation's expansion of the Burrup seawater supply and brine disposal scheme. This will connect to the Karratha urea project once it is built. Additionally, the state government has committed more than AUD 50 million to support early design works and upgrades to public infrastructure.

UNITED KINGDOM

CRU and Argus launch low-emissions ammonia price services

CRU launched a new low-emissions ammonia (LEA) price assessment in February as part of its *Fertilizer Week* price reporting service. This calculates a premium on the Northwest European ammonia price based on the value of mitigated emissions.

The new assessment combines proprietary emissions data with weekly European carbon prices to attach a value to emissions mitigation. The LEA price assessment uses information compiled by CRU's Emissions Analysis Tool – a comprehensive asset-by-asset emissions dataset for the nitrogen industry.

CRU says that calculating premiums in this way allows customers to assess how the switch to LEA can deliver value to their

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businesses while also contributing to company decarbonisation strategies.

Argus also launched a new suite of cost indicators for low-carbon ammonia production in February. This covers ammonia made with renewable fuels, or with fossil fuels using either carbon capture and utilisation (CCU) or carbon capture and storage (CCS).

Argus now publishes 312 costs of production for decarbonised ammonia at key locations around the world. These indices are published in the Argus Hydrogen and Future Fuels service – complementing the 470 decarbonised hydrogen costs this service already provides. This service supplements the company's long standing and comprehensive price coverage for the 'grey' ammonia market. This assesses market prices for ammonia made with fossil fuels where the carbon is not mitigated.

CHINA

Stamicarbon licenses its largest low energy urea plant

Stamicarbon has signed a contract for a new Ultra-Low Energy urea plant in Jiangxi province, China. This will be the seventh plant based on this innovative design and, with a capacity of 3,850 t/d, is Stamicarbon's largest low energy urea plant to date.

The contract is for a urea melt and prilling plant. It covers the process design package, licensing, equipment supply – including proprietary Safurex® high-pressure equipment – and associated services. It will also apply Stamicarbon's Ultra-Low Energy design to the urea plant's pool condenser for the first time. The customer has not been named.

Stamicarbon's Ultra-Low Energy design allows heat supplied as high-pressure steam to be used three times instead of the usual two. This reduces steam consumption by about 35 percent and cooling water consumption by about 16 percent, versus traditional processes, as has been demonstrated at two plants currently in operation.

"This award is significant, being Stamicarbon's largest Ultra-Low Energy urea plant to date and the first plant where this breakthrough technology is applied to a pool condenser. It shows Stamicarbon's commitment to innovation and technology development to improve the sustainability of the fertilizer industry," said Pejman Djavdan, Stamicarbon's CEO.

PHOTO: INCITEC PIVOT

The Waggaman ammonia plant, Louisiana.

UNITED STATES

Incitec Pivot sells Waggaman plant to CF Industries

Incitec Pivot Limited (IPL) has sold its Waggaman ammonia plant in Louisiana to CF Industries for $1.675 billion.

The plant was completed in 2016 at a cost of $850 million and has a nameplate capacity of 880,000 t/a.

The plant will continue to supply at least 200,000 t/a of ammonia – about 20 percent of its output – to IPL's Dyno Nobel Americas (DNA) explosives business under a 25-year offtake agreement. The ammonia supply deal with IPL is valued at $425 million, leaving CF needing to fund the remaining $1.25 billion of the purchase price from its cash reserves.

CF Industries will also sell ammonia produced at Waggaman to two other US customers. About 75 percent of the plant's output is destined for industrial applications, according to CF.

"We are pleased to reach this agreement with Incitec Pivot Limited," said Tony Will, the president and CEO of CF Industries. "We believe the Waggaman facility will fit seamlessly into our network, as well as our strategic focus on ammonia as a clean energy source, given its proximity and pipeline connection to our Donaldsonville, Louisiana, Complex, its distribution and logistics flexibility, and its favorable characteristics for the addition of carbon capture and sequestration (CCS) technologies to enable low-carbon ammonia production."

"With the decision to sell this world-class asset, we will reduce our excess exposure to commodity and operating risks while maintaining Waggaman's strategic value," said Jeanne Johns, IPL's managing director and CEO.

IPL is planning to demerge its Pivot Fertilisers and Dyno Nobel explosives businesses to create two separate listed entities. IPL will use the cash from the sell-off to pay down debt and help with the demerger.

Waggaman's sale remains subject to US anti-trust regulatory clearance and the completion of other customary closing conditions.

Yara and Enbridge plan large-scale Texan blue ammonia plant

Norway's Yara International and Canadian pipeline company Enbridge are planning to collaborate on a $2.9 billion blue ammonia project near Corpus Christi in Texas.

The proposed plant would be Yara's biggest, supplying 1.2-1.4 million t/a of low-carbon ammonia by capturing, transporting and permanently storing about 95 percent of the CO_2 generated. The project will be located at Enbridge's Corpus Christi oil storage and export facility.

Yara plans to use the plant's ammonia output as a feedstock for its global production assets, including those in Europe, as well as selling this into emerging clean ammonia markets such as shipping fuel. Low-carbon ammonia production could potentially begin within 4-5 years, although a final investment decision has yet to be made.

The project was originally planned before the introduction of last year's Inflation Reduction Act (IRA) by the US government. The IRA's higher carbon storage tax credit ($85/t) now makes the proposed blue ammonia plant a much more attractive investment, according to Yara.

Atlas Ag to use KBR's green ammonia technology

KBR is to license its K-GreeN® ammonia technology to the renewable fertilizer project developer Atlas Agro AG.

Under the terms of a recently signed memorandum of understanding between the two companies, KBR will provide technology licensing, basic engineering design, proprietary equipment and catalysts for a series of planned investments by Atlas in zero-carbon nitrate fertilizer plants. The engineering design for the first of these plants, located in the US, began in March this year.

"We are excited to support Atlas Agro's vision of zero-carbon fertilizer production through our market leading green ammonia technology, K-GreeN," said Doug Kelly, KBR President, Technology. "We are also confident that we can drive schedule synergies across the series of plants to accelerate availability of clean ammonia globally."

"We are proud to partner with KBR and use its K-GreeN process for our green fertilizer facilities construction," said Petter Ostbo, Atlas Agro's CEO. "Each of our green ammonia plants will produce fertilizer that will help feed nearly 16 million people and avoid global carbon emissions of more than one million tons per year."

BANGLADESH

Green fertilizer plant 90 percent complete

The Ghorashal-Polash Urea Fertilizer Project (GPUFP) is now 90 percent complete, according to Chinese state media. The project is said to be running two months ahead of schedule, with completion now expected this December.

More than 850 employees from the China National Chemical Engineering & Construction Corporation, in collaboration with Japan's Mitsubishi Heavy Industries, have been working round the clock to complete the large-scale project. The fertilizer plant is being developed as part of China's strategic 'Belt and Road' initiative.

The GPUFP is located in Narsingdi district, 51 kilometres northeast of the capital Dhaka. It has a production capacity of 1,600 t/d for ammonia and 2,800 t/d for urea. It will become the biggest fertilizer plant in Bangladesh and one of the largest in South Asia when it enters operation.

The project will supply around 40 percent (1.0 million t/a) of current fertilizer demand in Bangladesh (2.5 million t/a). The blue ammonia unit also incorporates carbon capture, making GPUFP the first-ever green fertilizer plant in Bangladesh.

Wu Xiangong, senior vice president of China National Chemical Engineering Group Corporation, said: "On the basis of this project, we will work together to build Bangladesh's chemical industry system, so as to let the Bangladeshi people feel the deep friendship between China and Bangladesh as well as enjoy the fruitful results of cooperation."

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QATAR

Bedeschi to supply sulphur-handling equipment

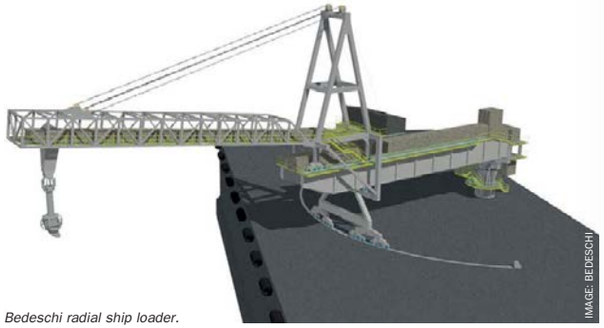
Bedeschi is to supply new sulphur-handling equipment to the NXFP sulphur project.

This follows QatarEnergy's award of a $600 million construction contract for the project to joint venture partners Spain's Técnicas Reunidas (70%) and China's Wison Engineering (30%) in April last year.

This project will process and export sulphur from liquefied natural gas (LNG) facilities at Qatar's Ras Laffan Industrial City (RLIC) complex. The project's new sulphur plant has the capacity to process around 5,000 t/d of molten sulphur.

As part of a large-scale and comprehensive supply and engineering contract with Técnicas Reunidas and Wison Engineering, Bedeschi will supply:

- Six conveyor belts with a total length of 1,400 metres with a capacity of 550 t/h, including galleries and transfer towers
- Four conveyor belts with a total length of 480 metres with a capacity of 2,000 t/h, including galleries and transfer towers
- One conveyor belt with a total length of 120 metres with a capacity of 3,700 t/h, with a gallery and transfer tower
- Two trippers with a capacity of 550 t/h
- A double arm portal reclaimer with a capacity of 2,000 t/h
- A travelling slewing shiploader with a capacity of 2,000 t/h
- A radial shiploader with a capacity of 3,700 tonnes per hour.



Bedeschi radial ship loader.

BRAZIL

Unigel and thyssenkrupp to expand green hydrogen capacity

thyssenkrupp nucera and Unigel have agreed to quadruple the capacity of an under-construction green hydrogen plant in Bahia, Brazil.

Unigel, Brazil's largest nitrogen fertilizer producer, is on schedule to complete the country's first industrial-scale green hydrogen plant by the end of this year. The 10,000 t/a of green hydrogen generated by the 60 MW capacity thyssenkrupp nucera electrolyser unit will be used to produce 60,000 t/a of green ammonia.

Unigel will use green ammonia as a feedstock in fertilizer and acrylic production. The company will also offer green hydrogen and green ammonia to industrial customers – including steel makers, oil refiners and ammonia producers – to help them decarbonise their production chains.

Unigel and thyssenkrupp nucera have now announced plans to expand the Bahia project's water electrolysis capacity from 60 MW to 240 MW, as part of a new memorandum of understanding (MoU) agreed in mid-March. The MoU signing ceremony, held in Belo Horizonte, was attended by Dr Robert Habeck, Germany's federal minister for economic affairs and climate action, during his recent visit to Brazil.

"Unigel's green hydrogen plant will be the first on an industrial scale in Brazil," said Roberto Noronha Santos, Unigel's CEO. "We continue to negotiate strategic partnerships to enable the new phases of the project."

"Brazil is one of the nations predestined to take on a key role in the green transformation by consistently exploiting the potential in renewable energies," said Dr Werner Ponikwar, the CEO and chairman of thyssenkrupp nucera. "With our technologies for the development of a hydrogen economy, we are making our contribution to paving the way for this green transformation."

ITALY

Tessenderlo buys marketing and sales rights from Esseco

Tessenderlo Group has entered into an agreement to acquire the marketing and sales activities for ammonium thiosulfate (ATS) fertilizers produced by Esseco Srl (part of Esseco Group) in Trecate, Italy.

These ATS fertilizers will be sold and marketed by the Tessenderlo Kerley International business unit in future. Tessenderlo is also buying the Secofit® TS and Agrifix® agricultural trademarks for this product range. The agreement was due to become operational in March.

"This agreement confirms Tessenderlo Kerley International's commitment to the ammonium thiosulfate fertilizer market. Thanks to the production capacity of Esseco Srl, we will have additional volumes of ammonium thiosulfate fertilizers available," said Geert Gyselinck, the EVP of Tessenderlo Kerley International. "In addition to cooperating with a company which shares the same mindset towards continuous improvement in terms of both product and process, this agreement will also improve the service we offer to our customers."

Tessenderlo Group has also reported "great progress" on a new Thio-Sul® production unit at its Geleen site in The Netherlands. Construction of the new plant has been running at full speed since the final permits were granted in mid-January, according to the company.

The new plant at Geleen is expected to become fully operational by mid-2024. Construction work is being supervised by Le Gaz Intégral, the same contractor who built Tessenderlo's Thio-Sul® plant in Rouen, France, in 2017.

Tessenderlo has also announced the successful introduction of Thio-Sul®, its liquid ammonium thiosulfate fertilizer, into the Ukrainian agriculture market Growers are continuing to farm in Ukraine, despite the highly challenging situation.

Thio-Sul® provides prolonged sulphur nutrition and increases the efficiency of nitrogen nutrition for key broad-acre crops, such as rapeseed, potato, corn, and wheat. Working jointly with strategic partner Eridon, Tessenderlo is integrating Thio-Sul® into crop nutrition programmes across Ukraine. ■

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PHOTO: WWW.ICIS.COM

Mr Abdulrahman Al-Fageeh, SABIC's new CEO.

Abdulrahman Al-Fageeh is the new CEO of SABIC. He is also the current chairman of SABIC Agri-Nutrients, the company's fertilizer division.

Mr Al-Fageeh's tenure as CEO, which will run until 9th April 2025, was approved by SABIC's Ordinary General Assembly in mid-April. He was also confirmed as a member of the company's executive board.

SABIC's confirmation of its new CEO follows the recent appointment of **Dr Mohammed Yahya Al-Qahtani** as vice chairman by the company's board.

Abdulrahman Al-Fageeh told the General Assembly: "SABIC has successfully faced the challenging global conditions, investing in its collaborative relations with Saudi Aramco, which led to the successful supply of the world's first commercial shipment of independently certified blue ammonia to South Korea."

He also said that SABIC is sparing no efforts to achieve sustainable growth. This includes setting long-term sustainability goals and reducing the life cycle emissions of its products across their value chain.

Previously, Mr Al-Fageeh has held many senior executive positions at SABIC during his 35 years with the company. These include roles in project management, plant operations, and corporate & business management. Notably, he has been the executive vice president of SABIC's petrochemicals, performance chemicals and polymers strategic business units at various times. His other senior SABIC positions include vice president of the polyethylene business unit and president of Yansab for six years.

Externally, Mr Al-Fageeh is the chairman of both the Gulf Petrochemicals and Chemicals Association (GPCA) and the Saudi Petrochemical Manufacturers Committee.

Dr Aaron Waltz is Ostara's new chief technology officer. Dr Waltz brings deep agronomic expertise to the company alongside more than 20 years of agricultural industry experience.

Aaron began his career at DuPont Pioneer. Since then, he has worked in technology development roles in the adjuvants, biologicals and fertilizer industries.

"Aaron's skills are highly complementary to the existing executive team and will enable Ostara to realise our vision of global expansion as we increase production of our portfolio of Crystal Green phosphate fertilizers," said Kerry Cebul, Ostara's CEO. "Aaron's agronomic expertise, diverse science background, and leadership will be critical as we rapidly expand our platform of technologies and significantly increase production to meet grower needs."

In reply, Aaron Waltz said: "Ostara has developed a unique foundation of innovative crop nutrition products and technologies that help growers optimise yield, embrace sustainability, and reduce application rates. I am excited to join the organisation to build on this foundation and accelerate their adoption."

Dr Waltz's interest and involvement in agriculture began on his family's farm in Nebraska. After gaining his PhD from The University of Nebraska, Lincoln, he pursued a successful career in crop production and product development.

PhosAgro's shareholders elected a new board of directors during the company's annual general meeting (AGM) on 24th March. CEO **Mikhail Rybnikov** and chairman **Viktor Cherepov** were among those named.

The AGM also approved the company's 2022 annual report. PhosAgro produced a record 11.0 million tonnes of fertilizers last year, an increase of almost seven percent on 2021. This was divided between 8.4 million tonnes of phosphate-based products and 2.6 million tonnes of nitrogen-based products.

"2022 will certainly go down in the history of Russia's business as one of the most challenging years even compared to the period of the Covid-19 pandemic," said Mikhail Rybnikov, PhosAgro's CEO. "We were, too, affected by a number of sanctions, the disruption of international ties and supply chains that had developed over years of cooperation."

"The past year has offered Russian businesses unprecedented challenges: the rules and mechanisms of international trade, including those for fertilizers and agricultural commodities, no longer work as they used to," said Viktor Cherepov, PhosAgro's chairman. "PhosAgro Group, a supplier to farmers around the globe, was forced to adapt quickly to the new normal – and we did it." ■

Calendar 2023

MAY

22-24
IFA Annual Conference 2023,
PRAGUE,
Czech Republic
Contact: IFA Conference Service
Tel: +33 1 53 93 05 00
Email: ifa@fertilizer.org

JUNE

5-6
Argus Sustainable Fertilizer Americas,
TAMPA, Florida, USA
Contact: Argus Media
Tel: +44 (0)20 3923 0741
Email: conferences@argusmedia.com

9-10
46th AIChE International Phosphate Fertilizer & Sulfuric Acid Technology Conference,
CLEARWATER, Florida, USA
Contact: Bob Andrew,
Clearwater Convention chair
Email: vicechair@aiche-cf.org

JULY

11-12
IFA Global Markets Conference,
LONDON, UK
Contact: IFA Conference Service
Tel: +33 1 53 93 05 00
Email: ifa@fertilizer.org

OCTOBER

2-3
TFI World Fertilizer Conference,
WASHINGTON DC, USA
Contact: Valerie Sutton
Tel: +1 202 962 0490
Email: vsutton@tfi.org

17-19
Argus Fertilizer Europe Conference,
LISBON, Portugal
Contact: Argus Media
Tel: +44 (0)20 3923 0741
Email:
conferencesupport@argusmedia.com

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Argus Sustainable Fertilizer Americas welcomes you to Tampa!

The inaugural Argus Sustainable Fertilizer Americas Conference is being held at the Grand Hyatt Tampa Bay, Tampa, Florida, USA, 5-6 June 2023.

PHOTO: HYATT.COM

The Grand Hyatt Tampa Bay.

Argus is launching a new fertilizer sustainability event this summer. The pioneering event will explore ways of improving sustainability and maximising returns on investment in the fertilizer markets of the Americas.

The inaugural event is being held at the Grand Hyatt Tampa Bay, Tampa, Florida, in the first week of June. The conference's overarching themes include:

- The importance of sustainable fertilizer management and practices
- How to finance and build a sustainable fertilizer economy
- Case studies which highlight key policies and those companies at the vanguard of fertilizer market sustainability.

Why sustainability?

Global fertilizer markets have experienced unprecedented changes in recent times, with supply lines disrupted, global inflationary pressures driving prices upwards, and in 2022 the world's population soaring to over eight billion – to name just a few. As a result, the pressing concern across the global fertilizer community is how to work together to ensure food security, improve fertilizer self-sufficiency, and how to do so while meeting growing sustainability targets for the sector.

Future-proof your business

Attending the Argus Sustainable Fertilizer Americas Conference is a great way of ensuring your business is future-proof and helping to drive the industry forward. The event will provide attendees with unrivalled networking opportunities and a chance to link up with like-minded colleagues – all of whom are committed to furthering fertilizer industry sustainability.

The line-up of expert industry speakers, alongside insights from pioneering companies, will allow you to benchmark your sustainability strategy and embrace new opportunities in the fertilizer markets of the Americas – at a time when the sustainability, security, and affordability of fertilizer supply have become pressing matters.

Who will be there?

100+ delegates from across the fertilizer value chain are expected to attend the two-day event, including representatives from key producers, trading houses, financing firms, storage and logistics companies, governments, industry associations, AgTech companies and more.

There will be frequent discussion breaks throughout the two days. A cocktail reception on 5th June will also allow you to network and relax with colleagues, old and new, in an informal setting.

Learn from the experts

Featured expert speakers include:

- Jeremy Buchman, Senior Agronomy Manager, McCain Foods
- Mariana Contreras, Global Regenerative Agriculture Lead, Mars
- Dr Robert Mikkelsen, Director of Agronomic Services, Yara
- Matt Simpson, Chief Executive, Brazil Potash
- Dr Catherine Roue, Innovation and Sustainability Director North America, Fertinagro Biotech International
- Dr Kuide Qin, Chief Science Officer, Verdesian Life Sciences.

Experts from Aqua Yield, The Fertilizer Institute, PhycoTerra, Livestock Water Recycling, Nitricity, Phospholutions will also be speaking!

The sustainability agenda

Key topics on the agenda include:

- How can food and beverage companies support the drive for agricultural sustainability?
- Fertilizer self-sufficiency and food security: US and Brazil case studies
- An introduction to nutrient recycling and its role in a sustainable circular economy
- Renewable energy mixes, novel products and the future of fertilizer production. ■

Visit the website at www.argusmedia.com/sustainable-fertilizer-americas for more information and to secure your place.

IFA's Sustainable Fertilizer Academy – a certifiable success

The Sustainable Fertilizer Academy (SFA) offers everyone within the fertilizer industry access to education on sustainability via a certified e-learning programme. More than 150 students have registered to date and over 40 alumni have graduated from the academy since it opened in September last year.

Passionate about sustainability

The International Fertilizer Association (IFA) and its 450 members are passionate advocates for sustainability – spreading the message that sustainability is an opportunity, not just a challenge.

IFA believes that the fertilizer industry has a vital role to play in delivering the Sustainable Development Goals (SDGs) adopted by the United Nations in 2015. These 17 goals set out a shared blueprint for human wellbeing, prosperity and safeguarding the planet.

While there are increasing public expectations that companies will lead the way in setting environmental and social goals, it is not always clear where professionals should turn to for answers to basic questions, such as:

- What is sustainability?
- How does it apply to my business?
- What can I do to improve my company's sustainability performance?

That is why IFA launched the Sustainable Fertilizer Academy (SFA) in September 2022 – to provide those working within the industry with authoritative answers to these fundamental questions.

Uniquely, the e-learning and networking experience provided by the academy enables students to apply their skills and knowledge to the real-world sustainability challenges facing us all today. The curriculum examines fertilizer industry sustainability in its entirety: covering the sourcing of fertilizer raw materials, fertilizer manufacturing, and the use of fertilizers on farms.

The two-level programme offered by the SFA provides students with a wealth of knowledge on sustainability and the option to graduate with either an introductory or intermediate certificate. The programme includes 32 classes with 50 video lectures from 45 international subject matter experts.

PHOTO: IFA

Above: Alzbeta Klein, Director General and CEO of the International Fertilizer Association (IFA) signs a memorandum of understanding with Lucas Oliveira de Sousa, Secretary of International Relations at Brazil's Federal University of Mato Grosso (UFMT). The signing ceremony at Sao Paulo in February cemented the new academic partnership between IFA's Sustainable Fertilizer Academy and the UFMT.

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The SFA has attracted a lot of interest and is already proving a success. More than 150 students have registered to date and more than 40 alumni have now graduated – just eight months after the academy first opened its 'virtual doors'!

Student feedback has been positive (see quote) and there has been external recognition too. The SFA was named as a finalist in the 'Best Education or Professional Development' category during the 2022 International and European Association Awards.

Management and oversight

The primary objective of the SFA is to provide everyone within the fertilizer industry with easy access to education on sustainability.

The need for the academy was first identified during the development of IFA2030, the fertilizer industry's long-term sustainability strategy. Both IFA2030 and the academy were, in turn, heavily inspired by the fertilizer industry's commitment to meeting UN Sustainable Development Goals.

The academy is overseen by IFA's Sustainability Committee and managed day-to-day by a full-time Sustainability Education Coordinator who provides teacher coordination and student support. A Senior Advisory Group also meets quarterly to monitor the work of the SFA. This group, which comprises 10 founding partners drawn from IFA's membership and one academic partner, is also responsible for the future development of the SFA, its study programme and e-learning platform.

Curriculum

> **"The content is well balanced between topics. The number and type of quiz questions at the end of each module are helpful.**

The academy's curriculum was developed with the help of a working group of member companies. Learning is structured around classes, with each class comprising of an introduction, a teacher profile, a video lecture, downloadable slides and a short quiz.

The academy's curricular programme is divided into two attainment levels – Expert (Level 1) and Leader (Level 2) – with a final exam for each. Students who pass their exams receive either a Level 1 or Level 2 certificate from IFA. This two-level approach offers introductory and then more advanced content, as follows:

- **Level 1.** This provides an introduction to fertilizer industry sustainability, covering the basics of sustainable agriculture and the importance of sustainability in fertilizer production and use. This level is intended to provide a broad overview of sustainability issues for professionals who are new to these.
- **Level 2.** This more advanced and specialised course is divided into two subject areas: Level 2A – Product Stewardship and Level 2B – Nutrient Stewardship. This higher level course is designed for professionals who would like to learn more about the sustainable production and use of fertilizers.
- **Level 2A – Product Stewardship.** This covers the sustainability of fertilizer production, including issues around resource use, energy consumption, production emissions, and product quality.
- **Level 2B – Nutrient Stewardship.** This focuses on the sustainability of nutrient application and use, covering topics such as fertilizer application rates, timing and placement, soil health, water quality and nutrient cycling.

And this is just the start...

IFA's ambition is to make education about the sustainable production and use of fertilizers accessible to everyone. Because of this, the role of the academy has evolved continuously since its launch – as it seeks to expand its reach and improve its effectiveness.

The SFA was originally exclusive to IFA members, for example. But in early 2023, following external interest, a decision was made to open up the academy to everyone. Additionally, as part of IFA's commitment to providing quality education in multiple languages, English and Spanish subtitles have now been added to all the academy's classes, with more languages to be added soon.

To supplement existing online sessions, IFA is also introducing teacher and student Q&A sessions to the academy's e-learning platform, following feedback received from students and its members. In future, the SFA will also be providing students with the opportunity to learn from recognised sustainability experts by inviting external guest speakers to come and talk about relevant fertilizer industry topics.

Finally, a major goal is to create a community that continues to learn and grow together after graduation. The SFA is therefore looking at initiatives that will connect and bring our students and alumni together regularly, to share updates on sustainability and the latest fertilizer industry developments.

Future plans

IFA is committed to expanding the academy's global reach and impact. It is therefore exploring innovative ways to reach a wider audience and provide tailored educational offerings that meet the specific needs of our students. The new 'À la Carte' and 'On Demand' learning options are just two examples of how the academy is adapting to evolving demand for education and training:

- **À la Carte.** This bespoke option allows learners to select specific classes that align with their interests and needs. This flexibility enables students to design their own learning path and gain particular knowledge and skills that are most relevant to their professional development.
- **On Demand.** This mass access option is designed to allow companies to easily register employees in large groups. It provides students with quick and easy access to training materials and classes. This is particularly useful for companies that need to train a large number of employees on a specific topic.

In April, the SFA broadcast four nutrient stewardship classes on IFA member Sino-Agri's online TV station. These were watched by nearly one million viewers!

Currently, the SFA is collaborating with the Brazilian government and Brazilian universities on a pilot project to establish an 'À la Carte' fertilizer sustainability programme tailored to policy makers and agronomy students (see main photo). Plans are also underway to replicate this approach in other countries.

Fast-tracking sustainability

IFA's Sustainable Fertilizer Academy is a vital and comprehensive educational initiative that aims to accelerate the much-needed global shift to sustainable fertilizer production and use.

As it expands internationally, the academy is preparing to add hundreds of registrants to its existing cohort of students and graduates – equipping them with the skills and knowledge needed to move the fertilizer industry towards a more sustainable and environmentally responsible future. ■

Fertilizer financial scorecard: more records broken in 2022

PHOTO: YARA

We compare and contrast the 2022 financial performance of selected major fertilizer producers following the publication of fourth quarter results.

Above: Yara's CEO, Svein Tore Holsether (left), signs a memorandum of understanding with Walter Hernández, CEO of El Parque Papas (rights), for the purchase a new fossil-free 'green' fertilizer which Yara is introducing to the market in 2023.

Saskatoon-headquartered Nutrien once again reported record financial results in 2022. Due to its unrivalled scale and global reach, the Canadian company's performance tends to exemplify and set the tone for the whole fertilizer industry.

Indeed, all of the six major listed fertilizer producers highlighted here – Nutrien, Yara, Mosaic, CF Industries, K+S and ICL – reported unprecedented earnings in 2022. These six companies experienced annual earnings growth in the range 71-186 percent last year.

This double- or triple-digit earnings increase comes on top of what, for many, was already a record-breaking set of results in 2021 (*Fertilizer International* 508, p13). Nutrien, for example, has seen its earnings more than triple over the last three years – from $3.7 billion in 2020, to $7.1 billion in 2021 and $12.2 billion in 2022.

The fertilizer industry's recent financial performance reflects the transformation of global fertilizer market fundamentals since the end of the Covid-19 pandemic. A wide ranging set of factors – including supply chain disruptions, the unprecedented effects of Russia's invasion of Ukraine on commodity and energy markets, and the impact of sanctions on Belarusian potash supply – combined to create a market characterised by record fertilizer prices in 2022, triggering deep concerns over both fertilizer availability and affordability (*Fertilizer International* 512, p13).

Another record-breaking year for Nutrien

Nutrien's market capitalisation, at more than $36 billion, is more than double that of its nearest rivals (Figure 1). The world's largest crop nutrient company produces around 25 million tonnes of potash, nitrogen and phosphate products annually from operations and investments in 13 countries, distributing these to agricultural, industrial and feed customers across the globe. Its agriculture retail business serves more than 500,000 farmers worldwide through 2,000 plus retail outlets across the Americas and Australia.

Large rises in selling prices in 2022 – together with a strong retail performance – were a key factor behind the company's record results, with Nutrien reporting:

- An average net realised potash price of $630/t in 2022, more than double the 2021 average of $296/t, largely due to the impact of reduced Eastern European supply.
- An average net realised nitrogen price of $638/t in 2022, an increase of 72 percent on the 2021 average of $371/t. High benchmark prices, particularly for ammonia, were linked to tight global supply and higher energy prices in key nitrogen-producing regions
- Higher benchmark phosphate prices for the full year.

Nutrien's revenues grew by 37 percent year-on-year (y-o-y) in 2022 to $37.9 billion

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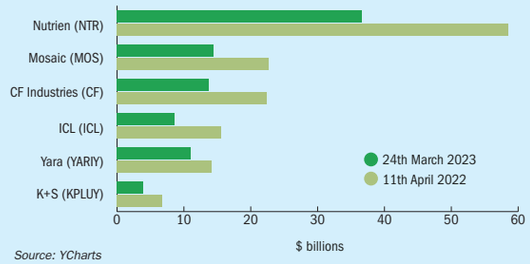
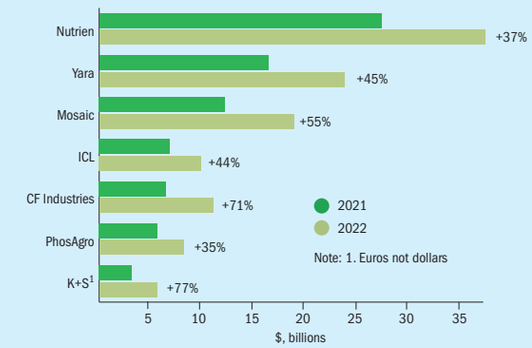
Fig. 1: **Market capitalisation snapshots, 2023 vs 2022**



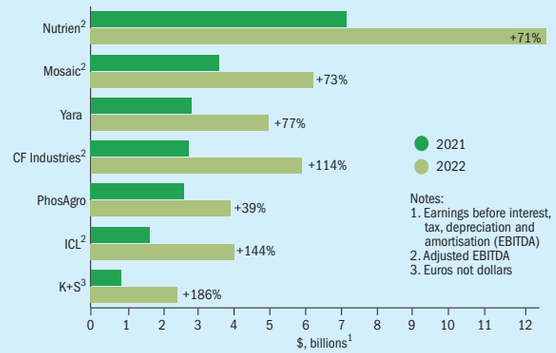
Source: YCharts

Fig. 2: **Revenues, 2022 vs 2021**



Source: Company filings

Fig. 3: **Earnings[1], 2022 versus 2021**



Source: Company filings

(Figure 2). Earnings growth (adjusted EBITDA) for the year was even more impressive; it soared by 71 percent to $12.2 billion (Figure 3). Free cash flow – a measure of profitability – ended 2022 at $8.1 billion (Figure 4), versus $4.3 billion for the preceding year.

Nutrien used the large cash proceeds generated in 2022 to return $5.6 billion to shareholders and invest £2.9 billion in its retail business and strategic production initiatives for potash, phosphates and nitrogen. A total of $400 million, for example, was used to expand the company's retail network by completing 21 acquisitions in Brazil, the US and Australia.

While the company's long-term debt increased by more than $500 million y-o-y to $8.0 billion (Figure 5), debt relative to earnings fell due to strong earnings growth.

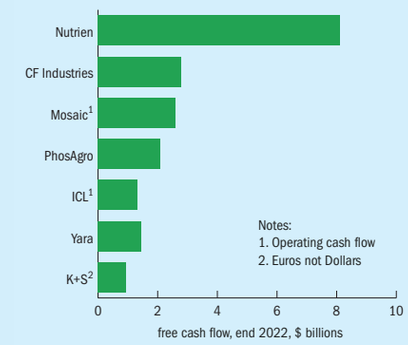
"Geopolitical events caused an unprecedented level of supply disruption and market volatility across agriculture, energy and fertilizer markets in 2022," said Ken Seitz, Nutrien's president and CEO. "Nutrien delivered record net earnings and cash flow in this environment due to the advantages of our world-class production, distribution and retail network."

Nutrien is the world's largest potash producer. The company achieved potash sales of 12.5 million tonnes from its six Canadian mines in 2022. Of this volume, 8.8 million tonnes were destined for overseas markets with the remaining 3.7 million tonnes being sold within North America.

Potash contributed 47 percent to Nutrien's full-year earnings. Potash earnings at $5.8 billion (adjusted EBITDA) in 2022 were 111 percent higher y-o-y, with higher international sales volumes and higher realised selling prices more than offsetting lower sales volumes in North America and cost rises. Nutrien's annual potash sales fell by almost 1.1 million tonnes in 2022, an eight percent y-o-y decline. The costs of goods sold (COGS) for potash also rose to $112/t last year, up by $18/t on 2021, due to higher royalties and mining taxes, according to Nutrien.

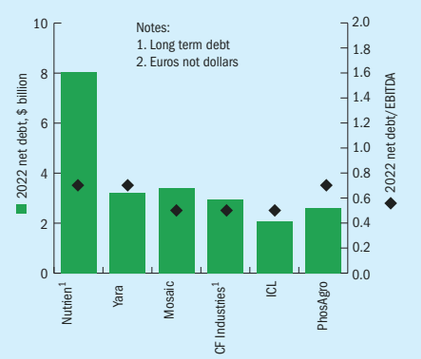
Similarly, Nutrien's nitrogen earnings increased by 70 percent in 2022 to $3.9 billion, thanks to much higher realised selling prices. These more than offset a seven percent y-o-y decline in nitrogen sales volumes to 10.0 million tonnes and rocketing natural gas costs. The average COGS for nitrogen products shot up to $319/t in 2022, a 110 percent hike y-o-y, due to

Fig. 4: **Free cash flow, end 2022**



Source: Company filings

Fig. 5: **Net debt, end 2022**



Source: Company filings

rising natural gas, raw material and other input costs.

Earnings at Nutrien's retail business, Nutrien Ag Solutions reached record levels. These grew by 18 percent y-o-y to reach $2.3 billion for the full year, driven by higher sales and improved margins. Crop nutrients sales for 2022 increased by 38 percent to $10.1 billion with higher selling prices more than offsetting lower sales volumes. Margins on crop nutrients also improved last year due to strategic procurement and the timing of inventory purchases.

Looking ahead, Seitz said: "The outlook for our business is strong as we expect global supply issues to persist and demand for crop inputs to increase in 2023."

Yara – flourishing despite extreme volatility

With a market capitalisation of $11.0 billion (Figure 1), Norway's Yara International is one of the world's largest crop nutrient providers based on total product deliveries.

The Oslo-headquartered company produced 18.3 million tonnes of finished fertilizers and 6.5 million tonnes of ammonia from its global assets in 2022. Finished fertilizer production included:

- 6.0 million tonnes of compound NPKs
- 5.6 million tonnes of nitrates
- 3.9 million tonnes of urea
- 1.7 million tonnes of calcium nitrate (CN)
- 0.7 million tonnes of urea ammonium nitrate (UAN)
- 0.3 million tonnes of single superphosphate (SSP).

Yara calculated that its premium product sales in 2022 generated $1.8 billion in added-value, compared to the commodity fertilizer alternatives, versus a 2021 sales premium of just $280 million.

Yara's annual product deliveries fell sharply by 17 percent y-o-y to 31.6 million last year. These were divided between:

- 22.7 million tonnes of fertilizers
- 7.2 million tonnes of industrial products
- 1.8 million tonnes of traded ammonia.

2022 was a year of many challenges, according to Yara's president and CEO Svein Tore Holsether.

"Our operating environment was extremely volatile. We experienced unprecedented movements in the price of natural gas and we have also had to shift the major part of our raw-material sourcing from Russian to alternative suppliers. We handled these supply chain disruptions well, with limited impact on Yara's production volumes," he said.

Yara's revenues grew robustly in 2022, rising by 45 percent y-o-y to reach a record $24.0 billion (Figure 2). Earnings (EBITDA) growth during the year was even stronger – increasing by 77 percent y-o-y to set a new record of $5.0 billion (Figure 3). Improved margins with higher selling prices more than offset higher production costs and lower deliveries. Regionally:

- European deliveries fell by 19 percent, mainly driven by lower demand due to high fertilizer prices and an increase in imported urea into key European markets. European production was also hit by plant curtailments.
- In the Americas, deliveries were 25 percent lower, this being linked to demand destruction from high prices and the impact of sanctions on Russian and Belarusian suppliers.
- Deliveries to Africa and Asia were 12 percent lower with higher fertilizer prices and weaker farmer profitability depressing demand.

Yara's energy prices reached record levels last year:

- Its global weighted average gas cost averaged $21.8/MMBtu in 2022 versus $9.3/MMBtu in 2021
- Its European weighted average gas cost averaged $31.8/MMBtu in 2022 versus $11.7/MMBtu in 2021

More positively, Yara reported the following double-digit price rises for its premium product offerings in the year's last quarter:

- 56 percent y-o-y increase in the average realised price of calcium ammonium nitrate (CAN) to $684/t
- 37 percent y-o-y increase in the average realised global compound NPK price to $874/t (average grade).

Yara said higher fertilizer prices in 2022 saw farmers and distributors in some regions

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postpone purchases – a market environment that created supply overhangs and prompted price declines and low market activity as 2022 ended and 2023 began. There is, however, an upside in these fertilizer price declines, in Yara's view, as they have improved affordability and therefore provided scope for a potential catch-up in fertilizer demand in most regions.

Record earnings for Mosaic

Florida-headquartered The Mosaic Company is the world's leading combined phosphate and potash producer with a market capitalisation of $14.5 billion (Figure 1). The company sold around 24 million tonnes of products in 2022, with sales volumes split between three business segments:

- Potash segment: 8.1 million tonnes
- Phosphates segment: 6.6 million tonnes
- Mosaic Fertilizantes: 9.4 million tonnes.

Similar to the preceding year, Mosaic reported record results in 2022. The company delivered earnings growth of 73 percent y-o-y to $6.2 billion (adjusted EBITDA) (Figure 3). This was achieved from full year revenues of $19.1 billion (Figure 2).

Phosphate earnings (adjusted EBITDA) totalled $2.2 billion in 2022, up from $1.7 billion in 2021. This reflected a $240/t increase in the average diammonium phosphate (DAP) selling price to $804/t last year. Higher prices more than offset lower phosphate production and sales volumes. The latter were negatively affected by a combination of Hurricane Ian, unplanned operational outages, and a slower-than-expected recovery in demand in 2022's second half. Sales volumes for Mosaic's MicroEssentials product were down on last year but still totalled 2.8 million tonnes in 2022. The gross margins achieved from this premium product last year were on average $33/t higher than the commodity phosphate equivalent.

The company's potash earnings (adjusted EBITDA) totalled $3.1 billion in 2022, up from $1.3 billion in 2021. In a new milestone, the company's Esterhazy K3 mine reached an annual run rate target of 5.5 million t/a tonnes in the first half of 2022. The addition of an eleventh miner in the fourth quarter will increase K3's output further. Colonsay mine, which temporarily ceased production in the fourth quarter of last year due to market conditions, is expected to restart in the first half of 2023.

Full year earnings (adjusted EBITDA) from Mosaic's Brazilian subsidiary Mosaic Fertilizantes, meanwhile, reached $1.0 billion in 2022, up from $821 million in 2021. The company's domestic distribution business saw its Brazilian market share grow to around 18 percent in 2022. Combining both distribution and production volumes, Mosaic Fertilizantes now accounts for 23 percent of all fertilizer sales in Brazil.

"Mosaic delivered record results in 2022, and we expect favorable agricultural markets to continue in 2023," said Joc O'Rourke, Mosaic's president and CEO. "Despite significant volatility through the year, our business was able to deliver strong free cash flow and return significant capital to shareholders, while also reinvesting in the business."

He added: "Mosaic is well positioned to continue delivering strong results in 2023, thanks to our low cost potash operations, our portfolio of value-added phosphate products, and our leading footprint in Brazil, the world's fastest-growing major agricultural market."

Looking ahead, Mosaic expects strong agricultural commodity prices to drive a recovery in fertilizer demand in 2023. Globally, demand for grain and oilseeds remain high, while stock-to-use ratios are at their lowest levels in more than 25 years. A combination of factors – food security concerns, rising biofuel consumption, and crop production headwinds – all suggest that crop prices will remain elevated through 2023 and beyond, according to Mosaic. Consequently, it expects strong global fertilizer demand 2023 with growers seeking to maximise their yields.

Mosaic anticipates first quarter phosphate and potash sales volumes, of 1.7-1.9 million tonnes (DAP price averaging $625-$675/t) and 1.8-2.0 million tonnes (MOP price averaging $425-$475/t), respectively.

CF Industries reports outstanding 2022 results

Leading North American and UK nitrogen producer CF industries was yet another major fertilizer producer reporting record results in 2022. Full-year revenues ($10.0 billion) and earnings ($5.9 billion adjusted EBITDA) rose y-o-y by 71 percent and 114 percent, respectively (Figures 2 and 3). Full year net cash from operating activities ($3.9 billion) and free cash flow ($2.8 billion, Figure 4) also both set new company records.

The Illinois-headquartered company has a market capitalisation of $13.7 billion (Figure 1). It partly attributed its strong financial performance to higher average selling prices across all of its nitrogen product segments. These increased by 88 percent y-o-y to average $936/t in 2022. This elevated price level compares to average selling prices of $498/t in 2021 and $271/t in 2020.

This large hike in the selling price last year was linked to decreased global supply availability. "Higher global energy costs reduced global operating rates and geopolitical factors disrupted the global fertilizer supply chain," CF said.

The company's costs were also affected by higher natural gas prices. These average $7.18/MMBtu in 2022 compared to $4.21/MMBtu in 2021.

Total products sold in 2022 were slightly down at 18.3 million tonnes versus 18.5 million tonnes for 2021. CF's sales volumes on a product basis last year were as follows:

- 9.8 million tonnes of ammonia
- 4.6 million tonnes of granular urea
- 6.7 million tonnes of UAN (32%)
- 1.5 million tonnes of AN.

Lower sales volumes for ammonia, ammonium nitrate (AN) and other products were mostly offset by higher urea and urea ammonium nitrate (UAN) sales.

"The CF Industries team delivered outstanding results in 2022, producing record financial performance for the fourth quarter and full year by working safely, operating our manufacturing and distribution assets extremely well, and serving our global customer base," said Tony Will, CF Industries' president and CEO. "At the same time, we drove significant progress across our clean energy and strategic initiatives by entering into our landmark carbon capture and sequestration partnership with ExxonMobil, commencing a front-end engineering and design study for our proposed blue ammonia plant in Louisiana."

Looking ahead, CF Industries expects global nitrogen prices to be supported by demand for the northern hemisphere's spring 2023 application season. Over the longer-term, the company believes that the global nitrogen supply-demand balance will remain tight out to 2025 – due to high agricultural demand and challenging nitrogen production economics for European and Asian producers.

"Looking ahead, we believe that the global nitrogen supply-demand balance and global energy cost structure will continue to present attractive margin opportunities for our cost-advantaged network," said Tony Will. "As a result, we expect to drive strong cash generation in the years ahead, enabling us to make disciplined investments in our clean energy initiatives to meet what we believe will be significant global demand for low-carbon ammonia."

K+S achieves best results in company history

Revenues at German potash and salt producer K+S grew by an impressive 77 percent y-o-y to €5.7 billion (Figure 2), while earnings (EBITDA) for the year almost doubled – rocketing by a sector-leading 186 percent to €2.4 billion (Figure 3). Free cash flow also rose by more than 100 percent y-o-y to €1.2 billion.

With a market capitalisation of €3.9 billion, K+S is Western Europe's largest potash producer, having a global market share of around nine percent, prior to the invasion of Ukraine and the sanctions placed on Belarus. The company is also growing its portfolio of speciality fertilizers. These products are chloride-free and/or supplement potassium with other elements such as magnesium, sulphur, sodium and micronutrients.

> **"The six major fertilizer producers highlighted here generated annual earnings growth in the range 71-186 percent last year."**

"2022 was an outstanding year for K+S," said its chairman, Dr Burkhard Lohr. "We are also optimistic for the current year. [2023] EBITDA earnings are expected to range between €1.3-1.5 billion – that would be another very good result!"

K+S said its outstanding 2022 results were supported by significantly higher average prices for its potash-containing products. The company's agricultural segment sold 7.1 million tonnes of fertilizer products in 2022 (down from 7.6 million tonnes in 2021). This sales volume was divided between 4.4 million tonnes of potash and 2.7 million tonnes of speciality fertilizers. K+S fertilizer products sold at an average price of €628/t in 2022 – more than double the average of €298/t in 2021.

"When looking at the business performance, it becomes clear that the largest share of our earnings improvement in 2022 is attributable to the fertilizer business," said Dr Lohr. "Demand in the agriculture customer segment was extremely strong in the first half of the year and encountered limited availability on the world market."

The decline in potash exports from Russia and the block in potash deliveries from Belarus created a global potash shortfall of around 15 million tonnes last year. K+S had benefitted from a potash buying shift towards other suppliers, particularly in Northern and Eastern Europe where Russian and Belarusian market share was high.

"As a result of this development, potash prices again rose very significantly in all sales regions [in the first half of 2022]," commented Dr Lohr. "In Brazil, the 1,000 US dollar per tonne mark was even exceeded."

The high average selling prices achieved by K+S more than offset lower sales volumes and higher costs. The company also avoided large energy cost increases in 2022 – potentially in the three-digit million euro range – by concluding long-term gas supply contracts at an early stage. K+S has now secured almost all its natural gas supply requirement for 2023 and most of its requirement for 2024, according to Dr Lohr.

K+S used some of its large cash proceeds to eliminate its debts last year, transforming a net debt of €606 million in 2021 into a €245 million surplus in 2022. This is an impressive turnaround, given that the company's net debt had previously been running at around €3.2 billion between 2018 and 2020.

Dr Lohr was very positive about prospects for 2023. "We expect good demand in the market and an attractive price level overall, although at a lower level than in the previous year. Most importantly, profitability in agriculture is intact in all sales regions. The expected increase in demand will be accompanied by limited supplies of potash from Russia and Belarus again this year," he said.

Record annual sales and earnings at ICL

Israel's ICL Group is a leading producer of potash, phosphates and speciality fertilizers with a market capitalisation of around $8.6 billion (Figure 1).

The company reported record annual sales and earnings across three of its business segments in 2022 (Industrial, Phosphate Solutions and Growing Solutions). Potash production at ICL's Dead Sea operations also exceeded four million tonnes last year, a new annual record.

ICL's annual revenues grew by 44 percent to $10.0 billion in 2022 (Figure 2). Full-year earnings (adjusted EBITDA) also rose by 144 percent y-o-y to $4.0 billion (Figure 3). Operating cash flow, at $1.3 billion in 2022, was also up by almost one-fifth on the previous year (Figure 4).

The Potash ($2.0 billion) and Phosphate Solutions ($1.0 billion) business segments contributed 50 percent and 24 percent, respectively, to overall company earnings in 2022. ICL's speciality fertilizer business, Growing Solutions, also generated 11 percent of earnings ($448 million).

ICL's total potash output (4.7 million tonnes) in 2022 was up by 177,000 tonnes annually due to operational improvements at both its Israeli (Dead Sea) and Spanish (Cabanasses) production sites. This included the connection of the ramp at ICL's Cabanasses mine in Spain.

Overall, ICL's potash business generated revenues of $3.3 billion in 2022, up by 87 percent on the previous year. This was helped by a big hike in the average realised potash price to $643/t in 2022, up from an average of $337/t in 2021.

Polysulphate production at ICL's Boulby mine in the UK, meanwhile, also continues to rise. Production of this polyhalite product – 953,000 tonnes in 2022 – was up by 21 percent y-o-y.

Total revenues at ICL's Growing Solutions business segment – which includes polyhalite products – increased to $2.4 billion in 2022. Higher prices for straight products (MKP/MAP/PeKacid), liquid and water-soluble NPKs, and controlled-release fertilizers (CRFs) offset lower sales volumes. Revenues from the FertilizerpluS polyhalite product range also increased last year due to higher selling prices.

"ICL delivered record sales of more than $10 billion and EBITDA of more than $4 billion for 2022," said Raviv Zoller, ICL's president and CEO. "Throughout the year, we navigated global uncertainty, supply chain challenges and cost inflation, while simultaneously focusing on operating efficiency and productivity, introducing new innovative products, and delivering value to all of our stakeholders."

Looking ahead, ICL is expecting full year earnings (adjusted EBITDA) in the range $2.2-2.4 billion this year, with $1.1 billion of this generated by its speciality businesses. ■

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Clean ammonia projects and technologies

New methods for low-carbon ammonia production are emerging, while project activity is also rising rapidly.

AMMONIA ENERGY ASSOCIATION

Scaling-up low-carbon ammonia production

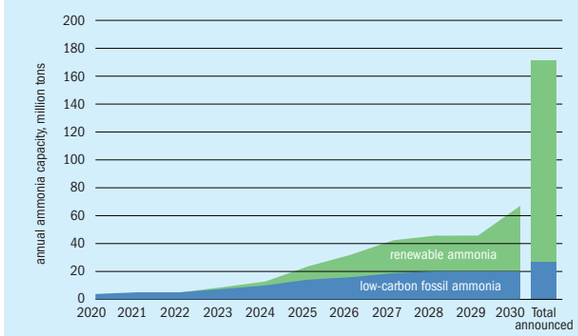
Trevor Brown and Kevin Rouwenhorst

A lot of low-carbon ammonia plants have been announced in recent years – so many, in fact, that you've probably lost count.

The more than 100 projects announced so far have a combined capacity of 172 million tonnes for low-carbon ammonia. That's equal to 95 percent of today's ammonia demand of around 180 million tonnes.

While some of these plants are already operational, most are still in the feasibility and pre-FEED (front-end engineering design) stages. One simple, key factor will determine how many of these projects succeed: demand. To de-risk project financing and support offtake agreements, clear demand signals are therefore required from both regulators and customers alike.

Fig. 1: **The total capacity of announced low-carbon projects**



AEA, 2023. Low-Carbon Ammonia Plants: Global Project List

A global project list

The Ammonia Energy Association (AEA) is an industry body that promotes the responsible use of ammonia in a sustainable energy economy. Our mission encompasses the decarbonisation of ammonia production on the supply side, as well as the adoption of ammonia in energy markets on the demand side. The AEA's membership includes more than 220 corporations from around the globe, representing the full value chain across multiple sectors.

More than 100 low-carbon ammonia plants are either operating today or have been announced and are in the project pipeline to be built in coming years. If every single announced project eventually enters operation, the combined capacity of these plants would be enough to produce more than 172 million tonnes of low-carbon ammonia each year (Figure 1).

The AEA has been tracking these projects since the first wind-to-ammonia pilot plant began operating in 2013. Now, for the first time, we are publishing a report in May this year containing the complete list of all low-carbon ammonia projects that are operational or have been announced, based on publicly available data.

This list includes relevant information about each low-carbon ammonia plant – the location, start-up year, company, capacity, feedstock, and technology – taken from a more detailed market intelligence database that is only available to members of the AEA.

The report also provides an analysis and assessment of the project list. This highlights observed trends in geography, timing, technology, and the capacity of low-carbon ammonia plants – all of which show significant shifts from existing market dynamics.

As part of this analysis, the list of plants has been divided into two categories: fossil-based and renewable. The renewable category primarily includes ammonia plants based on water electrolysis powered by renewable energy, although some projects also propose to use bio-based feedstocks. These are commonly termed 'green' ammonia plants.

The fossil-based category primarily includes fossil fuel ammonia plants incorporating carbon capture and storage (CCS) or utilisation (CCU). These are commonly

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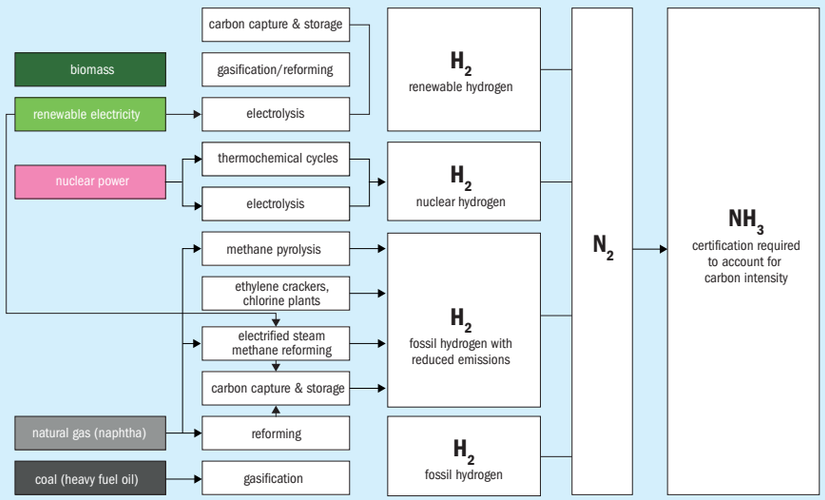
Fig. 2: **Low-carbon ammonia production pathways**



Source: IRENA/AEA, 2022. Innovation Outlook: Renewable Ammonia

termed 'blue' ammonia plants. The fossil-based category also includes plants based on methane pyrolysis or those that consume by-product hydrogen from other processes. Also included in this category are ammonia projects that propose to compensate for carbon emissions via the purchase of forestry offsets instead of through direct emissions mitigation measures. All these production pathways are summarised in Figure 2.

It is important to note that the two categories – fossil-based or renewable – do not necessarily indicate the carbon intensity of ammonia production, as certification (i.e., measurement of the carbon footprint) of the ammonia generated is required for that. Our report chooses to analyse these two categories separately because we have observed that separate trends and drivers apply to each – resulting in distinctly different technologies, cost curves, region-specific regulatory regimes, resource availability, and long-term scalability etc.

What is low-carbon ammonia?

Currently, there is no available global definition of 'low-carbon' ammonia, although various regions and organisations have defined emission thresholds, renewability criteria or other sustainability metrics.

The AEA's list is therefore technology neutral, being inclusive of all announced projects that appear to have potential for reducing the carbon intensity of ammonia production. Moreover, this list includes decarbonisation pathways that might deliver useful emission reductions (e.g., 10-25 percent cuts) even though these would fail to meet any commonly held threshold for low-carbon products (often defined as >60 percent reduction).

Hybrid ammonia plants, where decarbonisation technologies are partially installed at an existing ammonia plant, create additional complexity. That's because it's not always clear exactly what proportion of the plant's capacity will be low-carbon. We have therefore made a best estimate where such information is not publicly available.

Each of the projects listed could well produce ammonia with a different carbon intensity. Indeed, a single ammonia plant might produce batches of ammonia with different carbon intensities over its lifetime, depending on the month, day, or hour – even, perhaps, according to the market it intends to supply.

What is clear, however, is that clear and credible certification of the carbon intensity (and other relevant sustainability attributes) of ammonia will be necessary in future to enable markets and regions to specify what products are (or are not) acceptable. Recognising this, the AEA is developing a global ammonia certification scheme, which we intend to pilot in 2024.

Is this enough ammonia?

The existing and announced low-carbon ammonia plants would produce a lot of ammonia. 172 million tonnes per annum of ammonia is equivalent to 75 percent of today's global installed ammonia capacity (228 million t/a) (Figure 3), or 95 percent in terms of today's total global demand for ammonia (180 million t/a). However, many of the projects included in the collective 172 million t/a capacity total have not yet specified their start-up date.

Nevertheless, the 68 million t/a of low-carbon ammonia announced to start-up by 2030 is more than sufficient for supplying near-term markets. These include low-carbon fertilizers, explosives, or industrial feedstocks, as well as nascent markets like maritime fuel and power generation, and the use of ammonia as a carrier for transporting hydrogen.

In the long-term, however, we'll need many more low-carbon ammonia plants than have been announced so far: by 2050, in a 1.5 degrees aligned world, the global market for low-carbon ammonia could range from 540-1,140 million tonnes, according to the Ammonia Sector Transition Strategy published by the Mission Possible Partnership in late 2022. These volumes are divided between the following end-markets:

- Up to 110 million tonnes as a hydrogen carrier
- 35-105 million tonnes for power generation
- 210-250 million tonnes for fertilizer and existing industrial applications
- 295-670 million tonnes for shipping fuel.

The AEA's project data confirm that supply is not a bottleneck preventing these markets from developing. Low-carbon ammonia production is, after all, a very mature technology – given that the first industrial-scale renewable ammonia plant started up in 1921!

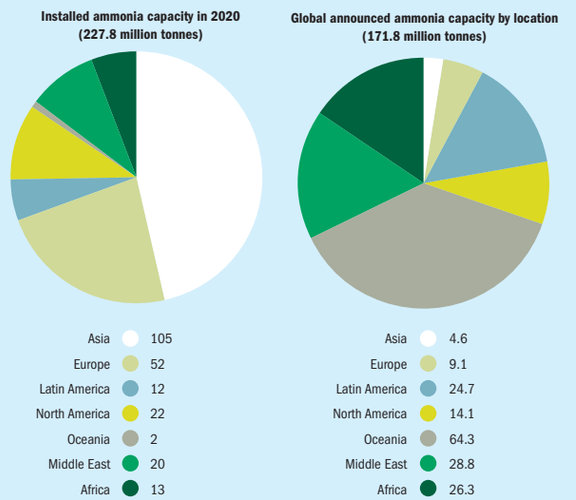
Low-carbon ammonia supply can also expand at the speed required to meet demand. But, to enable these projects to reach financial close and begin construction, clear demand signals will be required, from regulators and customers, to support offtake agreements and de-risk project financing.

Will low-carbon ammonia be available where and when we need it?

If all this supply were to come online, it would represent a swift expansion, quadrupling between 2020 and 2030 the volume of ammonia shipped internationally each year. Many additional investments have been announced, not included in this project list, that would expand the necessary infrastructure for storage, shipping, conversion, and delivery of ammonia around the world.

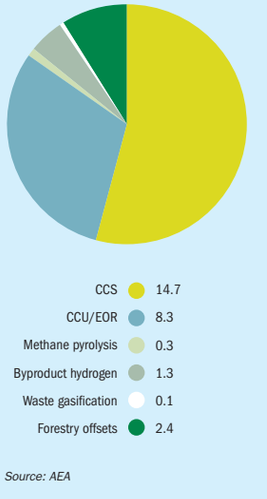
It is reasonable to expect that most of the announced low-carbon ammonia projects are looking to ship their products internationally, because we can observe a significant shift in the location of announced low-carbon ammonia plants versus the current location of existing ammonia plants (Figure 3).

Fig. 3: **Global ammonia capacity, by region. Installed in 2020 (left) and announced projects (right)**



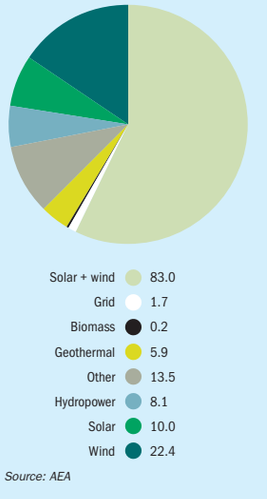
Source: AEA

Fig. 4: **Announced low-carbon fossil ammonia capacity by technology (27.1 million tonnes total)**



Source: AEA

Fig. 5: **Announced renewable ammonia capacity by technology (144.7 million tonnes total)**



Source: AEA

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Currently installed ammonia capacity (227.8 million t/a) is heavily centred in Asia. Capacity in this region (105.0 million t/a) represents almost half of global ammonia capacity, with China and India as established major producers (Figure 3, left). Europe, including Russia, represents almost another quarter of global capacity (52.6 million t/a). Most of the ammonia capacity in this region is dedicated to fertilizer production.

By contrast, less than 10 percent of announced low-carbon ammonia capacity (171.8 million t/a) is located in either Asia (4.6 million t/a) or Europe (9.1 million t/a). Instead, most of the announced low-carbon ammonia capacity is situated in Oceania, primarily Australia. Many other projects are located in South America, particularly Chile, as well as in the Middle East and Africa (Figure 3, right).

Some of the low-carbon ammonia plants scheduled to be built out over the next decade are very, very large (e.g., 10 million t/a capacity), initially supplying but ultimately outgrowing any domestic markets for fertilizer.

Will low-carbon ammonia be renewable or fossil-based?

It is observable from the data that low-carbon fossil-based ammonia is already available at greater volumes than renewable ammonia. In 2020, the capacity of low-carbon fossil-based ammonia capacity exceeded four million t/a, although none of this was specifically marketed as low-carbon.

Fossil-based capacity also represents the majority of the low-carbon ammonia capacity announced to come online in the first part of this decade – a fivefold expansion of supply to more than 20 million tonnes. This trend makes sense since fossil-based capacity scales up more quickly than renewable capacity, as these projects are often:

- Existing assets
- Using mature technologies
- In areas with existing industrial infrastructure.

Fossil-based projects are therefore smaller and quicker to develop investments that are easier to de-risk than renewable projects – which, in contrast, are generally:

- New-builds
- With new technologies
- In new places.

Given that renewable ammonia was barely produced in 2020, the announced project pipeline represents an exponential scale-up of renewable ammonia supply that looks set to outpace fossil-based supply before 2030. Some 47 million tonnes of renewable ammonia capacity have been announced to come online by 2030, more than double the volume of low-carbon fossil-based ammonia over this period.

This trend also appears to continue over the long-term, as there is significantly (five times) more renewable ammonia under development than fossil-based ammonia. In total, 27.0 million tonnes of low-carbon fossil-based ammonia is under development today (Figure 4), versus 144.7 million tonnes of renewable ammonia capacity (Figure 5).

These differences may be explained by resource limits. Expansion of fossil-based low-carbon ammonia capacity, for example, is physically constrained by the availability of natural gas and suitable sites for CO_2 sequestration. The physical constraints on the development of renewable ammonia projects, meanwhile, are primarily the availability of land and water providing high-quality renewable resources, and the manufacturing capacity for electrolysers. In the long-term, these differing constraints could allow renewable ammonia capacity to continue expanding faster than fossil-based ammonia capacity.

Many of the announced low-carbon ammonia projects will need a host of factors to be in place before they can reach financial close and begin construction. These include:

- Clear market signals and the long-term regulatory confidence needed to support offtake agreements
- Technology and manufacturing scale-up and deployment to push down costs
- The successful demonstration of new technologies and new markets
- Certification to verify the carbon intensity of ammonia products.

CASALE

Decarbonising ammonia production

Sergio Panza, technology manager

The development of green and blue ammonia production processes is largely being driven by carbon dioxide reduction commitments and the introduction of carbon taxes.

Blue ammonia is recognised as the lower cost and more immediate option for large-scale clean ammonia production. The recent natural gas price surge, meanwhile, together with the greater availability of low-cost renewable energy sources, is placing green ammonia on the development fast track.

As well as the installation of new production capacity, the retrofitting of green and blue ammonia technologies, by allowing the cleaner operation of existing production plants, can also help ammonia producers meet corporate and legislative targets.

Casale's strategy

Casale strategy for decarbonising ammonia production is based on three pillars:

- Moving towards zero carbon dioxide emissions by updating existing plants
- Designing new blue ammonia plants which capture and sequester carbon dioxide generated by conventional grey ammonia generation with natural gas
- Designing new green ammonia plants which avoid carbon dioxide emissions by using renewable energy and feedstocks.

Updating existing plants

Starting with the updating of existing production units, Casale can offer a customised approach based on process optimisation, improved equipment design and the integration of operating units.

The clean ammonia solutions developed by Casale are applicable to any ammonia production process, not just those based on its own proprietary technologies. Casale's track record in the ammonia industry also means its approach to clean ammonia projects can draw on the combined knowledge and expertise gained from its worldwide plant reference list.

The motivation for producers to update and modify their ammonia plants to reduce carbon dioxide emissions is usually provided by company environmental targets and/or the need for compliance with carbon legislation (e.g., the EU emissions trading scheme) or to benefit from policy incentives such as the 2022 US Inflation Reduction Act.

Clean ammonia projects at existing production plants offer the following advantages:

- Increased plant capacity and energy savings
- An accurate forecast of the necessary investment costs – these being much lower that the plant's original construction cost
- A typically short payback time for any plant modifications – usually less than three years
- Fast implementation – with plant modifications generally completed within two years.

Achievable CO_2 emission reductions for these kind of projects range from 10-100 percent. An existing ammonia plant can be therefore turned from 'grey' to 'blue' and finally to 'green', as the following two project case studies show.

PHOTO: CASALE

Casale's revamp of the CF Braun ammonia plant focused on the reduction of carbon dioxide emissions.

First case study: This describes an upgrade project at a long-established ammonia plant licenced by CF Braun. In this project, the reduction in carbon dioxide emissions was combined with a plant capacity increase.

The modifications to the plant were designed to increase the CO_2 capture rate from 62-69 percent and raise plant capacity by seven percent.

To meet these targets, modifications to the most energy intensive sections of the plant were necessary, namely:

- The reforming section
- The synthesis loop with the Casale converter
- The CO_2 removal section
- The steam system.

The integration of Casale's proprietary and third party technologies was central to this revamp project. The payback period for the project was less than three years.

Quite remarkably, this upgrade was successfully accomplished on an ammonia plant that was more than 50 years old. Despite its age, the plant remained profitable because the existing process technology was still modern and already quite efficient.

Second case study: The next case study describes a project where the carbon dioxide emitted by an operational methanol plant was captured and utilised to produce urea and then more melamine (Figure 1). This project provides an excellent example of how an existing production plant can be modified for carbon capture and utilisation (CCU) via the integration of new production units.

In this project, the release of carbon dioxide to the atmosphere was minimised in two ways: by either storing the captured and sequestrated CO_2 or fixing this inside a product (melamine).

Casale installed one of the world's biggest carbon dioxide removal (CDR) units at this plant to capture about 400,000 tonnes of CO_2 annually. Some 82,000 tonnes of this amount was then sequestrated within the melamine product.

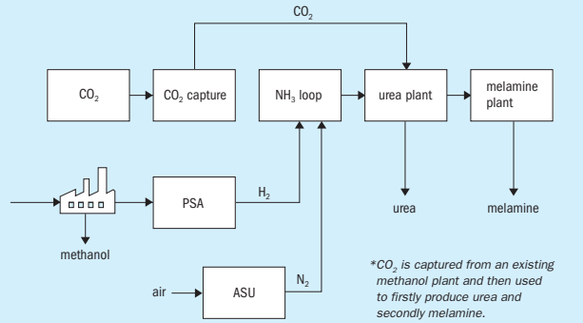
In general, the approach developed by Casale for converting existing grey plants to blue ammonia production (Figure 1) can achieve a carbon capture rate of 95 percent or more. For operators, the advantages of this blue ammonia conversion scheme include the ability to:

- Carry on using their existing natural gas feedstock
- Combine carbon dioxide emissions reduction with a capacity increase and lower energy consumption
- Benefit from a rapid payback time.

Plants that are already operative can also benefit from so-called hybridisation projects. These integrate electrolyser units to generate a green hydrogen feed for the existing ammonia plant.

Hybridisation enables existing grey production plants to be partially or completely replaced by green ammonia, hydrogen or methanol production (Figure 2). Valuably, hybridisation projects can also increase capacity without increasing either natural gas consumption or carbon dioxide emissions. In this concept, investment costs and modifications to the existing

Fig. 1: **Integrated 'blue' production complex***



**CO$_2$ is captured from an existing methanol plant and then used to firstly produce urea and secondly melamine.*

Source: Casale

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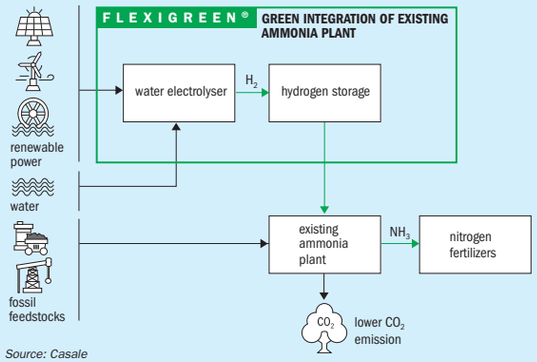
Fig. 2: **Hybrid ammonia plants can be created by installing a new green ammonia production unit alongside existing 'grey' ammonia production**



Source: Casale

asset are minimised, compared with the construction costs for a new plant of the same capacity.

However, in hybrid plants, care and attention must be given to variations in the renewable power used to generate hydrogen. This is because fluctuations in the plant's power supply – and therefore in the volumes of green hydrogen generated – could have a negative impact on the safe and reliable operation of equipment, as these are normally designed for steady-state operations. Fortunately, Casale has already developed patent-pending technologies designed to overcome this specific issue.

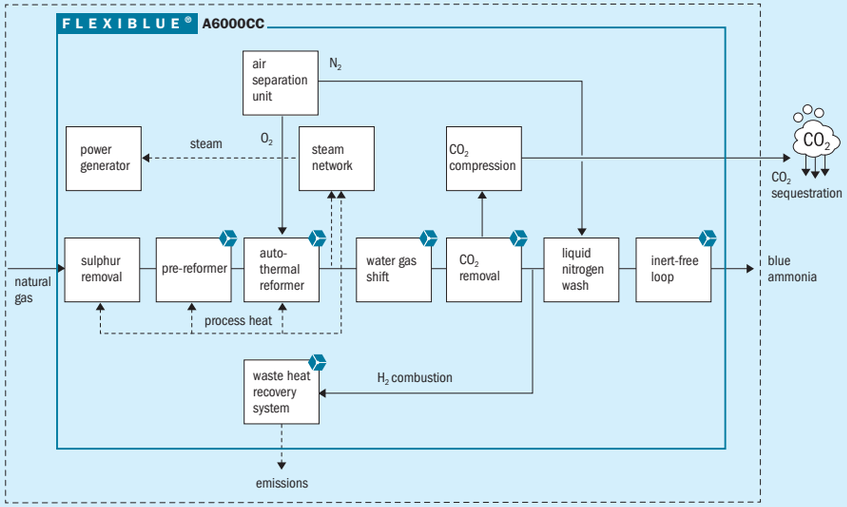
In one of Casale's most challenging hybridisation projects, an existing grey ammonia production plant, licensed by Pritchard, was updated and converted to 100 percent green production. This complete hybridisation project, one of the most important globally, fully replaced the hydrogen generated at the plant's front end with hydrogen generated by electrolysis.

The ability to minimise capital expenditure is one of the most attractive reasons for converting an existing grey production plant to green production. Project expenditure can be kept low because many of the existing units and sections can be reused. That includes the synthesis loop, the demi water preparation unit, and the CW system.

The main achievement of the Pritchard plant hybridisation project were:

- 100 percent reduction in carbon dioxide emissions
- This ended 700,000 tonnes of carbon dioxide emissions to the atmosphere annually
- An associated 30 percent ammonia production capacity increase, from 900 tonnes per day to 1,150 t/d.

Fig. 3: **Casale's carbon capture process for blue ammonia production**



Source: Casale

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New clean ammonia plants

New blue and green ammonia plant designs are also being developed, based on carbon capture and sequestration (CCS) and carbon-free production technologies, respectively. This is happening in parallel to the clean ammonia upgrades and conversions at operational plants described above.

The decarbonisation of industry, including ammonia production, will be necessary to meet the climate goals endorsed by 196 countries in the 2015 COP21 Paris Agreement. By 2030, the switch to net zero should become competitive for many sectors representing more than 70 percent of global emissions, according to the agreement. Currently, many new green and blue ammonia projects are being announced across globe, backed by public and private investor interest in these new opportunities.

Casale's approach to – and main technologies for – blue and green production of hydrogen and ammonia are outlined below.

Blue ammonia plants

The main motivations for investing in new blue ammonia plants are:

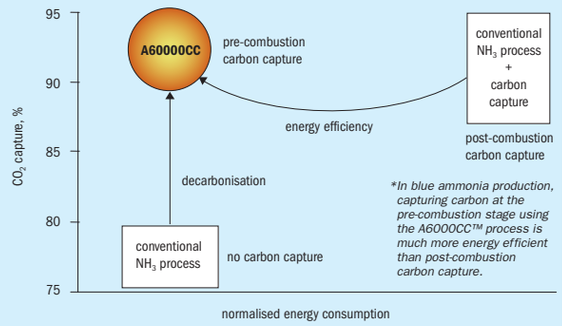
- Their ability to drastically reduce carbon emissions while still keeping natural gas as a feedstock
- Avoiding the limitations associated with green ammonia production such as renewable energy availability and the need to incorporate costly electrolyser units.

The installation of a new Casale-designed blue ammonia unit provides additional advantages. In particular, it offers production at a very high capacity using technologies that are closely related to those already used at standard ammonia plants – and therefore have similar investment costs.

The carbon capture process developed by Casale to produce blue ammonia, known as A6000CC™, has a single line capacity of up to 7,000 tonnes per day. The scheme converts a conventional ammonia plant into a blue plant by the addition of pre-combustion stage to sequester carbon at a capture rate of 95-99 percent (Figure 3).

Blue ammonia production using the A6000CC™ process (Figure 4) has the following features:

Fig. 4: **Carbon capture at the blue ammonia pre-combustion stage***



Source: Casale

- A pure autothermal reformer (ATR) process
- Carbon dioxide is recovered in a single CDR section installed in the plant's front-end.
- A hydrogen rich stream, taken downstream of CO_2 removal section, is used as a furnace fuel gas for the various pre-heating services.
- The CO_2 separated after purification and compression is delivered at a pressure above 150 bar

Table 1: **A60000CC™ performance**

Specific energy consumption (Gcal/$MtNH_3$)	7.4
CO_2 removal efficiency (%)	>95
Total CO_2 emissions to atmosphere (tCO_2/tNH_3)	0.08

Source: Casale

- The use of a liquid nitrogen wash system keeps the synthesis loop inert free.

Capturing carbon capture at the pre-combustion stage using the A6000CC™ process (Figure 4) is much more energy efficient than post-combustion carbon capture. That includes both energy consumption within the BL (battery limit, i.e., the perimeter of a specific industrial process) and that used by utilities.

The main components incorporated into the A6000CC™ scheme – the autothermal reformer, ASU, CO_2 capture units and ammonia converter – are well known and widely referenced at similar operational scales. The wide adoption of the underlying technology at similar plants means that Casale's blue ammonia production process does not pose any new technical or operational challenges.

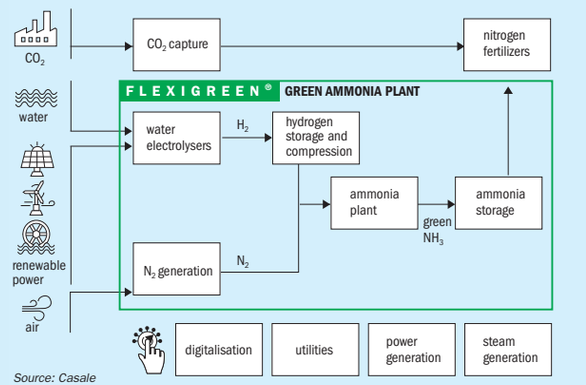
The A6000CC™ process performs well (Table 1) and is suitable for installation at new plants and for updating existing plants. Casale does, however, provide other technology options (H400CC™ and H1000CC™) for blue revamps, as discussed below.

Table 2: **Performance of Casale's two blue hydrogen production technologies**

	H400CC™ partial oxidation (POX) process	H1000CC™ autothermal reformer (ATR) process
Gross natural gas consumption (MJ NG/Nm^3 H_2)	<15.5	<14.5
Energy conversion efficiency (MW H_2/MW NG)	>0.7	>0.75
CO_2 removal efficiency (mol CO_2 CCS/ molCO_2 NG)	>0.99	>0.99
Carbon Intensity of produced hydrogen (kg CO_2 /kg H_2)	<0.1	<0.1

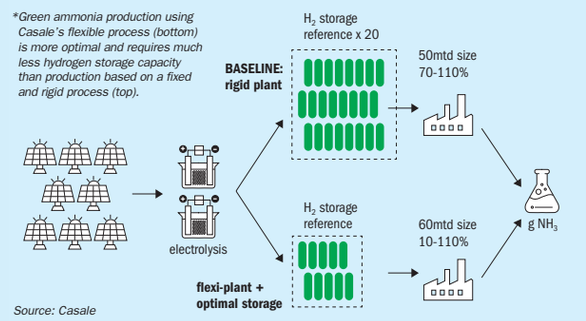
Source: Casale

Fig. 5: **The green ammonia plant**



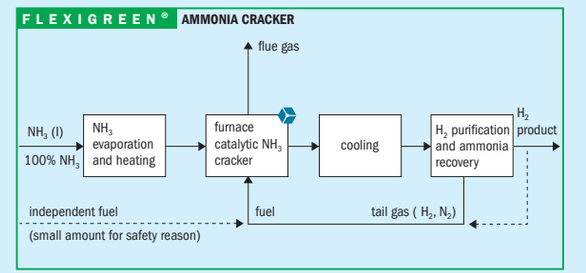
Source: Casale

Fig. 6: **Green ammonia production using Casale's flexible process***



Source: Casale

Fig. 7: **Schematic of Casale's ammonia cracking process**



Source: Casale

Casale has been able to develop this new business area due to its experience and track record in syngas generation. The achievable carbon intensity for both blue hydrogen processes is lower than 0.1 kg CO_2/kg H_2, while their energy consumption is in line with standard plants. Notably, Casale already has an ATR in operation with an equivalent hydrogen production capacity of more than 600,000 Nm^3/h.

- **The H400CC™ process** generates syngas through partial oxidation (POX). It can achieve blue hydrogen capacity of up to 100,000 Nm^3/h in a single line
- **The H1000CC™ autothermal reformer (ATR) process** is designed to achieve blue hydrogen capacity of between 200,000-400,000 Nm^3/h in a single line.

Green ammonia plants

The green ammonia project pipeline is developing fast. Indeed, some new green ammonia plants expected in the next decade are up to ten times larger than blue ammonia plants.

As stated previously, meeting company climate goals or compliance with legislation are among the main motivations behind green ammonia projects. The ability of these projects to, firstly, deliver the lowest possible carbon emissions and, secondly, benefit from access to sustainability-linked finance is also advantageous.

Casale's green ammonia production process (Figure 5) is based on the experience gained from designing and revamping hundreds of ammonia plants worldwide. By integrating its own proprietary and third-party technologies, Casale can customise the design of green ammonia plants and offer these in a wide range of capacities.

Casale can take complete responsibility for all the sections of the green ammonia plant including those sections with technologies supplied by third parties. The company is recognised as a global ammonia market leader and a benchmark

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technology provider for key sections of the green ammonia plant, such as the Haber Bosch loop.

Casale's design experience builds on an extensive track record. Its reference list includes more than 90 new onstream hydrogen and nitrogen plants using fossil fuel feedstocks. Casale can also provide hundreds of references for completed revamp projects.

The key features of Casale's green ammonia plants design are:

- The very high flexibility of its ammonia synthesis loop. This offers a capacity range of between 10-110 percent, versus the 70-110 percent range of standard 'rigid' loops.
- The incorporation of dynamic tools to fully exploit this capacity flexibility and minimise the levelised cost of ammonia (LCoA) production.
- A reliable and mechanically robust design capable of dealing with fluctuating renewable power (or green hydrogen) supply.
- The plant's fast response time to sudden changes in the boundary conditions (such as power supply changes).
- Minimal hydrogen storage volumes, where required by the project. These can be 20 times smaller than in standard plants.
- Offers better green ammonia production performance compared to other available technologies.

Combined, these design features offer a green ammonia plant that is flexible, efficient and economically viable, as has been demonstrated by various Casale projects and published reports. Importantly, the inherent flexibility of Casale's green ammonia design (Figure 6) guarantees a much lower LCoA compared to alternative rigid designs.

The digital control of the green ammonia plant – because it functions under erratic power and hydrogen supply conditions – is of paramount importance for efficient and reliable operation. Digitalisation via an advanced process control system also enables the safe and steady operation of the plant.

Green ammonia plants generally function under challenging operating conditions. These include very different loads (linked with the hydrogen supply profile) and specific ramp-up and ramp-down variations. Ultimately an inability to control this properly has the potential to damage plant operations by affecting catalyst life and equipment reliability. Digitalisation can, therefore, decide the difference between a profitable and a loss-making plant.

Casale provides a dynamic tool as part of the plant's digitalisation and control system. This tool evaluates the plant's boundary conditions and prevents adverse events from happening.

A simple dynamic analysis is carried out to assess plant's operating behaviour under cyclical feedstock conditions. Casale's advanced process control system is then able to smooth and stabilise the operation of the synthesis loop (e.g., the operating pressure and temperature of the catalytic beds). This helps protect the mechanical reliability of synthesis loop components.

Ammonia cracking

This is another technology of paramount importance to the energy transition. When ammonia is used solely as an energy carrier, effective cracking technology is vital, as it is needed to convert ammonia into high quality hydrogen for subsequent power generation.

Ammonia cracking is not a completely new technology – it is used, for example, to generate syngas for the start-up and shutdown of ammonia plants. But in today's energy markets ammonia cracking needs to meet a number of specific additional challenges, such as:

- Generating high purity hydrogen at high pressure
- Operate as an efficient and continuous process with zero or very low environmental impacts
- Use modern and effective cracking catalysts
- Offer a high ammonia-to-hydrogen conversion ratio
- Handle large volumes of ammonia from big plants
- Provide start-of-run (SOR) versus end-of-run (EOR) operation on a continuous basis
- Combine pure hydrogen production with power generation.

Casale offers a couple of catalytic cracking processes. These were developed to meet the following goals:

- Produce high purity hydrogen up to grade 5 quality, if required
- Function without the need for a hydrogen compressor
- High ammonia-to-hydrogen conversion at the battery limit
- Prolonged catalyst life (SOR and EOR conditions are met)
- Guarantee equipment longevity and lower capex – via the selection of the correct materials
- Offer combined hydrogen and power production.

The development of these new ammonia cracking processes has benefitted from Casale's unmatched experience with ammonia synthesis. The ability to properly select materials for the synthesis section, for example, can make the difference between a plant that operates reliably and efficiently and a poorly performing, malfunctioning plant.

Casale's ammonia cracking processes are self-sustaining and operates without requiring significant external power or other fuel sources. They also provide a feedstock-to-hydrogen conversion efficiency of up to 80 percent.

Conclusions

Our fertilizer manufacturing, chemical industry and power sector clients have a window of opportunity to decarbonise their operations to help avoid the disruption that climate change will ultimately bring. That applies to legacy plants as well as new plants.

The energy transition and the necessary shift to a net zero society are making clean, low-carbon production technologies (both 'green' and 'blue') for hydrogen, ammonia and methanol of paramount importance to the future of our world.

Sustainable power and chemical production remain a challenge, especially the avoidance of negative environmental impacts and the need to reduce carbon footprints. Nevertheless, Casale offers – and is continuing to develop – a broad range of technologies and products to meet the global sustainability challenge.

Casale's blue and green schemes for hydrogen, ammonia, and methanol production are efficient and viable, being based on technologies that are already available and installed across a large number of references globally.

With its extensive know-how and dedication to innovation, Casale is fully committed to helping our society on the long journey toward a low-carbon future. ■

THYSSENKRUPP UHDE

Clean ammonia production – challenges and solutions

Dr Klaus Noelker and Karan Bagga

The traditional use of ammonia as a feedstock for nitrogen fertilizers is long established and well known. Nowadays, however, ammonia's use as an energy and hydrogen vector is gaining more and more attention.

These emerging yet fast-growing end-markets are prompting the development of new process technologies and plant set ups for ammonia production, either via renewable energy ('green' ammonia) or by combining conventional fossil fuel processes with carbon capture ('blue' ammonia).

This article discusses the production challenges triggered by the growing demand for green and blue ammonia – and highlights the solutions developed by thyssenkrupp Uhde to address these.

Green ammonia – the process challenge

Green ammonia is produced from hydrogen generated from the electrolysis of water using renewable power. This process avoids CO_2 emissions – unlike the conventional natural gas based production of ammonia that predominates today.

The key challenge associated with green ammonia production is the fluctuation in renewable energy, i.e., the electricity supplied from a wind farm or solar PV power plant (Figure 1). These energy supply variations must be addressed and compensated for in the design of the downstream electrolysis and ammonia synthesis processes.

While most established electrolysis technologies have the capability to adjust to load changes from fluctuations in electrical output from renewable power plants, this is a major challenge for a conventional ammonia synthesis loop design – since traditional fertiliser production processes do not need to have the flexibility to cope with this kind of intermittency.

If not adequately addressed, with suitable process design and control measures, intermittent plant operations can have costly and damaging consequences – such as the collapse of the reaction in the ammonia converter and production curtailments.

Ultimately, such events will adversely affect the economic viability of the project by imposing capex and opex penalties. Therefore, to build a credible business case, the intermittency of renewable electricity, its varying price and other conditions, must all be considered early in the project's development phase.

Optimising green ammonia plant design – the RHAMFS® analysis tool

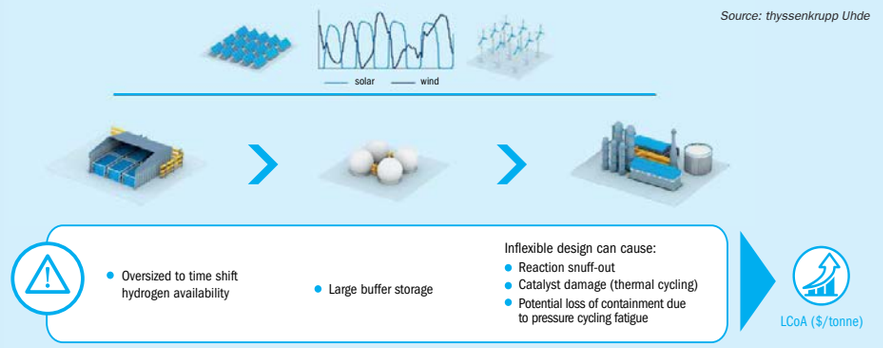
When it comes to the design of the green ammonia plant, the ideal solution should offer operational flexibility yet minimise technical inefficiencies. The key to this is combining:

- **The most appropriately sized intermediate energy storage** – provided by batteries and/or buffer vessels for hydrogen
- **With inherent process flexibility** – in terms of the plant's turndown and ramp-up/ramp-down capabilities.

An important point to make here is that providing too much process flexibility, which can be both unnecessary and too costly, is also undesirable. Instead, a project-specific (technical-economic) analysis is needed to develop the optimum flowsheet for the green ammonia process.

thyssenkrupp Uhde has, in fact, developed an analysis and optimisation tool – known as RHAMFS® – specifically to perform such an assessment early in the project design stages. The RHAMFS tool determines the most viable energy storage size for the plant and the optimum process flowsheet using a life cycle cost

Fig. 1: **Green ammonia production via a conventional ammonia synthesis loop is costly and challenging due to its inflexible design***



The electrolyser (left) needs to be oversized and large buffer storage (centre) provided to improve hydrogen availability and avoid catalyst damage and production curtailments (right). This results in large increases to the levelised cost of ammonia (LCoA).

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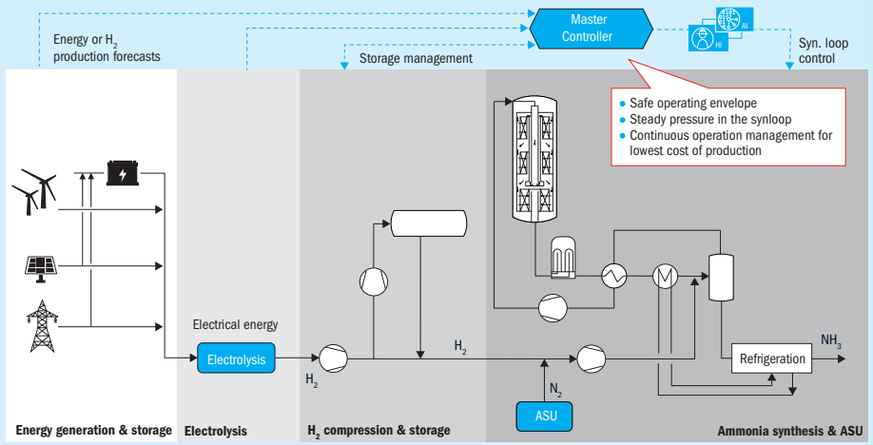
Fig. 2: **thyssenkrupp Uhde's integrated green ammonia plant**



Source: thyssenkrupp Uhde

approach. The assessment takes account of the project's renewable energy profile or grid power supply requirements (e.g., load shedding and power arbitrage). The tool also incorporates all of thyssenkrupp Uhde's technology and integration know-how.

Optimising green ammonia production – the Master Controller®

The reliable operation of today's green ammonia plants requires new process controls capable of seamlessly managing their dynamic production conditions.

In practice, the actual pattern of renewable energy supply is likely to deviate from the predicted or measured power profile used as the design basis of the plant. Under these circumstances, managing plant performance is a major challenge – one that can prove to be too difficult for conventional plant controls. Instead, a dynamic digital control system is generally necessary to ensure trouble-free plant operation, as well as minimising production costs at all times.

thyssenkrupp Uhde has developed such a proprietary advanced process control system. Known as Master Controller, this adjusts the load of the ammonia plant to the available and forecasted power, while also taking account of the loading and unloading of the intermediate storage elements (Figure 2).

Master Controller also considers a myriad of other technical and safety parameters – in the electrolysis, hydrogen storage and the ammonia unit – on a real time basis when setting up the plant for the forecasted power supply scenario. The control system offers the ability to:

- Maximise plant utilisation
- With a minimal hydrogen storage requirement
- While maintaining the efficiency benefits of an integrated approach.

In summary, thyssenkrupp's proprietary Master Controller:

- Offers seamless integration with upstream hydrogen generation
- Manages plant operations dynamically to ensure high availability against intermittent feed supply
- Maintains critical pressure and temperature parameters within the synthesis loop to keep these within the equipment and process design limits
- Can be deployed across any electrolysis technology to achieve end-to-end power-to-ammonia production.

Blue ammonia

Blue ammonia production combines a conventional, natural gas based ammonia process with carbon capture to reduce CO_2 emissions to the atmosphere. Carbon dioxide streams are generally removed using:

- Carbon capture and utilisation (CCU)
- Carbon capture and sequestration (CCS) to permanently store CO_2 underground in a suitable geological formation.

Although there is no recognised definition of blue ammonia production, in term of the necessary CO_2 capture rate, many current projects are calling for 90-95 percent removal.

Essentially, there are two alternative industrial methods for producing hydrogen and ammonia from natural gas – steam methane reforming (SMR) and the autothermal reformer (ATR) process. Both production routes have a similar overall energy consumption and generate similar volumes of carbon dioxide.

SMR and ATR also have two identical points in the process where CO_2 is emitted:

- **The reforming section.** This consist of steam reformer flue gas in the SMR process and flue gas from a fired heater in the ATR process – both being available at atmospheric pressure.

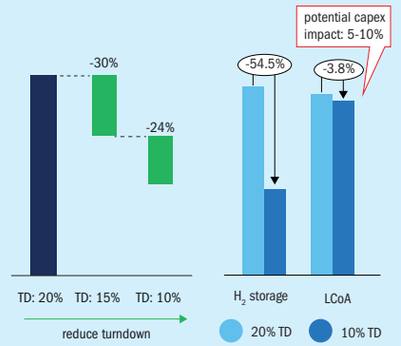
RHAMFS TOOL CASE STUDY

thyssenkrupp Uhde performed a RHAMFS assessment on a 700 t/d green ammonia plant in Australia. This was subject to a variable hydrogen feed which, throughout the day, ramped-up/ramped-down between 60-120 percent of the plant's nameplate capacity per hour.

The assessment identified that substantial reductions in hydrogen storage (>50%) were possible for a plant turndown as low as 10 percent, a threshold which is well within the capabilities of the Uhde ammonia synthesis loop design. The resulting saving in the levelised costs of ammonia (LCoA) amounted to 3.8 percent (Figure 3).

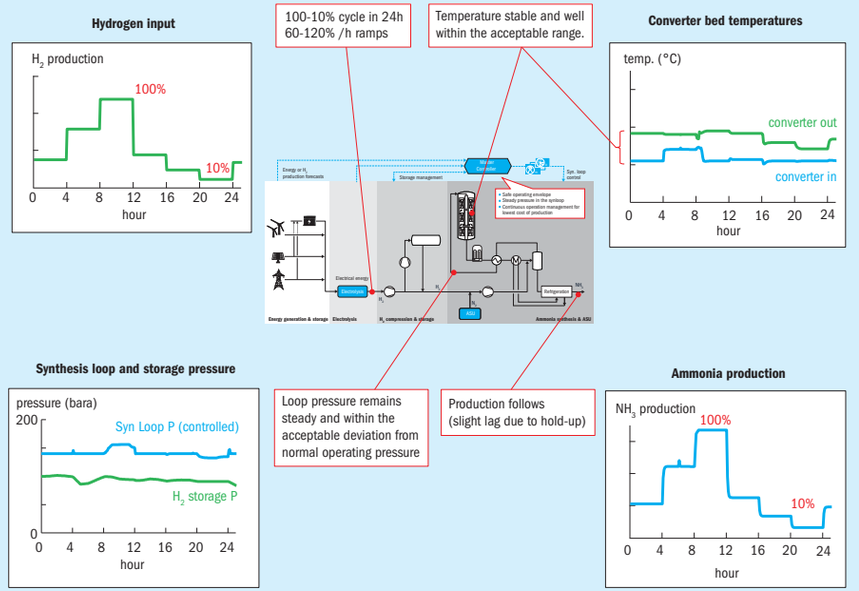
Based on the optimum flowsheet identified via RHAMFS, detailed process modelling was performed to mimic dynamic plant performance for location-specific renewable energy and hydrogen generation profiles. Master Controller, thyssenkrupp Uhde's digital plant control system, was then enabled to manage the plant's performance. As a result, the green ammonia plant operated trouble free at between 10-100 percent of nameplate capacity, with ramp-up/ramp-downs of between 60-120 percent of the maximum load possible per hour (Figure 4). ■

Fig. 3: **Plant turndown vs hydrogen storage for an Australian green ammonia plant (700 t/d capacity)**



Source: thyssenkrupp Uhde

Fig. 4: **Maximising the performance of a dynamic ammonia plant (700 t/d capacity) with a Master Controller**



Source: thyssenkrupp Uhde

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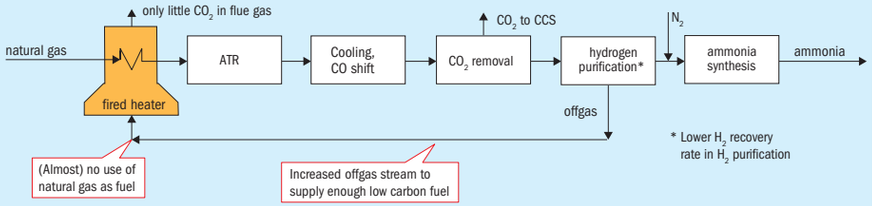
Fig. 5: **Blue ammonia production with an improved autothermal reformer can reduce CO_2 emission by more than 90 percent**



Source: thyssenkrupp Uhde/Mielke & Noelker (2023)

- **The CO_2 removal unit.** This is where carbon dioxide is separated from the process gas.

The carbon dioxide stream from the CO_2 removal unit is the larger of the two emissions points. It usually generates CO_2 with a purity of more than 99 percent and is sequestration-ready, i.e., it is a pure carbon dioxide stream generated by equipment that is already part of the ammonia process. It is therefore logical that the CO_2 emissions generated at this point are the first to be reduced, as the only additional capex is for compression and export infrastructure.

However, higher carbon capture rates require further effort and investment, as an additional unit (e.g. a scrubbing unit) for separating the CO_2 from the flue gas needs to be installed to generate a pure carbon dioxide stream, prior to compression for export.

One significant difference between SMR and ATR processes is the split in CO_2 emissions between these two points: about 70 percent of total CO_2 is generated at the CO_2 removal unit in the standard SMR ammonia process, while in the ATR process it is about 85-90 percent. (The reason for this is that CO_2 is left in the process gas in the ATR process, as the heat for the reforming reaction is supplied from the combustion of a portion of the feed gas, and not by external combustion.)

This means that, intrinsically, ATR can deliver a higher rate of CO_2 reduction, without the installation of an additional flue gas scrubbing unit. Normally, however, the ATR process will still need equipping with flue gas scrubbing, if reduction rates above 85-90 percent are required.

Some customers are understandably reluctant to do this because extra capex, opex and operator effort are required to install an additional process unit that is not present in a conventional ammonia plant.

The improved autothermal reformer

thyssenkrupp Uhde has therefore developed an alternative, more cost-effective solution for the ATR process that can reduce CO_2 emissions by up to 99 percent, if desired.

Much of the current focus for blue ammonia production is on ATR process technology. That is because future ammonia plants for the energy sector are expected to be large plants – and ATR plants offer a capex advantage over SMR plants, especially at larger production capacities.

A key feature of the thyssenkrupp Uhde ATR process is its ability to minimise/eliminate the carbon-carrying natural gas portion of the fuel used by the fired heater[1] (Figure 5). Instead, the amount of hydrogen-containing offgas supplied to the fired heater is increased to such an extent that it completely covers the energy demand of the fired heater. Natural gas supply to the heater is reduced to virtually zero as it is only needed during start-up.

The only CO_2 emissions generated by the fired heater are from residual amounts of CH_4, CO and CO_2 left by the hydrogen purification unit. Using this pre-combustion solution, 99 percent of CO_2 emissions can be avoided without the installation of an additional costly flue gas scrubbing unit (post combustion solution).

Geismar blue ammonia project

The number of clean ammonia projects has increased in recent months. This has been due to a combination of high ammonia prices and better financial incentives for reducing carbon emissions. At the end of 2022, the world's largest fertilizer producer Nutrien awarded thyssenkrupp Uhde the engineering contract for a 3,500 t/d, single-train ammonia plant in Geismar, Louisiana (*Fertilizer International* 511, p8). This world-leading blue ammonia plant will use the ATR process described here (Figure 5) and achieve a carbon capture rate above 90 percent for storage via CCS.

Summary

There is an emerging new market for low-carbon ammonia as an energy and hydrogen carrier.

Yet the intermittency of renewable energy poses a challenge for the economical production of green ammonia. To address this, thyssenkrupp Uhde has developed a flexible, safe and reliable proprietary process for green ammonia based on renewable energy. This process, when coupled with innovative digital control systems, can provide a fully integrated solution for green ammonia production.

thyssenkrupp Uhde has also developed an optimised and cost-effective autothermal reforming (ATR) process for new blue ammonia plants. This process can reduce carbon dioxide emissions by more than 90 percent – without the need for an additional flue gas CO_2 removal unit. The use of process gas as carbon-free fuel means more CO_2 can be captured. The engineering on a large scale blue ammonia plant using this process is already underway in the United States. ■

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CRU Phosphates 2023

Packed auditorium on Tuesday morning as CRU's Humprey Knight opens the conference with his keynote phosphate market outlook presentation.

More than 370 delegates from over 160 companies and 40 countries gathered at the Hilton Bomonti Hotel, Istanbul, Turkey, 27 February to 1 March, for CRU's Phosphates 2023 conference.

We report on the main keynote and market outlook presentations given at CRU's 15th Phosphates International Conference and Exhibition held in Istanbul in March.

Privilege to be in Istanbul

Nicola Coslett, the CEO of CRU Events, opened the event with a heartfelt message for the victims of the magnitude 7.8 Turkey-Syria earthquake that took place on the 6th February, several weeks before the conference opened:

"Devastating earthquakes in Turkey and Syria have killed thousands of people and destroyed hundreds of buildings. We offer shared condolences and strength to the many people affected. CRU has donated a significant amount to the urgent rescue efforts through the Disasters Emergency Committee.

"We feel it is a great privilege to be holding the 15th Annual Phosphates Conference here in Istanbul. We'd like to open the conference with a brief reflection, a poem commissioned for this occasion written by British writer Ben Michaels."

This moving poetry reading was followed by a two-minute silence for everyone affected by the earthquake – the victims, their families and rescue workers alike.

Amanda Whicher, portfolio director at CRU Events, also welcomed delegates to Istanbul for Phosphates 2023:

"Despite the tragic recent events, we are pleased to be able to run the event in Turkey for the first time. It also marks our first phosphates comeback in Europe since 2016.

"The event is now in its 15th year and on behalf of CRU I'd like to thank all of you for your continued support of the event. It's a great pleasure for me to warmly welcome back old friends as well as new faces to the event.

"We're pleased that 2023 marks another successful year for the event with 370 delegates registered to meet in Istanbul in the next few days. Our audience represents the multifaceted nature of the global industry – with delegates representing engineers, operators, buyers, sellers and solution providers from over 160 companies and 40 countries worldwide."

Prices still moving downwards

Phosphate fertilizer prices look set to decline further in 2023, as supply limitations ease. That was the key message from CRU's **Humphrey Knight** in his global market outlook presentation.

Agricultural fundamentals remain supportive of high crop prices, Knight said. Currently, these are double what they were three years ago, this being linked to very tight stock-to-use ratios. As a consequence, crop prices have stayed persistently high in 2022 and will remain well above historical norms in 2023, Knight predicted.

Diammonium and monoammonium phosphate (DAP/MAP) shifted from the affordable to unaffordable last year as prices trebled/quadrupled. As a result, annual DAP/MAP demand fell by nine percent globally in 2022. This was the biggest year-on-year drop in the 21st century, said Knight, taking global phosphate fertilizer demand back to 2014 levels.

DAP/MAP affordability has improved since, although not by enough to provoke an across-the-board demand uplift. Demand recovery in the phosphate market still faces headwinds, currently, such as middling affordability – which Knight described as "not great, not terrible" – and a stock hangover from 2022.

CRU therefore expects global DAP/MAP demand to recover by 7-8 percent to around 63 million tonnes in 2023. Regionally, the recovery is forecast to be patchy with surges in year-on-year (y-o-y) demand in the US (+25.0%) and Brazil (+18.4%) partly offset by downward corrections in China (-7.6%) and India (-3.5%).

On the supply side, annual DAP and MAP exports from China (-45%) and Morocco (-8%) were down in 2022 – although supply remained ample despite these limitations. Much the same is expected this year, suggested Knight, with China likely to ease its major export reductions from April onwards. Morocco is also expected to relax its supply management measures this year in response to lower pricing.

Overall, CRU expects phosphate fertilizer prices to remain under pressure throughout 2023, with supply availability outweighing demand. Price falls for the phosphate sector's two key raw materials, sulphur and ammonia, will also push the industry's cost floor lower.

Phosphate rock pricing, in contrast, has followed a divergent trend in the last 12 months due to a large shift in trade patterns.

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Exports of high-grade rock shrunk as Russian output slowed sharply. The supply of lower-grade rock, meanwhile, remained ample with both Jordan and Egypt increasing their export volumes.

Looking further ahead, phosphate fertilizer prices are set to hit the cost floor next year before rebounding, with CRU forecasting an average DAP price (f.o.b. Morocco) of $477/t in 2024. At the same time, the price disparities between high- and low-grade phosphate rock should gradually close.

"Over the short term, we have further declines in DAP/MAP prices with demand recovery expected to be outweighed by the easing of supply limitations," summed up Humphrey Knight. "Over the medium term, after hitting a bottom dictated by the industry cost floor, we expect prices to rebound – given that the project pipeline is busy but not too crowded.

"Then there are a few things to watch out for over the longer term – China's inward focus, the niche use of LFPs [batteries] and finally increasing interest in low emissions ammonia from the DAP/MAP sector."

China's phosphate contracts and restructures

Dr Lee Bo of the China Phosphate and Compound Fertilizer Industry Association (CFFIA) highlighted the changing face of China's phosphate industry. She listed a plethora of problems and pressures facing the industry in China, including:

- Declining demand
- Surplus production capacity
- Environmental protection measures
- Fast changing trade patterns
- Drawing down of phosphate rock reserves.

In response, China's phosphate industry is undergoing a structural readjustment – the aim being to increase the production and use of more functional and higher efficiency products. This is linked to a national agricultural action programme designed to drive down fertilizer usage and improve fertilizer efficiency by 2025. This programme is promoting new technologies such as fertigation, and the speciality fertilizers associated with these such as water-soluble fertilizers (WSFs) and micronutrient enriched products.

At the same time, the country's industrial policies are restricting domestic DAP/MAP production capacity and driving up the utilisation rates for phosphogypsum – a phosphate industry by-product that is generated on a vast scale in China and elsewhere globally. Assessments of commercial phosphate rock reserves are also needed to ensure consistent domestic supply and stable prices.

Simon Inglethorpe, editor, Fertilizer International magazine, introducing Tuesday afternoon's technical session as moderator.

China remains a global phosphate industry colossus. The country is the world's largest phosphate fertilizer producer with 21.4 million tonnes (P_2O_5) of production capacity – 36 percent of the global total – although this has fallen by 3.3 million tonnes since 2016.

The country's DAP/MAP production capacity accounts for 86 percent of domestic phosphate production, or 46 percent on a global basis. Unsurprising, given these production strengths, China has generally exported phosphate fertilizers on a very large scale, with DAP and MAP exports each accounting for 35-40 percent and 19-24 percent of global trade, respectively.

China's farmers also consume 11.3 million tonnes of phosphate as an agricultural nutrient (P_2O_5) – some 23 percent of world demand.

Chinese phosphate production is, however, in long term decline, having fallen every year since 2015 (except for 2021). Domestic production last year was below 15 million tonnes (P_2O_5), down 12 percent on 2021. On a product basis, Chinese DAP and MAP production in 2022 fell by 13 percent y-o-y to 27 million tonnes.

A combination of sharp export falls, high prices and tight phosphate rock supply was behind last year's major contraction in phosphate production, suggested Lee Bo.

Mosaic's main markets

The Mosaic Company's **Andy Jung** gave an update on the company and the state-of-play in its primary markets – North America, Brazil, India and China.

Mosaic is the largest supplier of phosphates to the large, mature North American market, with a market share of more than 40 percent. Annual phosphate shipments (DAP/MAP/NPS/TSP) to North America are forecast to rebound in 2023 to exceed nine million tonnes, having contracted sharply last year. Jung noted the increasing focus on sustainability and efficiency as a driver of investment in new products and technologies in North America. The trend for digitalisation is also accelerating throughout the whole of agriculture in this region.

In Brazil, meanwhile, wholly owned subsidiary Mosaic Fertilizantes made total fertilizer product sales of 9.4 million tonnes last year. Mosaic has a leading production and distribution position in what is one of the world's largest and fastest-growing fertilizer markets. Brazil, as a global agricultural powerhouse, has seen consistent rises in both the area planted to crops and crop yields. Fertilizer shipments to the country of 45 million tonnes or more are anticipated this year.

In China, structural changes to the phosphate industry are expected to continue to constrain export volumes, Jung suggested. He linked this to China's national priorities in three areas: domestic supply in support of higher crop yields; the rationalisation of inefficient capacity along with a reduction in the environmental impacts of production; investment in industrial (non-fertilizer) production segments.

India is emerging as a bright spot for 2023 global phosphate demand, in Jung's view. Although this market remains heavily influenced by subsidy changes and the strength of Monsoon rains, a more balanced approach to crop nutrition is supporting a solid future for phosphates demand on the subcontinent. Consequently, Mosaic is forecasting Indian DAP shipments of more than 10 million tonnes this year.

US phosphate demand set to rise?

On the basis of farm profitability, demand for phosphate fertilizers from US farmers in 2022/23 should be high. Total usage should also increase due to a rise in the planted area. Those were two of the conclusions reached by **Ryan Doyle** of Itafos in his US phosphate market outlook.

US famers have benefited from a series of highly profitable consecutive years, said Doyle, and are expected to have "another big year" in 2023. Profitability has been driven more by crop prices, suggested Doyle, not by the costs of inputs such as fertilizers.

The combined US corn, soybean and wheat acreage is likely to rise by 7-8 million acres in 2022/23 – an annual increase of around 3.5 percent. The planted area has been boosted by factors such as sustained crop prices, fewer pandemic-related problems and better spring weather.

Annual US phosphate fertilizer use is expected to rise by nine percent to reach 3.85 million tonnes (P_2O_5) in the current fertilizer year 2022/23 ending on 30th June. This follows the sharp 18 percent decline to 3.53 million tonnes seen in the previous 2021/22 year.

On a product basis (DAP/MAP/NPS/TSP), US farm use of phosphate fertilizers is projected to increase by seven percent to 7.82 million tonnes in 2022/23. Meeting greater US consumption levels in 2022/23 should require higher import demand, given that US phosphate exports and domestic phosphate production have remained roughly flat. Higher imports have, however, yet to materialise.

Total US phosphate fertilizer imports (DAP/MAP/NPS/TSP) during the first six months of the 2022/23 fertilizer year were down 993,000 tonnes – a 31 percent decline on a year ago. While these are still projected to pick up this spring, it is unclear whether imports will be lower or flat compared to last year.

"Higher demand for imports is required, but we've had less imports in the year-to-date versus last year," concluded Doyle. "This means more tonnes should still be required – although we are very close to the spring application season!"

This situation has raised concerns about the ability to move enough product into the US agricultural system ahead of spring. The other question mark is whether there will be some cutbacks in overall phosphate fertilizer use in the US market – either because of price or a lack of availability.

Bulgaria and Romania's speciality fertilizer market

The market for complex NPKs and speciality fertilizers has taken off in Bulgaria and Romania over the last five years, explained **Philippe Rombaut** of Agropolychim. This has largely been at the expense of the commodity phosphates DAP and MAP.

Agropolychim, which operates a fertilizer production plant at Devnya in north-eastern Bulgaria close to the Black Sea port of Varna, has seen a rise in the popularity of the following products:

- NPKs (15:40:10)
- NP+S (15:25 + 12S, 20:20 + 13S)
- NP+S+Zn (18:38 + 5S + 0.3Zn)
- NPK+S (16:16:8 + 12S, 15:15:15 + 10S)
- Urea ammonium nitrate plus sulphur (UAN+S) liquid
- Urea with nitrification and urease inhibitors.

Combined Romanian and Bulgarian sales of these products grew from 105,000 tonnes to 123,000 tonnes between 2018 and 2021, to finally reach 170,000 tonnes last year. One reason behind their substitution for DAP/MAP is the ability of these speciality products to provide essential potassium and sulphur – as well as micronutrients such as zinc for wheat, barley and corn.

Boron-enriched foliar sprays are also being favoured by local rapeseed and sunflower growers. In general, the region's famers have simply found DAP and MAP too expensive, compared to these competitor products, when applied to crops at the same application rates.

Foliar fertilizer sprays, including liquid UAN products, are now a €20 million market in Bulgaria, having experienced average annual growth rates of five percent since 2015. They are now applied to 47 percent of the country's crop area, with half of the foliar sprays used by Bulgarian growers containing multiple components.

Technical presentations

Summaries of key presentations from this year's excellent technical programme can be found in the CRU Phosphates 2023 preview in our January/February magazine (*Fertilizer International* 512, p32).

Market information

Please note that market information and commentaries reported here date from the time of event in late February and early March 2023. These should therefore be interpreted with caution. ■

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The under-construction Woodsmith polyhalite mine in the UK.

PHOTO: ANGLO AMERICAN

Anglo American scales-up its Woodsmith mine ambitions

Anglo American recently unveiled the long-awaited strategy update for its large-scale Woodsmith mine project in the UK. Initial production of the company's POLY4 polyhalite fertilizer is now scheduled to begin in 2027. The mine's ultimate annual output has also been increased to 13 million tonnes.

Mining major Anglo American is currently developing the UK-based Woodsmith mine project This will access the world's largest known deposit of polyhalite, a natural mineral fertilizer containing potassium, sulphur, magnesium and calcium – four of the six major and minor nutrients that every plant needs to grow.

The under-construction Woodsmith mine is located around five kilometres south of Whitby, a small fishing port in North Yorkshire on England's North Sea coast. Anglo American gained control of the project in March 2020 through the cash purchase of Sirius Minerals for $496 million (£405 million) (*Fertilizer International* 495, p10).

Woodsmith will extract polyhalite from the deeply buried underground ore deposit – containing 290 million tonnes of permitted reserves – via two 1.6-kilometre-deep shafts (Figure 1). Unusually, the ore extracted at the mine will then be transported to the port of Teesside through a 37-kilometre-long underground tunnel on a conveyor belt system. This mineral transport system (MTS) is designed to minimise the project's surface environmental impact.

On arrival at Teesside, polyhalite ore will be granulated at a materials handling facility at Wilton to produce a premium-quality, low-carbon fertilizer certified for organic use. This product, known as POLY4, will be exported from Redcar Bulk Terminal, the company's dedicated port facility.

Strategy update – investment, capacity and timescale

Anglo American now looks set to invest in the region of $4 billion to complete the Woodsmith project. The latest investment plans were unveiled as part of a strategy update for the large-scale polyhalite mine released on 23rd February.

Anglo has also increased project capacity by revising upwards the mine's ultimate output. It now expects initial production of POLY4 fertilizer to begin in around four years, with production then ramping-up over time as the market for polyhalite develops.

"As noted in a number of market updates throughout 2022, we are enhancing the project's configuration – including the capacity of the shafts and other infrastructure to accommodate higher production volumes and more efficient and scalable mining methods over time – to ensure we deliver maximum commercial returns from Woodsmith over the expected multi-decade asset life," Anglo American said. "These project team proposals, endorsed by the Board at the end of the year, indicate an extension of the development schedule and the capital budget, compared to what was previously anticipated."

In light of these changes, Anglo American now expect to bring POLY4 to market in 2027, with an annual capital investment of around $1.0 billion. The company is also proposing to increase Woodsmith's design capacity to around 13 million tonnes per annum – up from 10 million t/a previously – subject to further studies and approval.

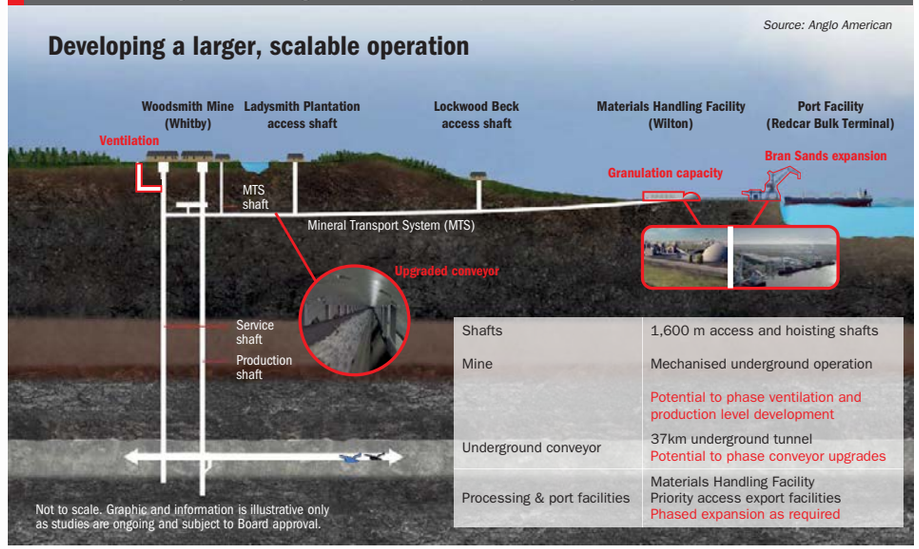
Anglo American has already approved $0.8 billion of investment for the Woodsmith mine project in 2023, with most of this expenditure going to shaft sinking and tunnel boring activities. This comes on top of $522 million of capital expenditure in 2022 and nearly £390 million in 2021 (*Fertilizer International* 508, p62).

Investment and construction activities – and the announced strategic changes to these – are being directed at core project infrastructure (Figure 1), in particular:

- The mine's two 1.6-kilometre-deep shafts that sink down to the mechanised underground polyhalite mining operation
- The 37-kilometre-long underground mineral transport tunnel (MTS) needed to carry material from the mine to the materials handling facility (granulation plant) at Wilton on Teesside
- Three smaller intermediate access shafts to the MTS needed for maintenance and ventilation.

Delivering these project elements are part of the mine's critical path to production. The additional project activities on Teesside – the construction of the materials handling facility at Wilton and the Redcar Bulk Terminal – although not on the critical path, are also part of Woodsmith's core infrastructure. ■

Fig. 1: **In a strategy update, Anglo American has announced changes to the core infrastructure of its Woodsmith mine project. These are designed to deliver larger and more scalable polyhalite mining operation.**



Polyhalite – a unique resource

Polyhalite is a natural mineral fertilizer containing potassium, sulphur, magnesium, and calcium plus numerous micronutrients. Anglo American's POLY4 product is suitable for organic farming and is made by simply crushing and granulating polyhalite. This provides POLY4 with a carbon footprint that is up to 85 percent lower than typical chemical fertilizers.

"There is no other natural mineral fertiliser with the scale of potential impact of POLY4, and Anglo American has the only scalable source of polyhalite globally. This mineral is distinct in its composition, behaviour, benefit, and therefore its value," says Duncan Wanblad, Anglo American's CEO.

He adds: "Farmers today must produce more food for a growing global population, whilst meeting increasing consumer, supply chain and governmental expectations for improved sustainability. POLY4 is uniquely positioned to help simultaneously address these interconnected challenges, because it increases yield and nutrient use efficiency, is low carbon and improves the health of the soil compared to conventional chemical fertilisers."

"POLY4 will help farmers achieve more balanced, sustainable fertiliser practices at a scale not seen in the industry for decades," comments Alexander Schmitt, chief marketing officer for Anglo American Crop Nutrients. "The product delivers better results than the same blend of nutrients available from conventional sources today, delivering sustainability benefits beyond the nutrient content and setting POLY4 apart from traditional fertilisers."

"Our commercial trials have demonstrated that POLY4 can improve the efficiency of nitrogen and phosphorous by six percent compared to MOP, potentially reducing the amount of chemical fertilizer that needs to be applied," adds Dr Schmitt. "This is down to its prolonged nutrient release profile and multi-nutrient nature; just like you or me, consuming a more balanced and nutritious diet makes plants stronger, healthier and more productive." ■

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SPEAKING TO INVESTORS

Anglo American's CEO **Duncan Wanblad** spoke in detail about the company's new strategy for the Woodsmith mine during an annual results presentation on 23rd February. Selected highlights are provided below.

A big reset

"A lot has happened since we acquired Woodsmith [mine project] immediately before the pandemic set in. 2022 was a big reset year for us following further integration [of the project] into Anglo American and our technical review.

"Firstly, …we have made significant changes to the scope, design, and approach to execution, ensuring that we bring the project up to Anglo American's high safety and technical standards, and employing modern mining methods, to set the project and the operation up to deliver its full potential. We have changed the execution strategy to an EPCM [engineering, procurement and construction management] model… and engaged a specialist contractor to execute the deep shaft sinks.

"Secondly, on the project timelines and scope, we are making changes to allow for an expanded scope …which we want to set up correctly from the beginning. Nobody wants to turn around in ten years' time and wish we had made everything more scalable."

Progress on core infrastructure

"On the two deep shafts: These are both being excavated using Shaft Boring Roadheaders (SBRs). We are over 20 percent down the service shaft, while in January we hit a key milestone as the SBR began cutting on the production shaft, 120 metres below surface.

"On the Mineral Transport Tunnel (MTS), we are well over halfway on tunnel boring activities, currently at around 21.7 kilometres of the 37-kilometre distance between mine and port. Three shallower intermediate shafts … sink down to the MTS at depths of between 320-360 metres – and are all progressing well. One, Lockwood Beck, has been completed and connected to the tunnel and the other two are planned for completion this year."

Phased project development

"Let me assure you, in Anglo American's hands we are taking a long-term view focused on maximising value for the asset's life, which extends well beyond 40 years.

"We are setting up to be able to deliver 13 million tonnes per annum – a 30 percent larger operation than the previous plan of 10 [million tonnes]. We are going bigger because we believe in the asset, we believe in the product and we believe in the market.

"Our project will cost more and take longer than was envisaged under its previous owner. The annual spend will vary from year-to-year but is likely to be around the $1 billion mark. We expect to hit polyhalite by 2027, from which point we will be in a position to bring some volume to market.

"The exact ramp-up will depend on the outcomes of [additional] studies and our market development work …and remains subject to board approval. But we expect Woodsmith to have the capacity to produce up to five million t/a by 2030, with the ability to expand to 13 t/a as the market develops.

"Gone are the days where mining companies invest billions on the back of a single bankable feasibility study. You need the detailed technical information to get these things right and to ensure that you are embedding the very latest techniques and technologies. That's critical for assets of this scale and longevity."

A larger, scalable operation

"In underground mines you need to build the core infrastructure such as the shafts and tunnel up-front, as changing this later once the operation is up and running becomes very challenging and costly. Do it once and do it properly.

"As an example, on the core infrastructure, we have already taken the decision to widen the deep shafts by 75 centimetres to deliver the operating performance we expect at that larger scale.

"Something that we have previously raised is addressing additional ventilation requirements. This would bring forward investment that would anyway have been required to allow future expansions.

"We also need to do the studies to conclude the optimal mining method. The baseline is continuous mining – but given the rates at which technologies are developing, we think there may be interesting opportunities and we have the time to get that right.

"Next, we will review the capacity of the underground conveyor and optimise the tunnel fit-out for larger volumes over time. And finally, we need to get the correct configuration of the materials handling, port and storage facilities to allow all these parts of the process to handle higher volumes of material." ■

Duncan Wanblad, Anglo American's CEO.

PHOTO: ANGLO AMERICAN

Barracuda bucket wheel excavator.

PHOTO: THYSSENKRUPP

FLSmidth completes thyssenkrupp Mining purchase

In September last year, one of the largest mining equipment and technology deals in history closed when FLSmidth finally completed its purchase of thyssenkrupp Mining. We look at the implications for the fertilizer sector and phosphate and potash mining.

Mining mega purchase

thyssenkrupp Mining had a presence in 24 countries, with engineering and global service centres across the world, and almost 3,400 employees. The company generated revenues of €780 million in 2020.

Despite its strong identity and history, the name thyssenkrupp Mining was swiftly abandoned as a separate mining industry brand with immediate effect following its acquistion by FLSmidth. All its equipment offerings will now be sold under the FLSmidth marque instead.

The addition of thyssenkrupp Mining to FLSmidth creates a new business with a total annual revenue of €3.0 billion (2020 basis). The move should increase FLSmidth's mining revenues by more than 50 percent and position the company as a top-tier mining industry supplier. Efficiencies and cuts to costs from the purchase are also projected to generate savings of €50 million this year.

The acquisition is expected to boost FLSmidth's growth ambitions. These have a strategic focus on mining, which is likely to account for around 75 percent of company revenues in future.

"In addition to the competitive advantages of scale, FLSmidth will be able to offer a stronger value proposition to customers through combined competencies, a wider offering and a more extensive customer reach," FLSmidth said in a statement.

A complementary offering?

thyssenkrupp Mining offers FLSmidth strong competencies in in-pit crushing & conveying (IPCC), high-pressure grinding rolls (HPGRs) and large mine conveyors (Figure 1). These capabilities also contribute to FLSmidth's MissionZero sustainability strategy and its objectives:

- **In-pit crushing & conveying (IPCC):** Promotes mine electrification and reduces the need for diesel trucks.
- **Overland/large mine gearless conveyors:** These are the cornerstone of mine decarbonisation, offering significant power savings though electrification. thyssenkrupp's conveyor offering also comes with excellent simulation capabilities.
- **Crushers:** thyssenkrupp's eccentric roll technology further enhances mining operation efficiency.
- **High-pressure grinding rolls (HPGRs):** These significantly reduce energy consumption of energy-intensive grinding processes.

Commenting on the purchase, FLSmidth said[1]: "The acquisition was identified as a good opportunity, as it allows us to strengthen our position as one of the leading suppliers for our customers in the global mining industry. The combined coverage of FLSmidth and thyssenkrupp's mining business includes a strengthening of our pit-to-plant range of technology, equipment and service expertise, covering continuous mining, mineral processing, mining systems and material handling.

"thyssenkrupp Mining's equipment offering consists of open-pit mining equipment and systems, mineral processing solutions and material handling solutions. Thyssenkrupp is primarily involved in crushing, conveying, grinding and processing, which we see as broadly complementary to our offering.

"We do have some overlap of technologies, but we see a clear complementary offering – especially in the areas of sustainability and digitalization. For example, thyssenkrupp mining has a strong in-pit crushing set up that is complementary to our existing offering, and in grinding, they have a strong position with HPGRs [high pressure grinding rolls], whereas we are one of the leading providers in other grinding solutions, such as SAG [semi autogenous grinding] mills."

Acquisition closes

Mikko Keto, FLSmidth's CEO, spoke to *International Mining* on the day the acquisition closed last September[2].

"It is important to emphasise that we are getting some big missing pieces into our portfolio – TK Mining was, and therefore we now are, the clear HPGR market leader in mining, both in technology and installed base, which they had built

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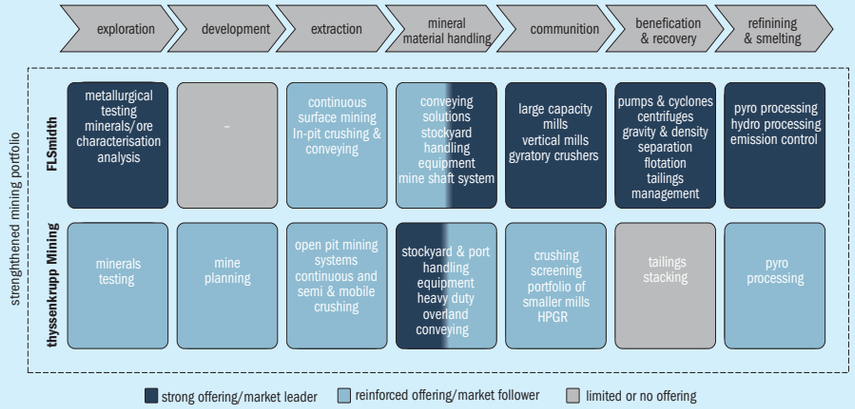
Fig. 1: **thyssenkrupp Mining and FLSmidth have complementary equipment offerings that when combined should benefit customers**



Source: FLSmidth

up over many years," Keto said. "Another example is …the highest throughput, most challenging conveying projects, where again TK Mining has led the way – especially in areas like gearless driven conveying working with Siemens where they, and now we, are the clear leaders in the market."

The purchase had been broadly welcomed by customers, according to Keto.

"The majority of the feedback we have had, including the major Tier 1 miners, has been very positive. It was no secret in the market that TK's mining business was up for sale – and they had a huge installed base, especially in areas like primary and secondary crushers, mills including HPGRs, and within the IPCC space with conveyors and crusher stations. So there was concern as to who the new owner might be – and FLSmidth is seen as a welcome new parent, being itself a large and established player in mining technology, plus having a long term commitment to invest in and grow the business."

In-pit crushing & conveying (IPCC), suggested Keto, was an area with opportunities for the new combined business.

"One area we are focussed on is further advancing a more modular approach to IPCC crushing stations. While IPCC projects are all bespoke to a certain extent, some standardisation of engineering helps reduce costs for both us and customers. Bringing the opportunities of IPCC to smaller and medium sized mines is also something we will continue to do. Of course, IPCC also brings huge MissionZero related benefits in terms of decarbonisation for miners."

Keto said thyssenkrupp Mining's Russian market exposure was under control.

"New business in Russia has been suspended and contracts with non-sanctioned customers are being finalised to the extent possible. The outstanding order backlog from Russian activities amounted to around €43 million by end July 2022 while other potential exposure and risks related to Russia remain subject to audit."

Compact bucket wheel excavators

The purchase of thyssenkrupp Mining strengthens FLSmidth's equipment offering for phosphate and potash mining. This includes the Barracuda range of bucket wheel excavators introduced in 2016 (*Fertilizer International* 495, p37). These compact mining machines use a larger number of teeth per bucket to cut materials with a compressive strength of up to 50 MPa.

The Barracuda's innovative design allows harder materials to be excavated, including phosphate rock, potash and limestone, without the need for drilling or blasting operations. By combining ore excavation, loading and the transport within a single machine, the Barracuda can seamlessly replace a complex system of multiple machines with a single mining unit.

FLSmidth can now offer several versions of the Barracuda, each with different ore transport configurations. They range from a compact machine and conveyor – for a basic extraction process – to the advanced Barracuda C machine. This combines a compact bucket wheel excavator with a discharge boom operating in tandem with a conveyor system.

The Barracuda has three particular features that make it an attractive excavation option for mine operators:

- Streamlines ore transportation
- Offers predictable operational costs
- Able to eliminate pre-blasting.

In ore transport, integrating the Barracuda with continuous mining/conveyor systems widens the range of potential mine applications and also delivers major cost reductions in comparison to conventional truck transportation. The machine's electrical drive can also reduce the carbon footprint of mining operations. One Barracuda machine, by potentially replacing more than 10 other mining equipment units, also streamlines both operations and maintenance efforts.

But is the elimination of pre-blasting that is the main overall factor which makes the Barracuda a leaner, more cost effective and safer mining process option. Conventional bucket wheel excavators are unable to cope with harder ore materials and – unlike the Barracuda – still require blasting to fracture rock in-situ prior to extraction. The need for pre-blasting can add more than $0.2 per tonne to extraction costs – a major cumulative cost for multimillion tonne mining operations.

The Barracuda, by removing the need for drilling and blasting, can therefore offer significant cost reductions, especially for mine expansions or new mine projects which require investment in new equipment anyway. The use of Barracuda mining machines also offers a more sustainable alternative to blasting, which is subject to increasingly stringent environmental regulations for noise, fumes, dust and vibrations.

In-pit crushing & conveying (IPCC)

thyssenkrupp Mining also brings to FLSmidth key capabilities for in-pit crushing & conveying (*Fertilizer International* 475, p54). The company's market leading IPCC system is designed to limit truck haulage and has the following advantages versus a conventional system using diesel trucks:

- It is electrically driven with a higher efficiency than diesel motors
- Has a lifetime of up to 40-50 years with regular maintenance
- Significantly reduces operating personnel due to partial automation
- Increases mine safety
- Increases utilisation
- Reduces CO_2 emissions, the amount depending on the origin of the electricity used.

Although the relative investment costs are generally higher for IPCC systems, opex reductions can typically generate a return on investment within 2-4 years.

In 2015, thyssenkrupp successfully installed an IPCC system at the Koashvinsky phosphate mine near the city of Kirovsk on the Kola Peninsula in northern Russia. This is operated by OJSC Apatit, a subsidiary of fertilizer producer PhosAgro (*Fertilizer International* 475, p54). The IPCC system designed for the Koashvinsky mine is a combined crushing unit with the capacity to handle up to 30 million tonnes of waste a year. The system needed to be able to accept materials with compressive strengths averaging 50-190 MPa up to a maximum of 320 MPa.

The hoppers installed have sufficient design capacity to accept trucks with a payload of up to 220 tonnes. The direct feed crushing plant is also equipped with a gyratory crusher designed to accept 6,200 tonnes of material per hour.

IPCC also replaced previous truck haulage of waste materials outside of the mine. Instead, these materials are crushed to a conveyable size and transported by a curved conveyor over a distance of around four kilometres to an external waste site. At the end destination, a crawler-mounted spreader with an hourly capacity of 6,200 tonnes then discharges material from the conveyor.

The IPCC system has substantially cut the Koashvinsky mine's operating costs, maintenance costs and CO_2 emissions. It also provides a higher level of operational safety. ■

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China Works, Black Prince Road
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Crystallisation and evaporation in fertilizer production

Evaporation and crystallisation are widely used throughout the fertilizer industry. These powerful production processes are helping fertilizer manufacturers diversify their product portfolios, improve profitability and meet sustainability goals.

VEOLIA WATER TECHNOLOGIES

Crystal clear advantages

Evaporation and crystallisation have many fertilizer industry applications. These include the manufacture of fertilizer products from primary raw materials (*Fertilizer International* 477, p56).

Their ability to economically recover by-products for fertilizer use – from other industrial processes or previously discarded waste streams – is also valued. This helps fertilizer producers control manufacturing costs and meet sustainability and circular economy objectives by increasing resource efficiency and improving waste management (*Fertilizer International* 496, p50).

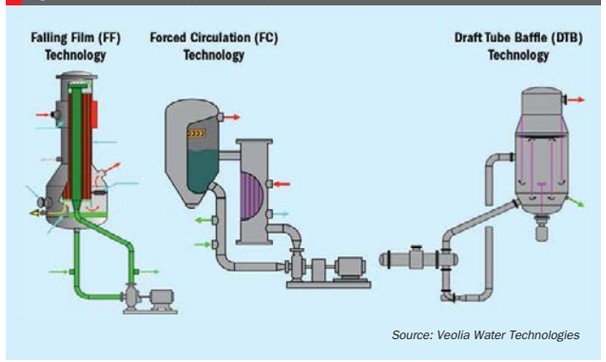
Such advantages are clearly shown by the production of monoammonium phosphate (MAP), the most popular type of water-soluble fertilizer consumed globally. Crystallisation enables high quality MAP to be produced from low-grade phosphoric acid feedstocks. This is beneficial as poor-quality phosphoric acid, is classed as waste product and was previously unusable without costly purification.

It is vital that fertilizer raw materials should not go to waste, given their growing scarcity and the energy used in their extraction and processing. Fortunately, the adoption of evaporation and crystallisation by fertilizer producers now make this possible – due to the ability of these technologies to treat and recover waste streams and recycle low-grade feedstocks.

PHOTO: VEOLIA WATER TECHNOLOGIES

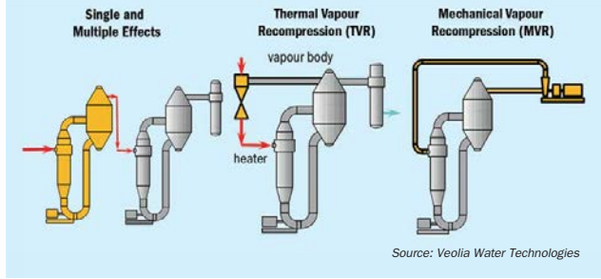
Veolia's HPD® ECRP™ system recovers high quality potassium sulphate crystals from wastewater for fertilizer use.

Fig. 1: **Three common types of evaporation or crystallisation equipment**



Source: Veolia Water Technologies

Fig. 2: **Three main configurations of evaporation or crystallisation equipment**



Source: Veolia Water Technologies

Process selection

Evaporation and crystallisation describe a range of different process options. These include:

- Standard evaporation
- Evaporative crystallisation
- Cooling crystallisation
- Reactive crystallisation.

Process selection is influenced by the type and physical behaviour of raw materials, the desired quality of the end-product, and project-specific criteria.

Evaporation and evaporative crystallisation: In this process, the objective is to increase the concentration of dissolved salts via evaporation. This involves the removal of a solvent (typically water vapour) to concentrate the solute (the desired product). Evaporation is generally used in the fertilizer industry to preconcentrate dilute streams prior to crystallisation. It is also widely used to concentrate phosphoric acid.

Cooling crystallisation: Compounds whose solubility is highly temperature-dependent can be easily crystallised in cooling crystallisers. Crystallisation occurs when a hot saturated solution is cooled until supersaturation is reached. This is generally achieved by flash cooling water vapour under vacuum. Crystallisation is largely initiated by cooling the solute, although some concentration also occurs due to the removal of water vapour. This type of crystallisation is prevalent in potash production.

Reactive crystallisation: In this process, a crystalline product is formed by the chemical reaction that occurs when two compounds are mixed together. This type of crystallisation is used to manufacture ammonium sulphate from ammonia (either gaseous or liquid) and sulphuric acid, for example, and to produce monoammonium phosphate and diammonium phosphate (MAP/DAP) by reacting ammonia with phosphoric acid. Relatively pure reactants are generally required – although there is increasing interest in using less costly and lower purity raw materials or waste streams instead.

Equipment options

The most common types of equipment installed in fertilizer production (Figure 1) are as follows:

Falling film evaporators: These are typically used to concentrate a solution in non-scaling applications. They are often used to preconcentrate a stream prior to a separate crystallisation process – and can turn highly soluble salts such as calcium chloride into high concentration solutions.

Forced circulation crystallisers: These are used for processes where large crystals grow easily or where the particle size distribution of the product is not critical. Forced circulation crystallisers are often used for sodium chloride crystallisation in potash recovery from sylvinite deposits. They are also known as a 'mixed suspension, mixed product removal' (MSMPR) crystallisers because the slurry is mixed uniformly throughout the system.

Draft tube baffle (DTB) or **HPD partitioned internal circulation (PIC™) crystallisers:** These crystalliser types are in widespread use in the fertilizer industry – especially in those production processes requiring both a narrower crystal size distribution and a larger crystal size. Common applications include potash, ammonium sulphate and MAP/DAP production.

HPD Growth™ crystallisers: Also known as Oslo type or 'classified suspension, classified product removal' (CSCPR) crystallisers, these typically involve the circulation of a crystal slurry and the classification of crystals according to size using a fluidised bed. The advantages of HPD Growth™ units have been demonstrated in many applications – and include the production of potassium chloride (high-purity and fertiliser-grade) and ammonium sulphate (high-purity and by-product manufacture).

Process plant configuration

There are many different ways to configure evaporation and crystallisation equipment (Figure 2) to ensure that project economics and process efficiency are both maximised. Among the design factors that must

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VEOLIA SUCCESS STORIES

Monoammonium phosphate (MAP)


Water-soluble fertilizers: it's crystal clear!

Alkimia Group is a leading Tunisian chemical company specialising in the production of phosphate salts for industrial applications. The group has been able to diversify and generate new revenue streams from a new 25,000 t/a capacity monoammonium phosphate (MAP) plant (*Fertilizer International* 496, p50). The new manufacturing line exports this added-value fertilizer product from Gabes, Tunisia, to agricultural growth markets elsewhere in Africa.

Alkimia's new MAP plant, designed and delivered by Veolia, integrates two crystallisation stages with centrifugal separation, drying, cooling, and screening systems. The plant consumes merchant-grade phosphoric acid (MGA, a relatively low-grade acid) and ammonia to produce fully water-soluble, high purity (99 wt % minimum) MAP crystals with very low insoluble content (below 0.2 wt %). A series of laboratory tests carried out by Veolia were used to simulate and develop the process flowsheet and determine the correct plant design.

Potassium sulphate (SOP)

North American crop nutrient and salt producer **Compass Minerals** needed to expand potassium sulphate (SOP) production at its Ogden plant in Utah in the United States. Veolia successfully integrated its HPD® PIC™ draft tube baffle crystalliser unit into the existing plant (*Fertilizer International* 496, p50). This converts a brine feed containing schoenite into a high-purity SOP product, marketed by Compass as Protassium+®. Veolia simulated and developed the process at its research facility near Chicago before validating the design. The newly installed equipment also enabled Compass Minerals to significantly reduce its water consumption, being more efficient at recycling waster than the existing SOP plant.

High quality SOP from wastewater


Wastewater treatment technologies

Creating SOP from wastewater

Veolia's HPD® crystallisation technology is capable of manufacturing high-quality water-soluble SOP from a range of different feedstocks. One innovative production option is to manufacture SOP from the wastewater generated at pulp and paper mills (*Fertilizer International* 510, p42).

In this process, glaserite (a double salt of SOP and sodium sulphate) is initially recovered via a black liquor ash treatment system and then converted into high-quality SOP crystals for fertilizer use. This two-stage crystallisation process uses Veolia's ECRP™ system to recover the SOP from ash treatment purge. The system:

- Delivers rapid operational payback
- Reduces sulphate levels in mill effluent
- Returns potassium back to the forest via the production of SOP fertilizer – creating a closed nutrient loop
- Saves on the cost and usage of chemical consumables such as caustic and sodium sulphate.

be considered are:

- Utility availability and costs (steam, power and cooling water)
- The size of capital equipment
- Installation costs
- Metallurgy and process requirements
- Environmental constraints.

In steam-driven systems, the heat present in steam is used to concentrate a solution in heater tubes via evaporation. Energy efficiency can be improved with **multiple-effect evaporation (MEE)**. This process uses the vapour generated as a heat source to evaporate additional water. Vapour generation occurs at progressively lower pressure in each additional effect. This configuration greatly increases the steam economy, i.e., the amount of water evaporated for each unit of steam used.

Steam consumption can also be reduced by using **thermal vapour recompression (TVR)**. This configuration uses high pressure steam to compress the vapour generated in the evaporator to an intermediate pressure which is usable in the heater.

Mechanical vapour recompression (MVR) uses electrical energy to drive the evaporation in lieu of steam. The water evaporated is compressed using a mechanical vapour compressor. The resulting high-pressure vapour is then used in the heater to drive the evaporation. MVR has a much higher energy efficiency than a steam-driven system and is the most beneficial and practical option where steam or cooling sources are limited.

A **multiple stage vacuum flash configuration** is generally used for products that have an inverse solubility. These types of crystallisers use adiabatic cooling, i.e., evaporation under vacuum cools the liquor and the product precipitates as a result. This is the configuration typically used in KCl production.

Production objectives and process challenges

To develop or validate design parameters, bench or pilot-scale tests are generally an imperative. Ideally, these should be performed with the same feed solution that will be used by the full-scale commercial plant. The main process challenges in designing a commercial plant are:

- Production of **high-quality product salts**. Fertilizer products often need to meet specific crystal habit, size or purity requirements.
- Adaptation to **environmental constraints**, e.g., limitations on liquid wastes or other discharges to the environment, limited energy supply or cooling media supply etc.
- Valuable **product recovery** from waste streams or by-products.
- **Heat integration and water balance optimisation**. Some production processes, such as potash from solution mining, have large recycle flows and place very high energy demands on the system. It is vital for such systems to have a highly-integrated heat balance.
- Choice of **construction materials**. Because the feed or mother liquor is often at high temperature and contains high concentrations of corrosive compounds, a balance needs to be struck between the need for corrosion resistance and ensuring that the design remains cost-competitive.

Fertilizer production

The diverse range of fertilizers produced using evaporation and crystallisation technologies include:

- **Ammonium sulphate:** Crystals can be made from pure ammonia and pure sulphuric acid by reactive crystallisation or produced by evaporative crystallisation of a dilute ammonium sulphate stream.
- **MAP/DAP:** Monoammonium phosphate (MAP) and diammonium phosphate (DAP) can be made via reactive crystallisation using technical-grade phosphoric acid and pure ammonia. Opportunities also exist to make these products using less expensive green phosphoric acid or raffinate.
- **Potash:** Cooling crystallisation is used extensively in potash solution mining to generate potassium chloride (KCl, muriate of potash), and in conventional potash mining to improve potassium chloride grade. Many potash deposits contain sylvinite (a double salt of NaCl and KCl). Incorporating crystallisation equipment in processing plants – due to their ability to remove sodium chloride – can therefore be vital in potash recovery.
- **SOP:** Potassium sulphate (SOP) production methods often involve a crystallisation step. Interest in SOP production is rising due to unmet demand from cash crops such as tree nuts and tobacco. It also sells at a premium relative to potassium chloride.
- **Nitrate fertilizers:** Evaporation is used to concentrate ammonium nitrate and to produce products such as potassium nitrate and calcium nitrate.
- **Phosphoric acid:** Evaporation is used to concentrate dilute phosphoric acid into a marketable product or for onward use in phosphate fertilizer production.

Conclusions

Evaporation and crystallisation processes are prevalent in many commercial fertilizer production plants. New fertilizer production technologies continue to be developed in response to rising fertilizer demand and the decreasing availability of affordable raw materials. Evaporation and crystallisation play a key role in these emerging technologies. Research, bench-scale and pilot scale testing, and process development will also remain vital in bringing new applications to market.

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GEA GROUP

Efficient and sustainable fertilizer production

There is increasing market demand for water-soluble fertilizers (WSFs) for foliar applications, fertigation and NPK blends. For these value-added specialty products, the use of evaporation, stripping, crystallisation and membrane filtration units in manufacturing is ideal, as they can produce high-purity crystalline solids with the required shape and size characteristics (*Fertilizer International* 496, p45).

These production technologies can be harnessed to manufacture a wide range of fertilizer intermediates and end-products.

Evaporation and crystallisation – the essentials

Evaporation and crystallisation are chosen for a production process whenever:

- Removal of water or another solvent is required
- Concentration has to be increased
- Volume has to be reduced
- By-products or impurities need to be stripped or precipitated
- Valuable, high-purity crystals are being manufactured.

The main process options include:

- Evaporation and evaporative crystallisation
- Cooling crystallisation
- Reactive crystallisation.

Equipment selection and plant design is influenced by many product- and process-specific factors. Customer requirements, notably site characteristics such as the energy source and its cost, play an equally important role in determining the process engineering design of an industrial plant.

PHOTO: GEA

Reactive crystalliser unit used in ammonium sulphate production.

Crystallisation plants

Crystallisation plants need to be engineered to meet the customer's product and process specifications (purity, particle size, operating time, etc.) while also minimising investment and operating costs. The crystalliser unit is selected from a wide range of available technologies (forced circulation, draft tube baffled, Oslo or flash cooling) to match individual product requirements. Achievable particle size can range from microns to millimetres, depending on the crystalliser type.

Evaporative crystallisation is usually chosen as a process when the solubility of the solute is largely independent of temperature, allowing supersaturation to be achieved by concentrating the slurry instead. A forced circulation system is often required to properly control supersaturation, suspension density and crystal breakage.

Vacuum cooling crystallisation, in contrast, is usually chosen when the solubility of the substance to be crystallised is strongly temperature dependent. Supersaturation is achieved by adiabatic cooling of the slurry under vacuum without a cooling surface and by avoiding encrustation.

For end markets with high quality standards, a recrystallisation stage can be added to improve the purity of the final product.

Evaporator types

Several designs of evaporators are available to satisfy a wide spectrum of process requirements. They include:

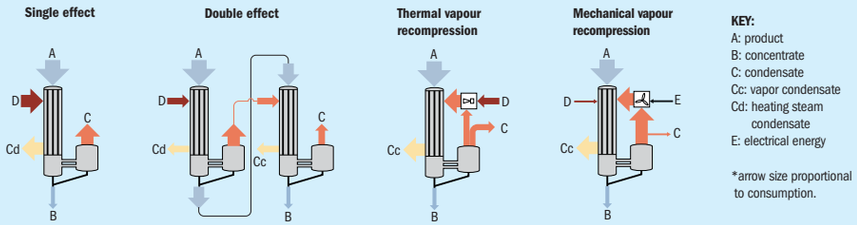
- Plate or tubular type falling film evaporators
- Plate or tubular type forced circulation evaporators
- Flash and multi-flash evaporators.

These evaporator types have different strengths and benefits. In each case, the most suitable type is selected by consideration of the main process parameters:

- Scaling tendency
- The product's thermal sensitivity
- Required particle size
- Annual operating hours
- Accessibility for maintenance.

To ensure the longest operational lifetime, evaporation plants are made from the most suitable and durable construction materials. These routinely include carbon steel, stainless and duplex steel, high nickel alloys, nickel and titanium. For the most highly corrosive applications, graphite, rubber-lined carbon-steel and fiberglass reinforced plastics are selected.

Fig. 1: **Evaporator mass/energy flow diagrams for the four different heating configuration options***



Source: GEA

> **Evaporators and crystallisers are widely applied in nitrogen, phosphate and potash production. This includes the large-scale manufacture of the fertilizer commodity potassium chloride and production of the process intermediate phosphoric acid.**

Heating configurations

Evaporation and crystallisation processes consume a substantial amount of energy. Operating costs are directly linked to the type of evaporator and the heating configuration selected (Figure 1). The main options are:

Multiple-effect evaporators. Classical multiple-effect evaporation uses low-pressure steam for heating of the first effect and vapour for heating in the subsequent stage or stages. The number of stages employed reflects the relative importance of operating costs versus capital investment. These factors are linked to evaporation capacity and the boiling point elevation of the solution.

Thermal vapour recompression (TVR) is used whenever steam is available at high- or medium-pressure. The flash energy of the steam is used to recompress part of the vapour given off, up to the pressure of the heating steam. This configuration, when available, achieves substantial savings in steam and cooling water at a relatively low cost.

Mechanical vapour recompression (MVR). In this configuration, all of the process vapours are recompressed to heat the evaporator. Virtually no steam is required, apart from pre-heating when starting the process. The only energy consumption necessary is the power required to drive the compressors. These are usually centrifugal fans, with one or several stages of compression, or positive-displacement type compressors. In some applications, a scrubber is installed prior to the compressor to prevent corrosion from acid vapours.

Current energy costs make MVR a very attractive configuration for evaporation and crystallisation. Choosing this option also delivers a saving on cooling tower and boiler investment.

A new crystallisation and evaporation plant must balance energy costs with capital cost. This is achieved by finding the right compromise (in terms of the total cost of ownership) between the customer's investment budget and operating cost, the latter being mainly linked to energy price levels. Existing production units can also be upgraded by reconfiguring and improving the existing heating configuration and/or by introducing more modern technology.

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KEY FERTILIZER INDUSTRY APPLICATIONS

Potassium chloride (MOP) production

For brine sources, highly pure crystalline potassium chloride is recovered at multiple flash cooling crystallisation plants. Brines typically contain both sodium chloride (NaCl, sylvinite) and potassium chloride (KCl). This process is notable for:

- High efficiency heat recovery
- Temperature drop from 110°C to 45°C
- Heat recovery in four stages is usual with condensation in three re-cooling stages
- K_2O content adjustable between 58-62 percent by remixing condensate
- Crystal size of up to 1.2 mm.

Potassium chloride is also commonly crystallised from conventionally mined carnallite ores (containing KCl, $MgCl_2$, NaCl, $MgSO_4$ and $CaSO_4$). Additional purification steps are generally necessary to generate a product of the required commercial quality at an economically-acceptable yield.

Potassium nitrate crystallisation

Potassium nitrate (KNO_3) can be manufactured via several process routes:

- GEA offers a direct conversion process for KNO_3 using crude, natural sodium nitrate product (caliche) and fertilizer grade potassium chloride (MOP). This innovative process design provides a capital cost saving on the sodium nitrate rectification plant.
- The reaction of MOP with nitric acid is another KNO_3 production method. This yields ammonium chloride as a by-product.
- Potassium nitrate can also be produced using an ion exchange and crystallisation process.

Ammonium sulphate manufacture

The industrial production of caprolactam (CPL), methyl methacrylate (MMA) and acrylonitrile yields large quantities of ammonium sulphate (AS) as a by-product. This route now accounts for 60-70 percent of AS production globally. Other sources of ammonium sulphate include:

- Purge gas washing, e.g., from large urea prilling towers
- Regeneration liquids from continuous ion exchange systems
- Production through reactive crystallisation of ammonia and (spent) sulphuric acid.

The heat generated by the reactive crystallisation of AS enables the evaporation process to be operated without any external energy source. While reactive crystallisation has an energy advantage over evaporative crystallisation, disadvantageously, it produces smaller crystals. Consequently, around 80-90 percent of AS crystallisers are operated in evaporative mode to produces larger size crystals. The market price of the larger crystals (2-3 mm) obtained can be up to three times higher than the price of smaller crystals (<1 mm) – a price premium that strongly favours the production of large crystals.

Water-soluble monoammonium phosphate

Highly pure and water-soluble monoammonium phosphate (MAP) can be manufactured from phosphoric and ammonia by a process with the following steps:

- Reactive crystallisation – the reaction of NH_3 with H_3PO_4 in a reactor
- Decantation
- Membrane filtration
- Forced circulation crystallisers with integrated scrubbers.

This produces MAP in highly concentrated form as white crystalline pellets. The demand for this type of water-soluble MAP – for fertigation or foliar application to crops – is growing globally. ■

Fertilizer production

Evaporators and crystallisers are widely applied in the production of nitrogen, phosphate and potash fertilizers (see box). This includes the large-scale manufacture of fertilizer commodities such as merchant-grade phosphoric acid (MGA) and granular muriate of potash (MOP, KCl). More importantly nowadays, evaporation and crystallisation are also used to produce value-added speciality products, especially water-soluble fertilizers (WSFs) such as monoammonium phosphate (MAP), potassium nitrate (NOP), potassium sulphate (SOP) and monopotassium phosphate (MKP).

GEA Group, with its expertise in evaporation and crystallisation, has developed and successfully installed numerous processes in fertilizer production plants worldwide. The company also has expertise in process design, gained from laboratory- and pilot-scale testing and process simulations carried out at GEA's development centre.

Innovations and sustainability improvements

High-purity phosphoric acid is generally used as the starting product for MAP manufacture. GEA, however, has developed a ground-breaking process that produces high-quality water-soluble MAP fertilizer from non-purified, merchant-grade phosphoric acid (MGA) instead (*Fertilizer International* 496, p45). This eliminates the need to purchase or manufacture more costly purified phosphoric acid (PPA).

In a landmark fertilizer industry project, GEA has successfully implemented this process at a production plant in Eastern Europe. This allows the customer to manufacture highly pure and soluble MAP at a yield of up to 70 percent. The installed production unit has avoided considerable capital costs and operational expenditure, thanks to its ability to consume MGA rather than PPA, while still producing high-quality, water-soluble MAP, a premium fertilizer product with a high market value.

The company's newly-developed MAP production process, as well as consuming lower grade MGA, incorporates a special ceramic membrane filtration (CMF) system that removes impurities (mainly struvite). The filter's ceramic elements are abrasion resistant and provide a high level of temperature stability while removing crystalline impurities from the MAP solution.

GEA, by providing the industry with the ability to manufacture high-quality water-soluble fertilizers (WSFs) for fertigation, is also supporting sustainability by promoting efficient and responsible nutrient use.

Fertilizer producers are minimising energy usage and cutting energy costs – to increase their competitive advantage, cut carbon emissions and improve operational sustainability. With these objectives in mind, evaporation and crystallisation can improve energy consumption in several ways such as:

- Better use of hot condensates
- Use of vapour recompression
- Installation of multiple-effect evaporators
- Heat integration between the evaporator and dryer
- Combining scrubbing or steam reforming with vapour recompression, when dealing with corrosive process vapours.

GEA is able to provide energy use audits and advise on all these options.

Water and product recovery from fertilizer production effluents is also becoming more important. Increasingly stringent wastewater regulations are creating growing interest in evaporation and crystallisation for waste reduction and treatment. As a technology, they offer customers a complete solution to water cycle management in industrial processes. The installation of evaporation and crystallisation equipment can deliver:

- Compliance with environmental regulations
- Recovery of distilled water
- Recovery of valuable chemicals
- Profits from waste treatment
- Positive improvements in environmental, social and governance (ESG) performance.

The management of phosphogypsum ponds and raffinates remains a great challenge for the phosphates industry. Evaporation and crystallisation technology, together with membrane filtration and ion exchange, offer one potential solution due to their ability to recover both valuable products and water.

Summary

Evaporation and crystallisation technologies can be customised to manufacture a wide spectrum of fertilizers, allowing these to be produced both efficiently and sustainably.

GEA – with a team of 150 evaporation and crystallisation specialists and brands like Messo, Wiegand and Kestner – is a long-standing provider of innovative production technology to the fertilizer industry. Founded nearly 140 years ago, the company combines an extensive track record in industrial evaporation and crystallisation with strong research and development capabilities. Its wide experience of full-scale production plants is backed by strong process design capabilities and laboratory- and pilot-scale testing facilities.

Around the globe, GEA plants are producing industrial-grade, high-quality fertilizers – in locations ranging from the Atacama desert in Chile to Europe's potash mines, and from the shores of Dead Sea in the Middle East to phosphoric acid plants in Asia and Latin America. ■

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Innovative gas scrubbing at SSP plants

Single superphosphate (SSP) is relatively easy and cheap to make. Yet traditional gas scrubbers often limit production and create plant maintenance issues. Fortunately, an innovative scrubbing technology developed by Armatec Environmental can overcome many of these problems. Based on high efficiency void towers, this new approach helps SSP producers meet stringent global emissions standards, explains Armatec's **Shane Pope**, while simultaneously maximising production and improving worker conditions.

PHOTO: ARMATEC

Above: This Armatec scrubber system, installed in 2014, was the first in Egypt to meet the new fluorine emissions limit of 5 mg/Nm³.

Single superphosphate (SSP) is a well-known and long-established fertilizer. Currently, it is seeing a resurgence in popularity as other energy-intensive fertilizers have become more costly to make.

SSP is produced by reacting phosphate rock with sulphuric acid in a mixer. The resulting mixture is then cured – usually in a den with a moving floor. The process reaction produces steam and fumes that contain numerous contaminants. These must be scrubbed before discharging to the atmosphere.

From a scrubbing perspective, the most challenging contaminant is fluoride, evolved as both hydrogen fluoride (HF) and silicon tetrafluoride (SiF_4). In wet scrubbers, fluoride is absorbed by water to produce hydrofluorosilicic acid (H_2SiF_6), known as FSA or HFA. The cleaned gas is then discharged to the atmosphere via a stack.

Emissions limits

In recent years, many countries have reduced the allowable discharge of fluoride from the stack plumes of phosphate fertilizer plants. This is due to the increasing awareness of the atmospheric pollution from these emissions.

A total fluoride limit of 5 mg/Nm³, as recommended by the World Bank and others, is now being used as a common benchmark around the world. This mean that many phosphate plant scrubber systems, which may have been acceptable previously, are no longer capable of meeting discharge requirements. Upgrades are therefore required to meet the new and more stringent emissions limit.

The scrubbing challenge

The scrubbing of fumes generated by the SPP production process is uniquely challenging:

1. Very high removal efficiency is required. Fluoride levels in the fumes emitted from the den can range from 5,000-50,000 mg/Nm³. To reduce these to the current global standard of 5 mg/Nm³ therefore requires a scrubber efficiency in excess of 99.9 percent.
2. The hydrofluorosilicic acid (FSA) resulting from the scrubbing process is noxious, corrosive and dangerous. Traditional materials such as steel quickly corrode. The FSA is also laden with silica solids, making it even more difficult to handle.
3. The silica produced as an unavoidable scrubbing reaction by-product deposits itself throughout the system, creating blockages in pipes, ducts and spray nozzles if not carefully managed. Regular cleaning is therefore vital to maintain plant operation.
4. The cleaning of traditional scrubber systems can be dangerous, especially where entry to confined spaces is required. The corrosive acid present during cleaning, along with the potential for injury from falling solids, are hazardous to workers.

Because of these challenges, many SSP plants face the following difficulties with their scrubber systems:

- They have to run at reduced production rates so as not to exceed stack emissions limits
- They face regular, often unexpected, plant shutdowns to clear blockages
- Operation and maintenance of scrubber systems can be risky and hazardous for workers.

PHOTOS: ARMATEC

Silica deposits (left) are a natural and unavoidable by-product of scrubbing. These need to be carefully managed to avoid blocking pipes, ducts and fans (right).

PHOTOS: ARMATEC

Traditional void towers (left) struggle to meet today's strict emissions limits. Venturi scrubbers(right), while a common solution, also have several limitations.

As a consequence, the scrubber system ends up becoming the bottleneck for plant production.

Yet it shouldn't be this way – as clever design can manage these myriad challenges. What's needed is a high efficiency, multi-stage scrubbing system that is robust and easy to operate and maintain.

Traditional scrubbing approaches

Historically, three different approaches to scrubbing have been used at SSP plants.

Void towers are one traditional approach. At the top of these is a single spray nozzle, often arranged in multiple stages over a common sump, with scrubbing achieved using both counter-current and co-current water flow.

The benefit of void towers is that scrubbing efficiency is not significantly affected by silica build-up. They don't block like packed towers can, and their scrubbing efficiency is not highly dependent on geometry like a venturi scrubber. This means that scrubbers can continue to operate even with significant silica deposits.

There are, however, several problems with traditional void towers:

- The systems have limited removal rates and struggle to achieve today's strict emissions limits.
- Having the scrubbers installed over a common open sump means that workers are continually exposed to FSA liquor and fumes.
- Access for maintenance and cleaning can also be difficult and dangerous.

Another approach is to use a **crossflow scrubber**. In these systems, air passes horizontally through a packed bed and is contacted with scrubber liquor sprayed onto and flowing down through the packing. While crossflow scrubbers can achieve higher removal rates than traditional void towers, there is significant risk of the packing blocking with silica deposits. If this happens, cleaning can be difficult and time-consuming.

The third approach seen at SSP plants is **venturi scrubbers**. These can achieve quite high removal rates and have a smaller footprint relative to void towers. Nonetheless, Armatec has observed several limitations with venturi scrubber systems:

- A high energy requirement is necessary to overcome the pressure drop required for contaminant removal. Because of this, multiple fans are sometimes needed to move the air through the system.
- Mist carryover can limit overall system efficiency. Mist eliminators are needed at each scrubbing stage to address this. These can be prone to silica blockages, depending on the style of mist eliminator.
- Scrubber efficiency is highly dependent on the geometry inside the venturi throat. This geometry is affected by silica deposits with scrubbing efficiency decreasing as silica builds up – putting the plant at risk of exceeding its stack emissions limits.

Because of the above limitations, clients in New Zealand and elsewhere are now replacing their venturi scrubber systems and adopting a new approach instead.

High efficiency void towers

To overcome the limitations seen in other systems, Armatec has developed a new approach based on high efficiency void towers. Known as Fluorisorb, the full system comprises:

- Multiple stages of high efficiency void towers to provide the high removal

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China Works, Black Prince Road
London SE1 7SJ, England
Tel: +44 (0)20 7793 2567
Web: www.bcinsight.com
www.bcinsightsearch.com

PHOTOS: ARMATEC

Quick release access hatches (left) provide fast and safe access for inspection and maintenance. Clever design (right) allows maintenance to be done without confined space entry.

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Silica-laden hydrofluorosilicic acid (FSA) (left) can be difficult to manage and even more difficult to dispose of. Armatec can help plant operators develop a zero effluent system (right) that provides FSA for re-sale for water fluoridation and/or recycling to the process.

rates needed to meet the most stringent emissions standards
- Liquid flows counter-current to the gas stream to maximise efficiency
- Scrubber liquors are contained to prevent worker exposure to corrosive acid and fumes
- Quick and safe access for inspection and maintenance is provided.

Scrubbing systems based on Armatec's Fluorisorb technology provide the following benefits:
- By using void towers, robust operation with high scrubbing efficiency is guaranteed, even in the presence of silica deposits
- High efficiency scrubbing is achieved by the system's true counter-current design and the use of multiple sprays
- The incorporation of design features to handle silica deposits reduces blockages and subsequent down-time
- Clever design and strategically placed quick release access hatches provide quick and safe cleaning without entry to confined spaces.

Fluorisorb systems can be tailored to site-specific operating conditions. In some upgrade projects, for example, clients opt for a new Armatec system to completely replace their old scrubbing system. Others want to incorporate new Armatec technology within their existing scrubbing system to achieve improved performance while minimising costs. As engineers, we enjoy the challenge of finding the best solution for each client!

In summary, clients who have upgraded to Armatec scrubbing systems can run their plants at higher capacity rates without fear of exceeding emissions limits. They can also plan production around scheduled maintenance shutdowns for cleaning. Maintenance and cleaning are simple and safe and unscheduled stoppages due to blockages are extremely rare.

Eliminating Effluent

A further benefit to Armatec scrubber systems is the opportunity to eliminate liquid effluent.

Wet scrubbing at SSP plants, as previously mentioned, produces silica-laden hydrofluorosilicic acid (FSA) – leaving operators with the challenge of what to do with this scrubber liquor. Some clients concentrate and purify the FSA and then sell it for water fluoridation. Others neutralise and dispose of the FSA through a wastewater treatment system, although this solution can be costly.

A more attractive option for plant operators is to return the FSA to the process. This is achieved by introducing FSA to the mixer, alongside the sulphuric acid, so that it takes part in the reaction. This reduces – and even entirely eliminates – the amount of FSA handled elsewhere in the process.

But there is a potential difficulty with this approach: returning FSA to the mixer results in a significant amount of the fluoride being re-evolved back to the scrubbers. This can increase the fluoride load on the scrubbers anywhere from two to ten times. Therefore, to cope with this extra load, the scrubbing system must have a removal efficiency capable of achieving the required stack emissions, even with significantly higher incoming fluoride.

Armatec can design systems with the necessary efficiency to maintain stack emissions within required limits, even when 100 percent of the FSA is returned to the mixer. This provides operators with a zero effluent process as a potential option. Some alterations to the mixer are necessary to achieve this – which Armatec is well equipped to advise on.

Armatec has developed the Fluorisorb system based on its work with SSP clients for 30+ years. This technology can be applied to new SSP projects or incorporated as an upgrade at existing SSP plants. Case studies of two projects carried out with clients to upgrade their SSP scrubbers are provided below.

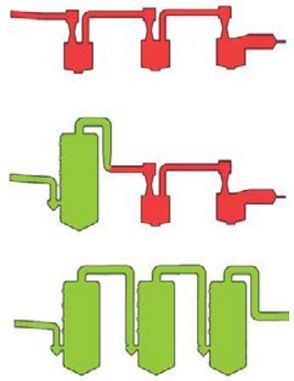
Case study 1: Replacing venturis

Prior to the upgrade, this client was using a scrubbing system comprised of three venturis. These had been acquired from another site and re-purposed. The system had a number of failings:
- SPP production was limited by scrubber performance
- Silica was being deposited throughout the system including in the fan
- Cleaning and maintenance were also difficult
- Caustic consumption at the plant was high to try to compensate for poor scrubber performance.

In the first phase of the upgrade, Armatec replaced the first venturi with a high efficiency void tower. Scrubbing performance immediately improved, and cleaning and maintenance became easier. The client could produce high strength FSA for sale for water fluoridation. But there were still issues.

The second phase of the upgrade saw the replacement of the second and third venturis with two more high efficiency void towers. All client goals were achieved:
- Scrubbing efficiency was maintained with a 47 percent higher air flow rate and 20 percent less water consumption
- The prevention of further silica deposition in the fan improved plant operation and reliability
- Caustic consumption was greatly reduced.

The site engineer reported that, "The scrubbers take everything we throw at them!"



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Case study 1: Two-stage upgrade of the client's venturi system (left, top-to-bottom). Armatec scrubbers (right) provide robust performance.

Case study 2: Zero effluent system

Prior to the upgrade, this client's traditional void tower scrubber system had the following performance issues:
- The site was not meeting its stack emission consent limits
- Production was being limited to try to reduce these stack exceedances.

The client wanted to upgrade the scrubber system to unlock more production while at the same time meeting their consent conditions.

In the first phase of the upgrade, Armatec retrofitted the existing towers to improve their performance and added a new Armatec high efficiency void tower. As a result:
- The client was able to unlock additional production capacity and meet their emissions limits
- The upgrade also enabled the site to eliminate their liquid effluent, which led to the operator winning an environmental award for their work.

The old towers, which were at end of their useful life, have now been replaced as part of the recently completed second phase of the upgrade. This has improved system reliability and unlocked extra production capacity while still complying with emissions regulations.

Conclusion

Single superphosphate (SSP) production is often limited by poor scrubber systems that limit plant output, exceed emissions limits, and cause hazards for workers. By understanding the limitations of previous approaches, Armatec developed its Fluorisorb scrubber system to help plant operators meet emissions limits while unlocking production capacity and making plant operation and maintenance simple and safe.

This innovative scrubbing technology is based on 30+ years of working with SSP clients in New Zealand and elsewhere. Fluorisorb systems are now being sought all over the world, as clients seek to meet stringent global emissions standards, while simultaneously maximising their production and improving conditions for their workers. ■

PHOTOS: ARMATEC

Case study 2: Phase 1 of the SSP scrubber upgrade (left) helped the client win an environmental award. The recently completed phase 2 of the upgrade (right) has future-proofed the site for increased production.

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Editor:
SIMON INGLETHORPE
simon.inglethorpe@bcinsight.com

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

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Sales/Marketing/Subscriptions:
MARLENE VAZ
Tel: +44 (0)20 7793 2569
Fax: +44 (0)20 7793 2577
marlene.vaz@bcinsight.com
Cheques payable to BCInsight Ltd

Advertising enquiries:
TINA FIRMAN
tina.firman@bcinsight.com
Tel: +44 (0)20 7793 2567

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Tel: +44 (0)20 7793 2567
Fax: +44 (0)20 7793 2577
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For further information and to book advertisement space contact:
Tina Firman, Publishing Director: tina.firman@bcinsight.com
Tel: +44 (0)20 7793 2567 Fax: +44 (0)20 7793 2577

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