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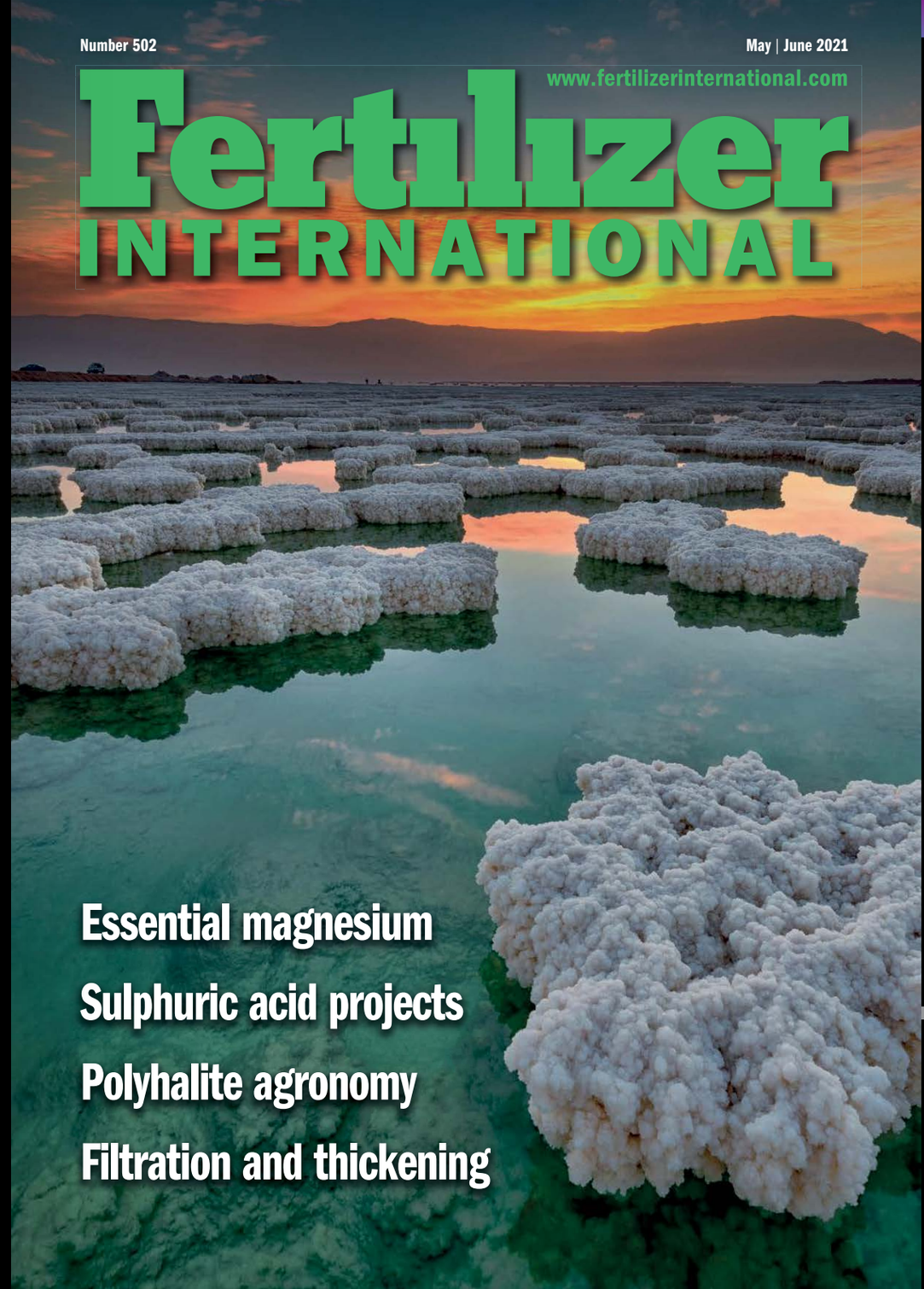

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Cover: Dead Sea at sunset.
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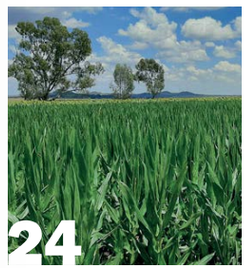

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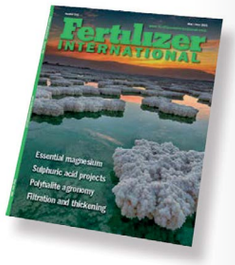
The great green leap forward



As recently as five years ago, decarbonising fertilizer production was little more than an aspiration.

Even assuming there was a collective wish to achieve this goal, the pathway to carbon reduction was unclear and the technical and financial obstacles remained formidable.

Renewable electricity prices were prohibitive, investment costs astronomical. The technologies required also looked uncompetitive and difficult to scale. That was the received wisdom, anyway.

The industry first became seriously engaged with decarbonisation several years ago. A landmark 2017 report from the European Chemical Industry Council (Cefic), for example, set out a pathway to carbon neutrality by 2050 (*Fertilizer International* 483, p20).

The report looked at the viability of low-carbon ammonia production. This involves generating hydrogen by water electrolysis using renewable electricity – the so-called 'green ammonia' route.

What leapt off the page were the staggering costs. At that time, the ticket price for the low-carbon economy looked eye-wateringly expensive.

Cefic calculated that investment in an industry-wide transition to green ammonia in Europe could exceed €70 billion out to 2050 – some 7-8 times higher than the business-as-usual investment of €9 billion expected over the next 30 years.

That was not all. Cefic's work on the commercial uptake of green ammonia in future decades was predicated on three key assumptions, namely: a stable and low electricity price (€40/MWh), drastic falls in the capex costs of water electrolysis units (from €1,450/kW to €375/kW), and a massive hike in the carbon price (to €196/tCO_2).

Reading this report, one could be forgiven for thinking that green ammonia production had major viability issues – and that meaningful decarbonisation of the fertilizer industry remained decades away. That pessimism, thankfully, has proved unfounded.

In recent months, bold investment decisions either side of the Atlantic by two of the fertilizer industry's biggest nitrogen producers – Norway's Yara International and CF Industries in the US – should see commercial-scale green ammonia production commence as early as 2023.

> **Bold investment decisions either side of the Atlantic should see commercial-scale green ammonia production commence as early as 2023.**

In April, CF signed a contract with Germany's thyssenkrupp for a 20 megawatt (MW) electrolysis plant for its Donaldsonville, Louisiana site, the world's largest ammonia manufacturing complex (see page 8). By supplying carbon-free hydrogen for ammonia synthesis at Donaldsonville, this plant will enable the production of 20,000 t/a of green ammonia.

Construction of the new electrolysis plant is scheduled to commence in the second half of 2021 and finish in 2023. When completed, the Donaldsonville green ammonia project will be the largest of its kind in North America.

CF is funding the project from its $400-450 million annual capital budget. In October, the company pledged to cut its production emissions in two stages – reducing its emissions intensity by 25 percent by 2030 followed by further cuts to reach net zero by 2050.

Not to be outdone, Yara is also targeting commercial-scale green ammonia production by 2026. In December, the company announced a new project to completely electrify its Porsgrunn ammonia production plant in Norway.

Yara is aiming to eliminate CO_2 emissions from the 500,000 t/a capacity Porsgrunn plant and dedicate its output to emissions-free shipping fuel, carbon-free fertilizer production and green ammonia for industrial purposes. CF is pursuing similar market opportunities.

Yara has set itself the goal of reducing its Scope 1 and Scope 2 emissions by 30 percent by 2030. It is also collaborating with Nutrien and the World Business Council for Sustainable Development on a sector-wide approach to nitrogen industry decarbonisation.

Nutrien has similarly pledged to cut its Scope 1 and Scope 2 emissions by 30 percent over the next decade. In April, the Canadian fertilizer giant promised to reduce its nitrogen production emissions by one million tonnes CO_2 equivalent by the end of 2023. Nutrien says it will invest $500-700 million in carbon reduction technologies between now and 2030, including blue and green ammonia production, in pursuit of the transition to low-carbon fertilizers (page 10).

In Spain, meanwhile, Iberdrola and Fertiberia are close to completing what will be Europe's largest green hydrogen project. The €150 million project, located next to Fertiberia's Puertollano ammonia plant, is expected to become operational later this year.

One thing is becoming crystal clear from all these developments. Green ammonia has taken a great leap forward – and will emerge as a fully-fledged commercial-scale technology within five years. ■

S. Inglethorpe

Simon Inglethorpe, Editor

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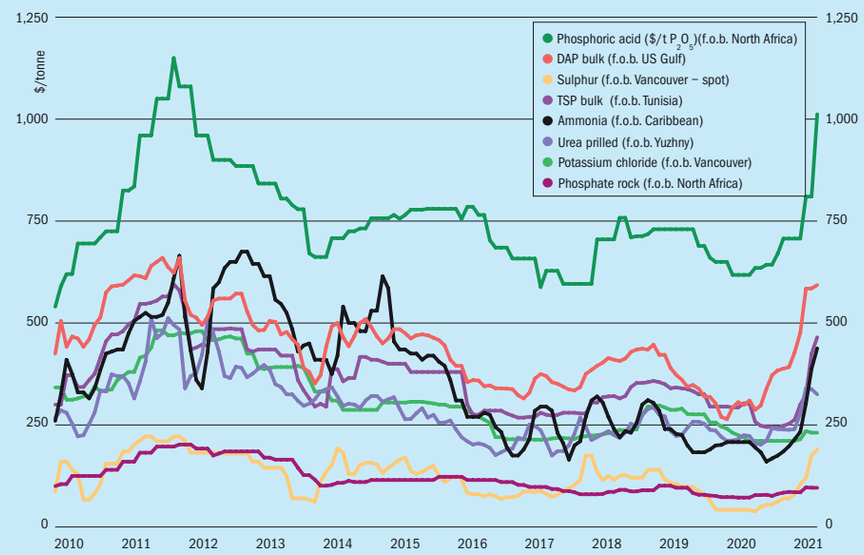
Historical price trends $/tonne



Source: BCInsight

Market Insight courtesy of Argus Media

PRICE TRENDS

Urea: Firmer Chinese urea prices provided the market with some welcome reassurance as April ended. Asking prices moved back up towards $340/t f.o.b. for May, with reduced production, stronger domestic demand, and anticipation of a large Indian tender, all contributing to the rise. Over the same period, small North African sales in the low-$330s/t f.o.b. were followed by larger tonnages sold at $340-344/t f.o.b. for May. Around 300,000 tonnes of urea was sold from this region in mid-April.

Support will come next from India, with a delayed tender – held for May/early-June shipment – likely in early May. Reduced production in India is raising the country's import requirements. Consequently, sources expect MMTC to seek more than one million tonnes of urea in the tender.

Key market drivers: firmer Chinese prices, the forthcoming Indian tender and market fundamentals.

Ammonia: Improving production across all key supply regions and market fundamentals suggest the end of the price rally may be in sight. Steady demand from East Asia continues to drive price gains east of Suez. But capacity brought back online by Saudi Arabian producers Sabic and Ma'aden in April should bring the region back to near normal capacity. The lack of spot availability before June is, however, keeping near term price sentiment firm.

In Ukraine, a Pivdenny cargo was loaded for South Korea in April, a result of the recent supply crunch in the Middle East. With improving supply, the movement of Trinidadian cargoes east to South Korea now looks possible, with prices providing a potential arbitrage opportunity for June-delivered cargoes.

Key market drivers: May cargo purchases by Taiwan and Saudi Arabia restarting two plants.

Phosphates: The market focus has remained on India. After months of lacklustre activity, Indian importers, in a flurry of sales in the $560-562/t cfr range, secured around 300,000 tonnes of Chinese DAP shipments in the latter part of April. Further cargoes are under discussion with the latest Indian business slightly higher at mid-$560s/t cfr. Latin American activity in the late April was muted. The further softening in Brazilian MAP prices to $600-610/t cfr reflected the lack of demand.

Key market drivers: the $200/t rise in the second-quarter phosphoric acid price, rising Indian DAP stocks, further delays to the Bangladesh tender due to the lockdown.

Potash: Demand remains strong despite seasonal lulls. Producers reported tight supply with Canpotex fully committed into September. The Brazil and Southeast Asia MOP cfr prices both moved upwards in the latter part of April. This brings Southeast Asian pricing into line with the new Indian contract price, while the Brazilian price reached levels not seen since January 2019.

Market price summary $/tonne – End April 2021

Nitrogen	Ammonia	Urea	Ammonium Sulphate	Phosphates	DAP	TSP	Phos Acid
f.o.b. Caribbean	430-460	-	f.o.b. E. Europe 135-165	f.o.b. US Gulf	572-613	-	-
f.o.b. Yuzhny	430-470	300-340	-	f.o.b. N. Africa	540-565	440-490	960-1,063
f.o.b. Middle East	440-480	320-355**	-	cfr India	560-595	-	998*
Potash	KCl Standard	K_2SO_4	**Sulphuric Acid**		**Sulphur**		
f.o.b. Vancouver	202-260	-	cfr US Gulf	135-185	f.o.b. Vancouver	180-200	-
f.o.b. Middle East	210-260	-	-	-	f.o.b. Arab Gulf	185-200	-
f.o.b. Western Europe	-	480-550	-	-	cfr N. Africa	160-190	-
f.o.b. Baltic	207-260	-	-	-	cfr India	206-232+	-

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.*

PHOTO: CANPOTEX

The potash market is tight with Canpotex sold out until September.

Key market drivers: steady China MOP prices and APC concluding a contract with India.

NPKs: Most of the large NPK producers have limited availability for May. Phosagro looks set to ship a total of 120,000 tonnes to India in May, having previously sold another panamax into the subcontinent for end-May/June loading. This latest cargo (60,000 tonnes of 10-26-26) was sold at $458/t cfr duty unpaid, the same level as its previous sale to India. Acron is also sold out for May, while OCP is still busy shipping its remaining NPS commitments to Ethiopia.

Limited near-term availability is helping to support prices, even pushing these up in certain regions. The Baltic/Black Sea f.o.b. price for 15-15-15, for example, has risen by $15/t on higher target prices and the lack of supply. But most prices are holding steady amid limited trade activity. Many market participants are taking a wait-and-see approach, following various raw material price movements, making it difficult to predict the direction for NPK prices.

Key market drivers: Delhi entering lockdown and the sharp rise in the Indian phosphoric acid price.

Sulphur: The market in the latter part of April was characterised by limited spot sales and stable spot pricing. Ramadan, China's absence from the market, and question marks over quarterly contract negotiations in the Indian market, combined to create to a subdued market.

Steep first-quarter spot market price increases have complicated second-quarter supply contract negotiations. Price disagreements have held up talks in Europe, while in North Africa the lack of clarity between contract and spot sales has also made agreement difficult. Additionally, problems over second-quarter Russian sulphur supply, linked to logistics delays, have created further uncertainty around the contracts. Currently, it is likely that no April or early May Russian exports will emerge. The late May and June export situation also remains unclear.

Key market drivers: the lack of clear direction and firming freights.

OUTLOOK

Urea: Deferred demand may see some price increases, after prices found their floor in May. Renewed pressure on f.o.b. levels still looks possible for June-July, despite strong fundamentals.

Ammonia: The market west of Suez may have plateaued. Seasonal fertilizer demand is winding down in the US and Europe, alongside a potential slowdown in industrial demand in northwest Europe. A growing list of spot cargo offers, from Egypt to Mexico, means the Tampa contract price is not expected to post any further gains in May. Early-June ammonia cargoes are being offered at firmer levels, but the market could start to see some easing in mid-to-late June.

Phosphates: India remains the focus as demand from other destination markets – including the US, Latin America and Europe – has slowed. Collectively, India, Pakistan and Bangladesh now offer important outlets for producers. Demand from all three countries should be sufficient to keep prices stable.

Potash: Tight supply, strong demand and positive crop fundamentals in major potash-buying regions will continue to push prices up. While US prices should remain at current levels, Brazil, Southeast Asia and Africa will continue to experience MOP price increases.

NPKs: The downside for NPK prices is limited in the near-term. The sharp rise in the Indian phosphoric acid price is expected to filter through to other regions. This will raise production costs of those 'ammophosphate' producers that have to purchase their acid. It may also signal a near term increase in phosphate prices. MOP prices are also trending upwards, while urea prices have also started to firm again.

Sulphur: The price rally of the first-quarter has given way to stable prices at slightly below peak levels. This relative stability is expected to be maintained by the continuing tight supply situation, despite some fall off in demand since the rally. Chinese import buying is expected to support the market in May. ■

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UNITED STATES

North America's largest green ammonia project

CF Industries has signed an agreement with thyssenkrupp to develop a commercial-scale green ammonia project at its Donaldsonville production complex in Louisiana.

thyssenkrupp secured the engineering and procurement (EPC) contract for a 20 megawatt (MW) alkaline water electrolysis plant from CF in April. By supplying carbon-free hydrogen for ammonia synthesis at the Donaldsonville site, this plant will enable the production of 20,000 tonnes of green ammonia annually.

Construction and installation of the new electrolysis plant – which will be managed by CF Industries – is scheduled to commence in the second half of 2021 and finish in 2023. CF says it will meet the cost of the project through its existing capital expenditure budget. This is typically in the range $400-450 million annually.

When completed in 2023, the Donaldsonville green ammonia project will be the largest of its kind in North America.

"Today we launch a new era for CF Industries as we sign a definitive agreement to develop the first commercial-scale green ammonia project in North America," said Tony Will, CF Industries president and CEO. "This project highlights the competitive advantage of our world class ammonia production… and reinforces our commitment to make significant progress in reducing our carbon footprint by 2030."

CF Industries, the world's largest ammonia producer, is developing ammonia as a clean energy source. This includes plans to produce ammonia via several routes – using either carbon-free hydrogen (green ammonia) or carbon capture and sequestration (CCS) technology and certified carbon abatement projects (blue ammonia).

The 20MW thyssenkrupp electrolysis unit selected for the Donaldsonville project is modular, allowing additional units to be added at the site in future to scale-up green ammonia production. CF says it will purchase all the electricity needed to power the electrolysis unit from available grid-connected renewable energy sources.

"We are pleased to partner with thyssenkrupp on our first green ammonia project at Donaldsonville," said Ashraf Malik, CF's senior vice president, manufacturing and distribution. "Their established and reliable technology complements our commitment to the clean energy economy. By integrating the water electrolysis plant into existing ammonia production at Donaldsonville, we will build on our ammonia manufacturing expertise and identify efficiencies that will allow us to scale production in the future."

With six ammonia plants, Donaldsonville is the world's largest ammonia manufacturing complex. thyssenkrupp has an established relationship with CF, having delivered Donaldsonville's largest ammonia plant for the company. This operates using thyssenkrupp's proprietary *Uhde*® process.

"Following the recent delivery of two world-scale ammonia and fertilizer plants to CF Industries we are honored to have now been selected by our long-term customer to contribute to the decarbonization of their operations and to support them in their mission to provide clean energy to feed and fuel the world sustainably," commented Dennis Lippmann, president, chemical & process technologies, at thyssenkrupp Industrial Solutions USA.

thyssenkrupp is a leading electrolysis equipment supplier with a strong footprint in North America. Regionally, the company has installed electrolysis units with a total capacity exceeding 1.4 gigawatts (GW) over the last 30 years. Combined, these units can generate more than 290,000 Nm^3/h of hydrogen.

North America is one of the company's key regions, says Dr Christoph Noeres, head of green hydrogen at thyssenkrupp Uhde Chlorine Engineers: "This second water electrolysis success after the recent announcement of an installation in Canada shows the region's leading role in making the green hydrogen economy a real deal."

CF committed to net zero – the complete decarbonisation of its production base – by 2050 as part of a new strategy unveiled last October (*Fertilizer International* 499, p8). Also in North America, Monolith Materials has announced plans to build a 275,000 t/a green ammonia plant in Nebraska using a proprietary methane pyrolysis process (*Fertilizer International* 499, p8). In Europe, Yara is pressing ahead with plans to completely convert its 500,000 t/a Porsgrunn plant in Norway to green ammonia production by 2026 (*Fertilizer International* 500, p10). ■

Phosphate imports duties confirmed

Import duties on phosphate fertilizers from Morocco and Russia have been confirmed by the United States International Trade Commission (ITC).

The ITC concluded in a ruling in March that subsidies associated with these imports are injuring the US phosphates industry. As a result of the ruling, the US Department of Commerce (DOC) will continue to with 'countervailing duties' on Moroccan and Russian import introduced at the end of November last year (*Fertilizer International* 500, p8). These were imposed following the launch of an ITC investigation in August 2020. This, in turn, had been prompted by a petition from US phosphates producer Mosaic (*Fertilizer International* 497, p8).

The US will now impose the following phosphate fertilizer import duties for at least five years:

- 19.97 percent for imports from Moroccan producer OCP
- 9.19 percent for imports from Russian producer PhosAgro
- 47.05 percent for imports from Russian producer EuroChem
- 17.20 percent for imports from other Russian producers.

These duties are based on estimates of each company's subsidy levels, as determined by the DOC in February.

Commenting on the latest ITC ruling, Joc O'Rourke, Mosaic's president and CEO, said: "Mosaic employees are proud to support American farmers by producing high quality, reliable fertilizer. Today's decision upholds our belief that fair trade is a cornerstone of a healthy US economy, and that American farmers will benefit from having a more competitive American fertilizer industry."

OCP Group hopes to continue supplying fertilizers to US farmers. "Despite this decision, OCP recognizes the supply challenges that American farmers face and is determined to serve them in the future, and will explore the most appropriate options to do so," it said in a statement.

Analysts expect the import duties to prompt major changes in phosphate trade flows and pricing. Commenting on their introduction last year, Glen Kurokawa, CRU Group's phosphate analyst, said: "Mosaic and other US phosphate fertilizer producers should be pleased with the result. The decision increases the likelihood they will receive some protection from imports from lower cost producers entering their home market."

Kurokawa added: "We've already seen dramatic changes in global phosphate flows since Mosaic filed its trade petition in July. Price spreads in the global and North American markets will change as a result.

"These duty rates indicate potentially big consequences for the future of US and global phosphate trade. The stakes are big."

Phosphate recovery plant under construction

Mineral Development LLC (MDL) has broken ground on a $70 million secondary phosphate recovery plant in Polk County, Florida.

The MDL plant is the first independent phosphate beneficiation plant to be built in the US for over 30 years. The company gave the go ahead for contractor DCO Energy to proceed last October. Construction is expected to take 22 months.

The recovery plant will produce 1.2 million t/a of high-grade phosphate rock concentrate (29-34% P_2O_5) by surface mining phosphate-rich tailings left behind from mining operations that took place between 1930- 1980 at the former Noralyn phosphate mine.

Commenting on the project's launch, Lance McNeil, MDL's CEO, said:

"MDL is extremely pleased to work with DCO on this secondary recovery project. MDL selected DCO because of its outstanding track record of on-time and on-budget delivery.

"Secondary recovery reprocesses old mine tailings into high-quality feedstock for fertilizer production. The project only extracts material from land that has been previously mined, the vast majority of which was disturbed before mandatory reclamation regulations, and MDL will reclaim this land according to modern reclamation standards.

"Secondary recovery is an efficient and responsible way to provide the world with the resources it requires to feed its growing population. It creates jobs for the community, supplies high-quality products to support farmers, and increases the value of the land."

The recovery process, as well as extracting high-grade phosphate, helps restore land and surface waters to their original state by planting native vegetation.

The innovative first-of-its-kind project is being funded by $90 million in bonds issued by the Polk County Industrial Development Authority.

Florida declares emergency over phosphate waste stack leak

A water leak from a former phosphate mine site at Piney Point, Manatee County, prompted Florida Governor Ron DeSantis to declare a state of emergency on 4th April.

Manatee County Administrator Scott Hopes warned of the risk of catastrophic flooding to adjacent land, most of which is agricultural. "We are talking about the potential of about 600 million gallons (2.3 billion litres) within a matter of seconds and minutes, leaving that retention pool and going around the surrounding area," he said.

Engineers first found a leak in the liner of a 77-acre (31-hectare) retention pond at Piney Point in late March. The pond, part of a phosphogypsum stack (gyp stack), stores hundreds of millions of gallons of impounded water.

Around 300 homes, businesses, and the nearby Manatee County Jail were subsequently evacuated due to the risk of catastrophic flooding from a full breach in the liner. US highway 41 was also closed.

Officials responded to the emergency by pumping more than 200 million gallons of pond water from the stack into Tampa Bay. The pumping was halted on 8th April to allow treatment of the remaining water.

The pond water was not radioactive, according to Florida's Department of Environmental Protection, although concerns were expressed over the presence of elevated nitrogen and phosphorus levels.

Governor DeSantis described the pond water as "primarily saltwater", stored from a dredging project at Port Manatee, mixed with "legacy process water and storm water runoff". He said that the water was not radioactive, as had been feared, and that the priority was to prevent a "real catastrophic flood situation". To prevent this, emergency workers assisted by the Florida National Guard started to pump water out of the pond into Tampa Bay at a rate of 33 million gallons a day.

Florida lifted the local evacuation order and reopened US 41 to traffic on 6th April. This was after the US Army Corps of Engineers lowered the risk of an uncontrolled breach of water from the Piney Point gyp stack.

Phosphate mining at Piney Point halted 20 years ago after the mine owners Mulberry Corporation went bankrupt, leaving the site with three gyp stacks and associated process waters. The site is currently owned by HRK Holdings.

Compass Minerals sells micronutrient business to Koch

Compass Minerals is selling its North American micronutrient business to Koch Agronomic Services (KAS), a subsidiary of Koch Industries, for $60.25 million.

Under the terms of the sell-off, announced in April, Koch will acquire Compass Minerals' *Wolf Trax*®, *Rocket Seeds*® and *Hydro Bullet*™ micronutrient brands and assets. This includes intellectual property, inventory, customer and marketing materials, and research and development projects currently in progress.

In a statement, Compass Minerals said the divestment was a strategic step that would allow the company to concentrate on its core businesses. These include three North American and the UK salt mines, and production and packaging plants in North America. The company also retains its Great Salt Lake solar evaporation operations at Ogden. These produce *Protassium+*®, the company's sulphate of potash (SOP) fertilizer.

This latest divestment comes weeks after Compass announced the sale of its Brazil-based subsidiary Compass Minerals América do Sul (formerly Produquímica) to ICL in March (see below). Combined, the two sell-offs signal a reversal in strategy for Compass Minerals. Previously, the company's ambition had been to expand its crop nutrient business to match the size of its salt business. This included the acquisition of Produquímica in 2016.

"Today's announcement, combined with the previously announced sale of our South America specialty plant nutrition business, highlights our strategic focus on strengthening our balance sheet and maximizing the productivity of our core operations," said Kevin Crutchfield, Compass Minerals' president and CEO. "We look forward to continuing to drive value for all stakeholders while producing and marketing an array of raw and manufactured materials supporting the transportation, agricultural, chemical, food and animal nutrition sectors."

The purchase of these leading micronutrient brands will strengthen and broaden Koch's speciality fertilizer portfolio.

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"At Koch, we strive to provide solutions to make every ton of nutrient applied more efficient than it is today, and this agreement allows us to offer a platform of innovative solutions for nutrients beyond nitrogen," said Steve Coulter, senior vice president of Koch. "We look forward to continuing the growth of these products and supporting our customers' micronutrients needs."

BRAZIL

ICL buys Compass Minerals' crop nutrients business

Israel's ICL has entered into a definitive agreement to buy Brazil-based Compass Minerals América do Sul S.A. for BRL 2,207 million ($402 million).

The purchase includes the South American crop nutrition business of Compass Minerals – minus the water treatment and chemicals businesses which will be carved-out. The transaction, announced in March, brings with it around $109 million of net debt and an earnout of up to $16 million.

Compass Minerals América do Sul was founded in 1965 and was formerly known as Produquímica until its purchase by Compass Minerals in 2016. The company is Brazil's leading speciality fertilizer company. Its seed treatment and plant health products can be applied to all of Brazil's key crops, including soybeans, corn, coffee, sugarcane, cotton, fruits, and vegetables. Its product range encompasses:

- Enhanced efficiency fertilizers
- Controlled-release fertilizers
- Soil and foliar micronutrients
- Secondary nutrients (calcium, magnesium and sulphur)
- Biostimulants and adjuvants.

Compass Minerals América do Sul has a presence in 25 out of Brazil's 26 states. It serves more than 2,000 farms directly and another 30,000 farms indirectly through a network of 250 agricultural retailers and co-operatives. Headquartered in São Paulo, the company employs more than 1,000 people and operates six production sites and a research and development centre.

Compass Minerals América do Sul is a profitable and growing company. The crop nutrients side of the business generating net revenues of BRL 1,442 million ($284 million) and earnings of BRL 235 million ($46 million) in 2020. It has been growing by around 10 percent per annum over the last five years.

The purchase of this prized Brazilian fertilizer asset follows ICL's buy-out of Fertiláqua for around $120 million last October (*Fertilizer International* 499, p10).

"This transaction, together with our recent acquisition of Fertiláqua in Brazil and our existing specialty plant nutrition business there, will position ICL as the leading specialty plant nutrition company in Brazil, one of the world's fastest growing agriculture markets. This important next step delivers on our stated strategy of achieving leadership positions in high-growth specialty plant nutrition markets, such as Brazil, and also accelerates our progress toward long-term global leadership for our Innovative Ag Solutions division," said Raviv Zoller, president and CEO of ICL.

"While the South American Plant Nutrition business is not part of our forward-looking strategy, we continue to believe the future is bright for these productive assets," said Kevin Crutchfield, president and CEO of Compass Minerals. "We are therefore pleased to see this business, and more importantly the strong team of professionals who operate it, find such a strategic home with ICL."

The purchase of Compass Minerals América do Sul is expected to close by the third-quarter of 2021. The sale is, however, conditional on the carve-out of the water treatment and chemicals assets, customary closing conditions and regulatory approvals.

ISRAEL

ICL secures another potash contract with India's IPL

ICL has signed a contract with Indian Potash Limited (IPL), India's largest potash importer, to supply 600,000 tonnes of muriate of potash (MOP) this year.

The agreement runs through until the end of December 2021 and includes the option to supply an additional 50,000 tonnes of potash. The new contract, signed on 5th April, was agreed at a price of $280/t (CIFFO Indian ports), $50/t above the previous contract.

"The contract we have signed in India, one of ICL's strategic markets, is part of the five-year supply agreement we signed in 2018 with IPL. This contract further testifies to the leading position ICL has in this market and reflects the growing positive momentum in the fertilizer market globally. Favourable weather conditions, an increase in planted areas, and tight supply are contributing to solid global demand for potash," said Eli Amon, ICL's chief commercial officer.

In January, the Belarusian Potash Company (BPC) agreed to supply IPL with 800,000 tonnes of potash in 2021 at a price of $247/t cfr – an increase of $17/t on BPC's settlement with India last year (*Fertilizer International* 501, p8).

Potash supply is tight currently. Canpotex, Canada's potash export consortium, recently announced that its international potash sales were fully committed into September 2021. "Strong demand for potash in numerous key offshore markets… continues to be supported by solid fundamentals for several major agricultural commodities and a focus on food security," Canpotex said in a statement on 20th April.

CANADA

Nutrien commits to 30% emissions cut by 2030

Fertilizer giant Nutrien has set a target to cut its greenhouse gas (GHG) emissions by at least 30 percent by 2030.

The commitment is a relative not an absolute target, the 30 percent reduction being based on emissions per tonne of product, relative to a 2018 baseline.

Nutrien's new pledge covers Scope 1 and 2 emissions generated by the company's direct operations and its electricity use. To achieve this target, Nutrien says it will:

- Reduce nitrogen production GHG emissions by one million tonnes CO_2 equivalent by the end of 2023
- Self-generate renewable energy at its four potash plants by the end of 2025 by deploying wind and solar power
- Invest in new technologies, including blue and green ammonia, and pursue the transition to low-carbon fertilizers.

Achieving these goals by 2030, estimates Nutrien, will require capital investment totalling $500-700 million.

The emissions reduction target forms part of wider set of climate and sustainable farming pledges announced in Nutrien's 2021 environmental, social and governance (ESG) report in April. Scope 3 emissions – those arising from on-farm activity by Nutrien's customers – are also being addressed by the launch of a carbon credit programme (*Fertilizer International* 500, p10). This will financially reward farmers for embracing climate-smart agriculture and improving the soil sequestration of carbon.

"We're in a really unique spot to address two big societal challenges – food security, and in a way that reduces our environmental footprint," Mark Thompson, Nutrien's chief corporate development and strategy officer, told Reuters.

Carbon credits could provide farmers with a top-up of $10-20 per acre in future, estimates Nutrien. This is also in the company's own self-interest. "If we can provide agronomic value and the value of the carbon credit over time, we'll have customer loyalty – we anticipate that we'll be a preferred supplier," Thompson said.

Nutrien eventually wants to see farmers adopt sustainable agricultural products and practices on 75 million acres of croplands globally.

Chuck Magro, Nutrien's outgoing president and CEO, said: "Nutrien is focused on meeting the United Nations' Zero Hunger Sustainable Development Goal in the coming decade by helping growers increase food production in a sustainable manner. Our 2030 commitments and ESG performance targets are ambitious, but necessary.

"Initiatives like our comprehensive Carbon Program will help lead the next wave of agriculture's evolution. This effort drives at the core of our strategy to feed more people, using less resources and with fewer emissions."

RUSSIA

Acron completes ammonia revamp

Acron has completed a revamp of its Number 4 ammonia plant at Novgorod. The Ammonia-4 plant was successfully uprated to its new production capacity of 2,500 t/d, having passed guarantee test runs.

The plant was originally commissioned in 2016 at a cost $500 million. It was the first ammonia plant built domestically by Russian engineers without the support of foreign contractors.

The Ammonia-4 revamp was carried out by Acron in conjunction with Haldor Topsoe. The revised design incorporates Topsoe's heat exchange reformer (HTER), changes to the CO_2 removal section, plus other modifications.

A team of Acron engineers and Topsoe specialists, working hundreds of miles apart, completed the successful overhaul of Ammonia-4 late last year, enabling the plant to reach its new design capacity.

"Haldor Topsoe and Acron have been in successful partnership for quite a while and the revamp project, delivered in November 2020, marks another milestone in our cooperation. We believe our partnership will develop further, to the benefit of both companies," said Peter Vang Christensen, managing director of Haldor Topsoe's Moscow office.

Aleksandr Popov, Acron's chairman, said: "Boosting the Ammonia-4 plant is an important project for Acron Group's investment program… [allowing] us to increase production of nitrogenous and compound fertilizers at our Novgorod site."

Shchekinoazot and Topsoe collaborate on emissions reduction

Haldor Topsoe and Shchekinoazot have agreed to work together to reduce the carbon footprint of Shchekinoazot's current and future production plants in Russia's Tula region.

As part of a memorandum of understanding (MoU) signed by both companies, Shchekinoazot is planning to begin production of green and blue methanol, ammonia, and hydrogen using Topsoe's expertise and technologies. These cover reforming, electrolysis, carbon capture and use, and ammonia and methanol synthesis.

Shchekinoazot and Topsoe's existing partnership dates back 15 years. To date, the two companies have successfully collaborated on five ammonia, methanol and hydrogen production projects. These have applied technologies and catalysts developed and supplied by Topsoe.

"We believe that with Haldor Topsoe's support we'll be able to lead the green transformation and be one of the frontrunners who will blaze the trail for the Russian chemical industry," said Boris Sokol, president of Shchekinoazot.

EGYPT

Stamicarbon to revamp Abu Qir urea plant

Stamicarbon has signed a contract with Egypt's Abu Qir Fertilizers to revamp the Abu Qir 3 urea melt plant in Alexandria.

The revamp of Abu Qir 3 will increase urea production capacity to 2,370 t/d. That compares to its current nameplate capacity of 1,750 t/d and design capacity of 1,925 t/d.

The existing urea plant dates from 1996 and uses Stamicarbon's CO_2 stripping process. Stamicarbon is providing both the license and the process design package for the revamped plant. This is expected to become operational in 2025.

The revamp is based on Stamicarbon's *EVOLVE CAPACITY*™ design with medium-pressure (MP) add-on technology. This allows capacity to be expanded, but without investing in high pressure equipment or a high-pressure CO_2 compressor, while simultaneously reducing energy consumption. The revamp will also reduce emissions to meet local norms.

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People

Mayo Schmidt, the former chair of Nutrien, became its president and CEO on 18th April. He succeeds **Chuck Magro** who is stepping down to pursue new opportunities outside the company. In a coordinated move, Nutrien also announced that **Russ Girling**, TC Energy's former president and CEO, would replace Mr Schmidt as the new chair of its board. Mr Magro made himself available to Nutrien until 16th May to allow a smooth transition.

"Mayo is a remarkable leader who is committed to our values of safety and integrity, our purpose and our strategy focussed on sustainably feeding the world," said Russ Girling. "Under his leadership, along with our deep and experienced executive leadership team and our 27,000 dedicated employees, the board is confident the company is well positioned to continue to grow and create enduring shareholder value."

"The outlook for our business is exceptionally strong," Mayo Schmidt replied. "I look forward to leading the continued execution of Nutrien's strategy and driving industry-leading performance across all our lines of business. Over the coming weeks, I will be connecting with our employees, valued customers and shareholders to continue building our positive momentum and our focus on advancing sustainable solutions to feed a growing planet."

Mr Schmidt brings over 30 years of agricultural business experience to Nutrien. He joined Agrium's board of directors in 2012 and has served as Nutrien's chair since May 2019. He was previously president and CEO of Viterra Inc, a diversified Canadian business that delivers agricultural and food ingredient products to customers in over 50 countries. He has also held senior positions in other agricultural companies such as ConAgra Grain and General Mills. Mr Schmidt was also president and CEO of Hydro One Limited, Canada's largest utility. Mr Schmidt's passion for agriculture started as a young boy, working on his family's fourth-generation wheat and dairy farm in western Kansas.

Russ Girling thanked Chuck Magro for his leadership of Nutrien: "On behalf of the board of directors and everyone at Nutrien, I would like to thank Chuck for his contribution to our growth and success since he joined the company in 2009. We wish Chuck all the best in his future endeavours."

Chuck Magro replied: "I am very proud of the strong foundation we have built at Nutrien over the last several years. I am grateful for the dedication of our employees, and the important partnerships we have forged with our customers and stakeholders. I have enjoyed every moment of my time at Nutrien, and I wish the company and its people continued success."

Nutrien has reduced its board membership from the 12 to 11 directors following Chuck Magro's resignation.

Fertilizer Canada has appointed **Karen Proud** as its president and CEO. She takes over from Garth Whyte who has served as president since 2015. Proud was previously the chief operating officer of Food Health and Consumer Products of Canada.

"Fertilizer Canada has a well-earned reputation in both programming and advocacy initiatives," said Proud. "Having worked for a number of manufacturing and retail sectors I am excited to take on this new role aimed at advancing the safe, secure, and sustainable production and use of fertilizer in Canada and around the world."

"Karen's experience in association management and regulatory negotiation will ensure a continued focus on our industry's priorities, including achieving federal recognition for 4R Nutrient Stewardship as the national standard for nutrient management and the industry's codes of practice as the standard in product safety, as outlined in our Strategic Plan 2025," said Brian Markand, chair of Fertilizer Canada's board. "As a proven leader and relationship-builder, in combination with her extensive background and knowledge of government decision making, Karen will further develop and build upon Fertilizer Canada's foundation of achieving fair, competitive and science-based policies."

Tove Andersen, currently executive vice president (EVP) Yara Europe, has been appointed president and CEO of Tomra Systems ASA. She will move from Yara International to take up her new position by the 1st November at the latest.

"It's been a privilege to follow Tove since making her part of our executive management team in 2016. I'd like to thank Tove for her significant contribution through more than two decades and wish her all the best in her new role in Tomra, a company which like Yara has sustainability at the core of its strategy," said Svein Tore Holsether, Yara's president and CEO.

Yara says it has begun the process of finding Ms Andersen's successor. ■

Calendar 2021

! The following events may be subject to postponement or cancelation due to the global coronavirus pandemic. Please check the status of individual events with organisers.

MAY

19

The Sulphur Institute Sulphur World Symposium, **Virtual event**
Contact: Sarah Amirie
Phone: +1 202 331 9660
Email: samirie@sulphurinstitute.org

26-28

IFA Plant Nutrition Solutions Conference, **Virtual event**
Contact: IFA Conference Service
Tel: +33 1 53 93 05 00
Email: ifa@fertilizer.org

SEPTEMBER

20-22

TFI World Fertilizer Conference 2021, BOSTON, USA
Contact: Mariana Gallo
Tel: +1 202 962 0490
Email: mgallo@tfi.org

27-29

IFA Annual Conference, LISBON, Portugal
Contact: IFA Conference Service
Tel: +33 1 53 93 05 00
Email: ifa@fertilizer.org

OCTOBER

20-22

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

NOVEMBER

15-17

IFA Strategic Forum, KIGALI, Rwanda
Contact: IFA Conference Service
Tel: +33 1 53 93 05 00
Email: ifa@fertilizer.org

Norway's Yara International is investing in promising future growth areas such as green ammonia, partnering with Statkraft and Aker on Europe's first large-scale green ammonia project.

From left to right: Christian Rynning-Tønnesen, CEO, Statkraft. Svein Tore Holsether, CEO, Yara. Øyvind Eriksen, CEO, Aker.

Fertilizer financial scorecard

We compare and contrast the 2020 financial performance of selected major fertilizer producers, following the publication of fourth-quarter results.

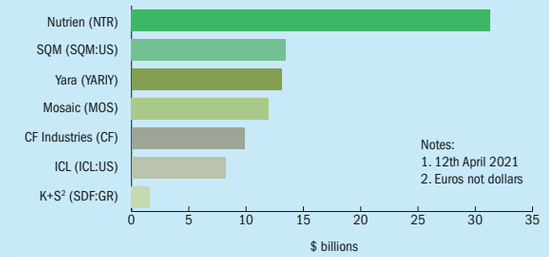
Nutrien – a year like no other

Nutrien is the world's largest crop nutrient company with a market capitalisation of more than $31 billion (Figure 1). From operations and investments in 14 countries, this fertilizer industry giant produces around 27 million tonnes of potash, nitrogen and phosphate products annually, distributing these to agricultural, industrial and feed customers across the globe. The Canadian company's agriculture retail business also serves over 500,000 farmers worldwide.

The Covid-19 pandemic had a limited impact on Nutrien's results, according to the company. Revenues grew by more than four percent year-on-year (y-o-y) in 2020 to $20.1 billion (Figure 2). Yet earnings (adjusted EBITDA) for the year fell by almost nine percent to $3.7 billion (Figure 3). Free cash flow – still impressive at $1.8 billion (Figure 5) – also declined by 15 percent on the previous year.

"2020 will go down in the history books as a year like no other," commented Chuck Magro, Nutrien's outgoing president and CEO. "While virtually every person, community and sector of the economy has been impacted by Covid-19, demand for agriculture products and crop inputs has shown incredible resilience."

Fig. 1: **Market captilisation, $ billions, 2020[1]**



Source: YCharts/Bloomberg

Nutrien primarily attributed the decrease in 2020 earnings to lower crop nutrient prices in comparison to the previous year. This negative factor more than outweighed the positive contributions to earnings, including strong growth in Nutrien's retail business, acquisitions and greater operational efficiencies.

Nutrien is the world's largest potash producer with a 21 percent share of global production capacity. The company achieved strong potash sales of 12.8 million tonnes in 2020, an 11 percent improvement on 2019 and the company's second highest annual total. Some 8.0 million tonnes of this volume was destined for overseas markets with the remaining 4.8 million tonnes being sold within North America.

Nutrien's 2020 potash earnings were 25 percent lower y-o-y, despite higher sales, due to lower realised selling prices. The company did, however, manage to reduce its average potash manufacturing costs ($59 per tonne) by $4 per tonne, relative to 2019.

Similarly, nitrogen earnings also decreased by 13 percent in 2020, despite a 700,000 tonne increase in sales volumes to 11.0 million tonnes and lower production costs, with lower selling prices being mainly responsible.

"Nutrien reported excellent results across our entire business. Our Retail Ag Solutions business delivered a record fourth quarter and we also reported higher potash and nitrogen sales volumes and lower production costs. Agriculture funda-

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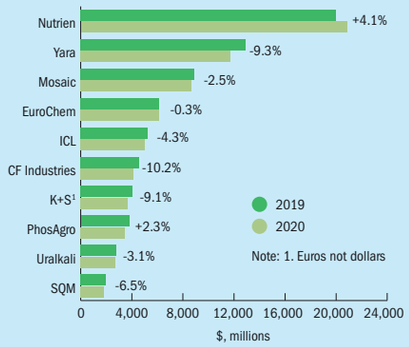
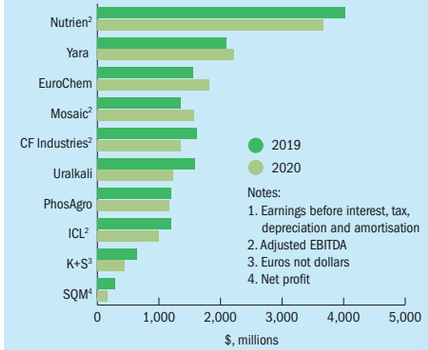
Fig. 2: **Revenues of selected major fertilizer producers, 2019-2020**



Source: Company filings

Fig. 3: **Earnings of selected major fertilizer producers, 2019-2020[1]**



Source: Company filings

mentals began to improve in late 2020 and we are starting to see the benefit to our business from this cyclical recovery," commented Chuck Magro.

The rise in Nutrien's fourth-quarter earnings signalled improving market conditions during the last three months of 2020, being linked to strong retail growth, improving prices and higher potash sales volumes in particular.

"Global potash demand surpassed expectations in late 2020 and we now estimate world potash shipments reached record levels at approximately 68 million tonnes. Potash prices also improved considerably in late 2020, with US Midwest prices up nearly $100 per tonne at the end of 2020 compared to mid-year levels," commented Nutrien.

The company also benefitted from the sale of its stake in Egypt's Misr Fertilizers Production Company (MOPCO) during 2020. This generated net proceeds of $540 million. Nutrien says it will redeploy these proceeds to generate higher shareholder returns. The investment in MOPCO, valued at $300 million, had generated around $15-20 million in annual earnings previously.

Yara's earnings grow despite the *annus horribilis*

Norway's Yara International – the world's second largest fertilizer company based on market capitalisation (Figure 1) – managed to growth its earnings (EBITDA) by six percent to $2.2 billion in 2020 (Figure 3). Lower gas prices, higher premium product deliveries and a stronger US dollar during the year helped the company offset weaker commodity prices and a slight rise in underlying fixed costs.

Higher earnings were achieved despite a nine percent y-o-y fall revenues to $11.7 billion in 2020 (Figure 2), the latter reflecting lower fertilizer market prices compared to 2019.

Yara's annual product deliveries rose to 38.1 million tonnes, a three percent improvement on 2019. This total included:

- 29.0 million tonnes of fertilizers
- 7.1 million tonnes of industrial products
- 2.0 million tonnes of traded ammonia.

Premium product deliveries grew particularly strongly – up eight percent y-o-y to 14.8 million tonnes. This included improvements in compound NPKs (+530,000 tonnes) and nitrates (+320,000 tonnes). Higher ammonia and finished fertilizers production (+115,000 tonnes) was partially offset by the closure of Yara's Trinidad plant.

"Thanks to the dedication and efforts by our more than 16,000 employees, we managed to keep our plants running and made sure our lifesaving products reached farmers at a crucial point in time," said Yara's president and CEO Svein Tore Holsether. "I was both proud and very satisfied when we closed the books on a year that will go down in history as an *annus horribilis*."

Svein highlighted major improvements in free cash flow (Figure 5) and the upward trend in return-on-investment capital (ROIC) over the last 30 months:

"[It] feels rewarding to continue to deliver improved prosperity through improving capital returns for 10 consecutive quarters and improving our free cash flow by $1.4 billion compared to 2019. This has enabled us to increase the level of dividend, even in such a challenging year.

"Through our strong focus on capital allocation and discipline, we are also able to invest in growth areas, such as green ammonia, utilizing our number one positions as ammonia producer, trader and transporter."

Yara is uniquely well-placed in the ammonia market due to its leading positions across production, trade and shipping:

- **Production:** 8.5 million tonnes of capacity across 17 units.
- **Trade:** a global trader with more than 20 percent market share and around 3.7 million tonnes of global export capacity.
- **Shipping & storage:** more than 200,000 tonnes of maritime transport capacity (11 ships), 580,000 tonnes of ammonia storage capacity and 18 marine ammonia terminals.

Mosaic bounces back with strong results

Florida-headquartered Mosaic is a leading international phosphate and potash producer, being responsible for around 13 percent and 11 percent, respectively, of global phosphate and potash output. The company sold more than 28 million tonnes of products in 2020, with sales volumes split between three business segments:

- Potash segment: 9.4 million tonnes
- Phosphates segment: 8.5 million tonnes
- Mosaic Fertilizantes (Brazil): 10.6 million tonnes.

Mosaic described 2020 as a year of strong results. The company certainly bounced back in 2020 with a 16 percent rise in annual earnings (adjusted EBITDA) to $1.6 billion (Figure 3). This followed a difficult 2019 in which earnings tumbled by 36 percent to $1.3 billion (*Fertilizer International* 496, p14).

This earnings improvement was achieved despite a slight fall back in 2020 revenues to $8.7 billion, a couple of percent lower than in 2019 (Figure 2).

In another positive sign, Mosaic also generated net earnings of $666 million in 2020 – compared to a net loss of $1.1 billion in the previous year.

Mosaic's 2020 performance was boosted by improved operational efficiency and higher sales across its phosphate, potash and Mosaic Fertilizantes business segments. Potash and Mosaic Fertilizantes sales volumes for the year both grew by over 10 percent, while the phosphates business segment delivered record *MicroEssentials* sales.

The company calculates that operational savings and efficiencies ('transformation benefits') across its businesses amounted to $318 million in 2020. In Brazil, Mosaic Fertilizantes alone achieved savings of $115 million last year. In Canada, meanwhile, shifting potash production from the idled Colonsay mine to the new Esterhazy K3 mine delivered a further cost saving of $100 million in 2020.

Mosaic reported an improving fertilizer market situation during the second half of 2020 – reflecting a tightening supply and demand balance for both potash and phosphates. In the US market, falling inventories and limited supply led to improvements in phosphate and potash prices during 2020's third- and fourth-quarters.

"Our actions to optimize our portfolio of assets and invest in efficiencies, along with our reduced inventories and expected strong global fertilizer demand, position the company well for 2021," said Mosaic's president and CEO Joc O'Rourke.

In a major milestone, MOP production from Mosaic's new Esterhazy K3 potash mine reached 1.3 million tonnes in 2020, and is expected to increase further to 3.2 million tonnes this year.

Record earnings at EuroChem

In a year of significant business growth, Swiss-headquartered EuroChem Group posted record earnings of $1.8 billion in 2020, a sector-leading jump of 17 percent y-o-y (Figure 3). This was achieved against the backdrop of the pandemic, lower average fertilizer prices and flat revenues (Figure 2).

Among the key contributors to the earnings rise at the Russian- and European-based fertilizer manufacturer were an increase in production output, strong iron ore concentrate prices (a key by-product) and favourable currency exchange rates.

Highlights of the year for EuroChem included:

- 12 percent increase in fertilizer sales volumes to 25.6 million tonnes
- Doubling in potash sales year-on-year to two million tonnes – this accounting for 12 percent of total fertilizer revenues
- Fall in the net debt/earnings ratio to 2.53 (Figure 4)
- Free cash flow of $86 million (Figure 5)
- 23 percent increase in capital expenditure to $1.2 billion.

The capital expenditure increase was linked to the decision to proceed with the EuroChem Northwest 2 (ECNW2) project to build a new 1.1 million tonne capacity ammonia and 1.4 million tonne capacity urea complex. EuroChem is also pursuing key expansion projects at its Usolskiy and VolgaKaliy potash mine sites in Russia.

"Our ability to post record EBITDA and decrease our leverage ratio in the conditions of the most challenging global pandemic in modern times speaks to our resilience, flexibility and governance," said EuroChem Group CEO Vladimir Rashevskiy. "With the help of meticulous planning, we have avoided any significant disruption to the business and kept our customers supplied with the nutrients they need to help feed the world."

He continued: "These results underpin our growth ambition to reach the top of the fertilizer industry by maximizing our vertically integrated business model and forging ahead with highly promising expansion projects such as EuroChem Northwest 2."

ICL – tough year with a strong finish

Israel's ICL Group is a leading producer of potash, phosphates and speciality fertilizers with a market capitalisation of around

COMPANY RESULTS

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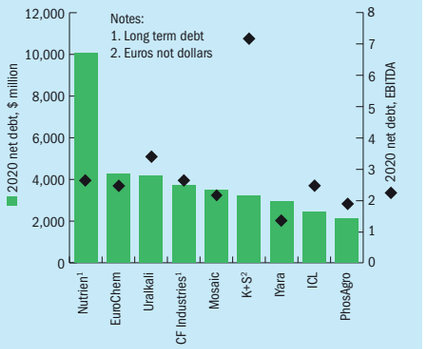
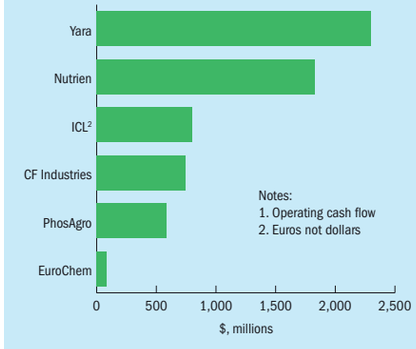
Fig. 4: **Net debt of selected major fertilizer producers, end 2020**



Source: Company filings

Fig. 5: **Free cash flow of selected major fertilizer producers, end 2020**



Source: Company filings

$8.1 billion (Figure 1). The company's annual revenues declined by four percent to $5.0 billion in 2020 (Figure 2). This decrease was mainly attributed to a $56/t fall in the average potash price, compared to 2019.

Full-year earnings also fell by 17 percent y-o-y to $990 million (Figure 3). Operating cash flow, at $804 million in 2020, was similarly down 19 percent on the previous year (Figure 5). ICL nevertheless described cash generation as "strong" due to its continuing focus on the "optimisation of capital expenditure, working capital as well as the implementation of efficiency measures".

ICL's potash ($1.3 billion) and phosphate ($1.9 billion) business segments contributed 27 percent and 39 percent, respectively, to overall company revenues in 2020. The company's speciality fertilizer business, Innovative Ag Solutions, also generated 14 percent of revenues ($0.7 billion).

ICL's potash sales at 4.7 million tonnes in 2020 were 548,000 tonnes higher y-o-y. This was linked to production increases and higher sales to China, Brazil, India and the US.

Potash output from operations in Spain and Israel reached 4.5 million tonnes in 2020 – up almost nine percent on 2019 levels – with output at ICL's Dead Sea plant reaching record levels following recent production upgrades. Polyhalite production (*Polysulphate®*) at ICL's Boulby mine in the UK was also up 12 percent y-o-y to 709,000 tonnes.

"To be certain, 2020 was a challenging year – for ICL, its employees, its customers and its communities – however, we are coming out of a tough year with a strong finish, and we believe we are well-positioned for 2021," said Raviv Zoller, president and CEO of ICL. "In 2020, our focus on innovative products drove record operating income for specialty phosphates and Innovative Ag Solutions division. We also had a record year at our YPH joint venture in China… and we broke the annual potash production record at The Dead Sea."

ICL's recently commissioned a food-grade phosphoric acid plant in China, as part of its YPH joint venture with Chinese phosphate producer Yunnan Phosphate Chemicals Group (YPC). The new plant will provide up to 70,0000 t/a of food-grade acid when it ramps-up to full capacity.

Production and sales volume records at CF Industries

Full-year revenues ($4.1 billion) and earnings ($1.4 billion) both fell at North American nitrogen producer CF Industries, contracting by 10 percent and 16 percent, respectively, y-o-y (Figures 2 and 3).

CF linked the drop in annual revenues and earnings to a 14 percent fall in the average selling price for its products in 2020, at $203/t for the year versus $235/t in 2019. This in turn was connected to increased supply availability for nitrogen products, with lower energy costs driving operating rates higher. The effects of the decrease in the average selling price were, however, partially offset by an increase in CF's annual sales volumes.

The Illinois-headquartered company was still able highlight a number of positives, including its cash flow generation and record operational performance in 2020:

- Free cash flow of $748 million (Figure 5)
- Four percent increase in total nitrogen product sales volumes to 20.3 million tons – a new company record
- Record annual and quarterly ammonia production figures of 10.4 million tons of 2.7 million tons, respectively, for the whole of 2020 and the year's fourth-quarter.

"Our team's outstanding execution in 2020 produced multiple records for safety, production and sales volume, and delivered strong results in a challenging environment," said Tony Will, president and CEO, CF Industries Holdings, Inc. "Nitrogen industry dynamics entering 2021 are the most favorable we've seen in nearly a decade, as rising grain values and higher global energy prices are driving significant price appreciation for nitrogen products. We expect that these conditions will provide a very positive backdrop for the year."

K+S drives down costs and debt

In a difficult year, revenues at German potash and salt producer K+S fell by nine percent y-o-y to €3.7 billion (Figure 2), while earnings (EBITDA) for the year declined by more than 30 percent to €445 million (Figure 3).

Lower potash prices and a very mild winter had a particular negative impact on the company's earnings in 2020. Earnings were also hit by one-off costs. Administrative restructuring linked to the sale of its American salt business and measures introduced to deal with the Covid-19 pandemic both hit earnings by about €40 million each, according to the company.

"The recovery in potash prices in the course of 2020 was weaker than expected. The mild winter in North America and Europe also negatively impacted sales volumes of de-icing salt," commented K+S.

The company described the general operating conditions in 2020 as challenging. "Despite the difficult conditions, we are not satisfied with the earnings [EBITDA] achieved in 2020," said Burkhard Lohr, the chairman of K+S. "On the other hand, we made good progress with the measures we could take ourselves."

Dr Lohr was referring to the successful implementation of operational improvements, business efficiencies, and a package of debt reduction measures at the company.

K+S was able to increase fertilizer production to 7.3 million tonnes in 2020, for example, an improvement of more than 15 percent on 2019. Some €2.5 billion in divestment proceeds, expected from sale of the company's salt business in the Americas, should significantly drive down company debt. K+S also anticipates a 30 percent reduction in administrative costs (60 million) in future due to the restructuring associated with this sale. These savings add to the €150 million cost reductions (synergies) already achieved in 2020 in areas such as procurement, logistics, production, and sales and marketing.

PhosAgro takes advantage of favourable conditions

PhosAgro is one of the world's leading integrated phosphate fertilizer producers. The Russian company was the only major fertilizer producer to deliver growth in both revenues and earnings in 2020.

PhosAgro's full-year revenues at RUB 25.9 billion ($3.5 billion) were two percent higher y-o-y (Figure 2), while earnings (EBITDA) rose by 12 percent to RUB 84.3 billion ($1,168 million) (Figure 3). Free cash flow was also up by 150 percent on 2019 to reach RUB 42.5 billion ($582 million) in 2020, a new record (Figure 5).

> **"The rise in Nutrien's fourth-quarter earnings signalled improving market conditions during the last three months of 2020.**

Revenue growth was driven by higher fertilizer sales volumes in 2020, as well as being linked to higher fertilizer prices and beneficial foreign exchange changes in the year's fourth-quarter.

PhosAgro's full-year fertilizer sales and production both increased by five percent y-o-y to around 10 million tonnes. The company was able to raise output to meet higher demand in key markets, thanks to the construction of new plant capacity and plant upgrades. The domestic Russian market accounted for 29 percent of the company's total 2020 fertilizer sales – almost the same share as in 2019.

2020 earnings were boosted by a fourth-quarter improvement of 64 precent y-o-y to RUB 18.4 billion ($241 million). This end-of-year hike was driven by "an increase in fertilizer prices while global prices for raw materials remained low", said PhosAgro.

The company also managed to reduce both net debt and its net debt/earnings ratio during the year to RUB 156.9 billion ($2.1 billion) and 1.86, respectively, by the end of December 2020 (Figure 4).

PhosAgro CEO Andrey Guryev said: "We experienced favourable market conditions during the year. Excellent demand and the affordability of fertilizers, on the one hand, and restrictions on the production of phosphate-based fertilizers in global markets, on the other, enabled us to increase sales of these products by more than five percent year-on-year."

He added: "All the investments in the development of production facilities that the company made in previous years were instrumental in this. Increased production of fertilizers – and an improvement in our brand structure in favour of high-margin complex fertilizers – enabled us to strengthen our position in the Russian market and increase sales to Russian farmers by almost 10 percent." ■

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Sulphuric acid projects and technology

Developments in sulphuric acid technology and engineering know-how are highlighted by recent project case studies from DuPont Clean Technologies, Metso Outotec and thyssenkrupp Uhde.

DUPONT CLEAN TECHNOLOGIES

AZFC Unit 6 revamp project

By 2015, the Unit 6 sulphur burning plant operated by Abu Zaabal Fertilizer and Chemical Company (AZFC) had been in service for 31 years. Unsurprisingly, three decades of operation at the company's fertilizer production complex in Egypt's Qulubia Governorate had taken their toll. Due to a host of problems, including corrosion, sulphate build-up and gas leaks, the unit was experiencing daily downtimes, multiple shutdowns and significant losses in production.

AZFC had originally considered shutting the plant down when its new Unit 7 was commissioned in 2009. But rising demand for phosphoric acid meant the company needed the extra capacity. The time had clearly come for a complete revamp. AZFC decided to act and selected DuPont Clean Technologies (DuPont) as a partner to revamp the acid plant and re-design the acid towers.

PHOTO: DU PONT

AZFC's Unit 6 after the revamp project.

The AZFC production complex, owned by Polyserve Group, was first commissioned in 1984 and includes two sulphuric acid production plants – Unit 6 and Unit 7. Unit 6 had been AZFC's workhorse. In its time, 18 million tonnes of single superphosphate (SSP) fertilizer had been manufactured from more than six million tonnes of sulphuric acid yielded by the unit. Unit 6 had also produced over 600 million KW of clean electricity over its lifetime, allowing AZFC to cut CO_2 emissions by 11,000 tonnes.

The decision to revamp Unit 6 was not an easy one to make, as Dr Eng Sherif El-Gabaly, chairman of AZFC, explains: "Unit 6 produces around 30 percent of AZFC's sulphuric acid. We therefore wanted to keep the shutdown to a maximum of 12 months. We needed a reliable and experienced partner who could oversee the project and support us with any technical issues. Given the experience, references and success DuPont had with similar projects, AZFC chose DuPont."

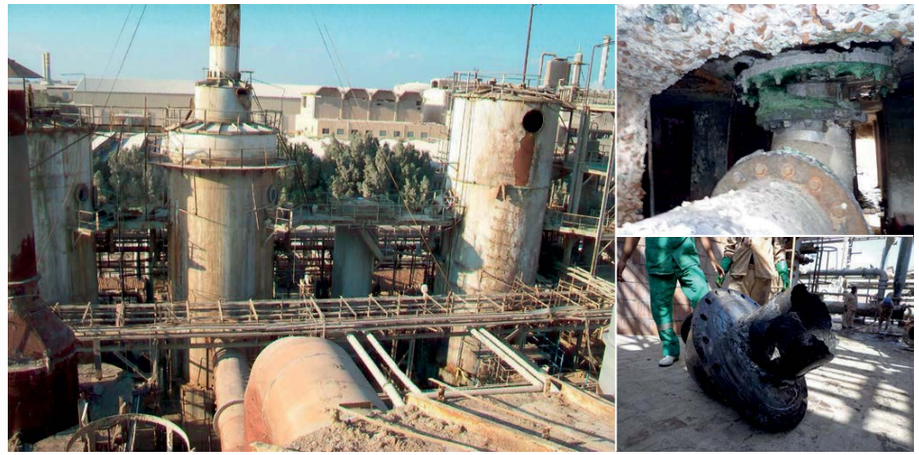
As well as resolving productivity issues, the overhaul of Unit 6 would enable AZFC to meet newly introduced Egyptian emissions regulations. These cut permissible SO_2 emission limits from 1,500 mg/m³ to 450 mg/m³ for new plants and to 800 mg/m³ for existing plants.

Before the revamp

The list of challenges facing AZFC was long. The original brick-lined drying and absorption towers were in very poor shape with visible signs of deterioration. In particular, acid leaking from the bottom of the vessels and at the outlet nozzles of the acid tower was causing sulphate build-up and severe corrosion.

Sulphate build-up on the tube sheet of the mist eliminators in the inter-pass absorption tower (IPAT) was also triggering shutdowns and causing corrosion. Additionally, sections of the old brick tower lining were regularly coming loose and falling into the acid cooler, leading to further leakage from cooler pipes. The furnace baffles had also fallen over. This suggested that the gas was not mixing sufficiently, and that sulphur was entering downstream equipment and causing corrosion.

AZFC was not only concerned about the acid towers at Unit 6. Severe corrosion on cast iron piping, notably on the elbow of the IPAT, had created a number of holes. Because the pipes were very heavy, installed at height and difficult to access, repairs were problematic and led to extended downtimes.



PHOTOS: DUPONT

Above left: AZFC's Unit 6 before the revamp– the drying and absorption towers were in very bad shape. Above right (top and bottom): Acid was leaking from the bottom of the acid tower, causing corrosion issues.

This was not all, either, as the following issues also needed to be put right:

- A significant plume from the stack
- Gas leaks from the shell of the cold heat exchanger
- Missing refractories in the waste heat boiler
- Corrosion on the tube sheet bundle and expansion joint of the boiler jug valve
- Unsafe demineralised water tanks due to corrosion.

Sometimes, the plant was shut down three to four times per day to attend to these myriad problems. Controlling the old plant had thus become extremely difficult and unsafe.

The revamp

As part of the revamp project, DuPont was asked to:

- Re-design and install new acid towers and reduce overall SO_2 emissions
- Improve converter performance
- Provide site supervision during the installation of *MECS®* equipment.

The new high-efficiency acid towers included modern *UniFlo®* acid distributors in corrosion-resistant *MECS® ZeCor®-Z* alloy as well as *MECS® Brink®* mist eliminators.

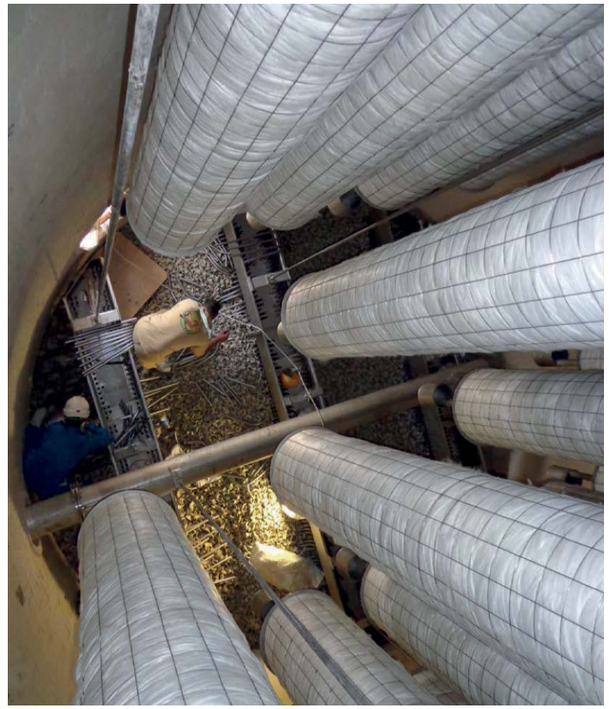


PHOTO: DUPONT

A view of the MECS® Brink® mist eliminators in the new acid tower.

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PHOTOS: DUPONT

Left: The new tower as it is lifted into place at Unit 6. Right: Since start-up, Unit 6 has operated to performance guarantees, producing up to 640 t/d of acid.

DuPont also introduced new *MECS® GEAR®* catalyst for increased conversion and supplied hard-wearing *MECS® ZeCor®-Z* acid piping for the acid towers and the drying tower mesh pad.

As well as guaranteeing a sulphuric acid production rate of 615 t/d, the aim was to also achieve SO_2 emission targets of less than 800 mg/Nm³, as well as SO_3 absorption and SO_3/acid vapour emission control levels of less than 35 mg/Nm³.

The revamp began in late 2015 with the dismantling of the old acid towers and repairs to the foundations. The new carbon steel tower vessels were fabricated offsite by local engineering company ASF–EL Sewedy Industries Group and transferred to Abu Zaabal in three sections – where they were then welded, lifted into place, and erected in a simple operation.

Highly corrosion-resistant *MECS® ZeCor®-Z* alloy was used for pipes, all elbows, bends, fittings and spool pieces. Their installation was carried by local engineering company IEMSA construction, whose welders had been qualified by DuPont.

Mr Abd El Hafeiz recalls: "Throughout the project, DuPont not only provided the process design and engineering for the acid towers, but also supported the revamp in an advisory role, and assisted us with the start-up of the plant."

During the revamp, most of the cast iron internals for the first pass converter, such as support grids and columns, were also replaced, and new woven wire screens installed for all passes. When the brick lining had been restored, the converter was then loaded with the new *MECS® GEAR®* catalyst. The revamp further included:

- Repair of the main blower and almost all rotating equipment
- Fitting of seven new gas valves
- A new gas duct for the IPAT
- Re-tubing of the cold inter-pass heat exchanger
- A pristine demineralised water plant
- The creation of a modern control room.

Success

The entire multi-million project was managed in a very short delivery time by AZFC's Ayman Abd El Hafeiz and Hassan Hussein, the coordinating manager, project department. The revitalised Unit 6 successfully started up on the 15th November 2016 after a shorter than anticipated shutdown. The full revamp was concluded on budget, on time and without a single incident or injury.

Since start-up, Unit 6 has operated to performance guarantees, producing up to 640 t/d of sulphuric acid. The revamped unit had its first cold shut down for maintenance in December 2019, following more than three years' operation. For its budget of $6.5 million, AZFC now has a highly effective plant at between one-fifth to one-tenth of the cost of a new plant, but with the same life expectancy.

Unit 6 revamp achievements

- The plant's average sulphuric acid production capacity increased from 480 t/d to 640 t/d
- Stack SO_2 emissions decreased from 2,000 mg/Am³ to < 600 mg/Am³
- Plant availability improved with reduced downtime
- Downtime average pre-revamp (average over 2 years) = 138 days per year
- Downtime average after revamp = 3.9 days per year
- Improved availability has eliminated LE 59 million per annum ($3.8 million p.a.) in lost sulphuric acid sales over that period
- Loss in production cut from 41.7 percent in 2014 to 0.87 percent in 2019.
- A step change in plant reliability
- The revamped plant ran for more than three years before the first cold shutdown, compared to shutdowns every 4-6 months previously
- No injuries or accidents during the entire revamp project
- A sparklingly clean and pristine plant with even roses now cultivated on site.

SULPHURIC ACID CASE STUDIES

METSO OUTOTEC

Mazidagi project, Turkey

Collin Bartlett of Metso Outotec and Kenan Soybelli of Eti Bakir A.S.

Cengiz Holding acquired Eti Bakır from the Turkish government in 2004 with a clear strategic aim: to build an industrial complex in the Mazidagi district of Mardin, Turkey – one that combined fertilizer production with metals processing at a single location. This plant was designed to create a high level of energy self-sufficiency by efficiently capturing energy from the various unit processes on site. The Mazidagi project concept, by successfully delivering a truly integrated production complex, has set a new benchmark for future plant designs.

With the Mazidagi production complex now fully operational, Eti Bakir has fulfilled its ambition to increase the contribution domestic production makes to Turkish fertilizer demand – a strategically critical objective for a country whose large agricultural sector has (to date) relied on large volumes of fertilizer imports. Crucially, it has been the additional revenues from metals recovery that have made the Mazidagi project economical.

Metso Outotec was chosen as the key technology partner for the Mazidagi project as its technology portfolio was able to cover a large proportion of key plant sections for the industrial complex (Figure 2, sections in dark green). In this case study, we focus on the technology applied in the interconnected pyrite roasting, off-gas cleaning and sulphuric acid production section (Figure 2, highlighted in yellow).

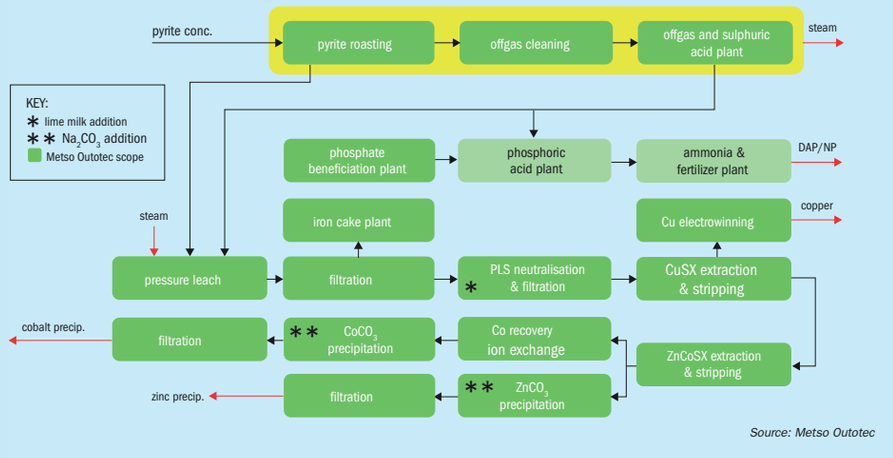
PHOTO: METSO OUTOTEC/ETI BAKIR

Mazidagi's sulphuric acid plant.

The Mazidagi production complex

The Mazidagi complex, which takes its names from its location in the Mazidagi district of Mardin province in Turkey, was built at an investment cost of approximately $1.1 billion, making it the highest budgeted project in Eastern Turkey.

Fig. 1: **Mazidagi project: Overall flowsheet and Metso Outotec's scope (dark green). Sections covered in this case study are highlighted in yellow**



Source: Metso Outotec

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Construction began in the first-quarter of 2015 and was completed in the first-quarter of 2019, with the project entering commissioning after 50 months and 20 million person-hours.

The complex incorporates six key production units (Figure 1):

- Pyrite roaster/off-gas/sulphuric acid plant
- Phosphate beneficiation plant
- Phosphoric acid plant
- Ammonia plant
- Fertilizer plant
- Hydrometallurgical plant.

Additionally, a relatively large number of auxiliary utilities are also required to efficiently operate this integrated facility, namely:

- Demineralised water production plant
- Chemical water treatment plant
- Water cooling plant
- Condensate purification plant
- Steam turbine and gas engine
- Auxiliary boiler
- Natural gas distribution stations
- Air compressor plant
- Pyrite and ash transport units
- Fire reservoir and distribution system
- Main water tank and water wells
- Switchyard
- Packaging facility.

The Mazidagi complex consumes 550,000 tons of locally-extracted phosphate rock and processes this to produce 750,000 tonnes of fertilizer annually. This includes 200,000 tonnes of diammonium phosphate (DAP) and 550,000 tons of NP products. Being the only fertilizer plant in the region, Mazidagi meets the entire fertilizer requirements of the surrounding Harran Plain. The plant's overall share of the Turkish phosphate fertilizer market will be 20 percent initially.

Roasting plant

In specific cases, pyrite roasting provides a viable alternative to sulphur burning as a source for sulphuric acid production, especially when pyrite is available from local sources. This is especially true for a land-locked location such as Mazidagi, where the logistics associated with supplying sulphur to the plant are particularly challenging.

The standard processing technology for pyrite is roasting in a fluidised bed reactor, as has been used on a commercial scale since the 1950s. While the principles of roasting remain unchanged, process control technology for roasting plants has advanced and improved greatly. In the past, environmental and safety standards were often the driving forces behind improvements in equipment and plant design. Today, however, the emphasis has shifted to plant efficiency and optimisation – as delivered via Metso Outotec's advanced process control philosophy. In recent times, responsibility for plant control and operation, traditionally the domain of owner/operators, has also shifted to process technology companies due to their ability to offer both integrated digital tools and specific process know-how.

Table 1: **Mazidagi project: roaster plant process data**

Plant Feed: 1,500 t/d pyrite	
Pyrite composition	
S	48%
Fe	46%
Cu	0.5%
Co	0.5%
Zn	0.2%
Roaster configuration: 2 x 750 t/d lines, each with 123 m^2 bed area	
Calcine: total 45 t/h (S < 0.6 wt%)	
HP Steam (WHB): total 129 t/h (60bar, 400°C)	

Source: Metso Outotec

Within the Mazidagi complex, the roasting plant fulfils two fundamental process objectives:

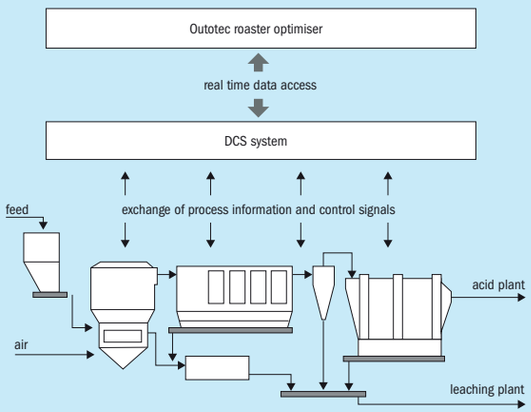
- Firstly, to provide an SO_2 off-gas source for sulphuric acid production
- Secondly, to produce a calcine capable of being processed in the downstream hydrometallurgical complex.

These dual process requirements meant there was a need to monitor and control roaster plant operations to ensure that – based on the composition of the concentrate, the operating temperature and the atmospheric conditions – roaster product quality remained constant.

Temperature control at this roasting plant was a key factor, given that different types of metals were being recovered, and was therefore best handled by an optimisation system. Excessively high roasting temperatures, for example, could potentially lock-up sub-microscopic particles in the calcine, while too low temperatures might negatively affect overall plant performance. Good process control was therefore of the utmost importance.

For the Mazidagi project, Metso Outotec applied state-of-the-art digitalisation tools for process monitoring, control and advisory activities – to ensure the best available support for commissioning of the plant. This was achieved by installing proprietary *Roaster Optimizer* technology at the roaster plant.

Fig. 2: **Roaster plant configuration for monitoring, control and optimisation**



Source: Metso Outotec

The *Roaster Optimizer*, configured with Metso Outotec's advanced process control (ACT) platform, functions independently from the plant's distributed control system (DCS) (see Figure 2), and DCS functionality therefore remains untouched. Instead, the role of the *Roaster Optimizer* is to read process values from the DCS, use these to calculate an optimised solution for plant operation, and then send back optimised values – such as feed rate, airflow or water addition rate – to the DCS.

Gas cleaning and sulphuric acid plants

The gas cleaning plant plays a central role in the smooth and efficient operation of a metallurgical sulphuric acid complex.

Nowadays, with most prime global deposits depleted, metal producers are increasingly having to process complex ores and concentrates. This often involves the dual challenge of extracting less valuable metals at higher production costs. In many cases, complex ores and concentrates are also associated with potentially polluting contaminants (e.g. arsenic and mercury) whose concentration tends to increase as the desired metal content reduces.

Given the challenging nature of complex ores, as highlighted above, the design of the gas cleaning plant clearly needs to consider all eventualities regarding off-gas impurities. For the Mazidagi project, the purity of the sulphuric acid required for downstream fertilizer production was another key consideration.

Dry/hot gas cleaning is the first gas cleaning step downstream of the roasting process. This involves removing any solid dust emitted by the process with the highest possible efficiency – generally by employing hot electrostatic precipitators (Hot-ESP).

The dedusted off-gas then enters the wet gas cleaning plant where the remaining impurities are removed using Metso Outotec's Otovent scrubber and packed gas cooling tower. This traditional and well-proven configuration is coupled with primary and second stage Editube wet electrostatic precipitators (Wet-ESP). Mercury is the main volatile generated by the roaster. This is removed via Metso Outotec's B-N mercury removal system, which remains the benchmark technology for the industry.

Once it has been processed in the wet gas cleaning section, the off-gas is then suitable for further handling by a conventional sulphuric acid plant (see main photo).

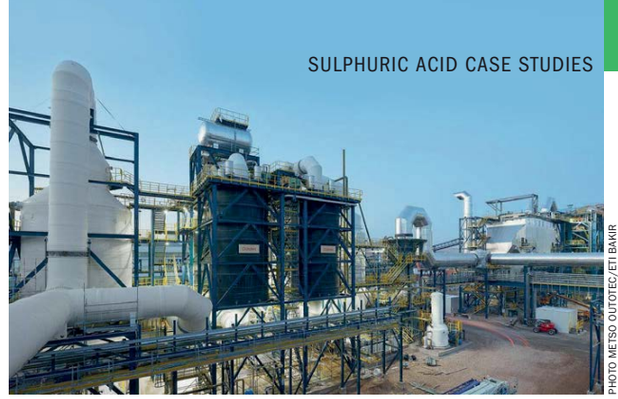


PHOTO METSO OUTOTEC/ETI BAKIR

Mazidagi's gas cleaning plant section.

PHOTO METSO OUTOTEC/ETI BAKIR

Mazidagi's roasting-gas cleaning-acid plant sections.

Summary

Cengiz's $1.1 billion investment in the Mazidagi metal recovery and integrated fertilizer project provided Metso Outotec with the opportunity to showcase process technologies that encompass the complete value chain at one production complex.

For the roasting plant-gas cleaning plant-sulphuric acid plant section at the Mazidagi complex (Figure 2), Metso Outotec's successfully implemented proven process technologies that demonstrated the following advantages:

- Adaptable to specific process conditions – being adjustable with respect to the complex mineralogical composition of the pyrite ore and the fine particle-size distribution of the feed material.
- Integration of a state-of-the-art ACT optimiser – complementary to the plant's control system.
- Installation of a gas cleaning system – capable of conditioning the off-gas to produce sulphuric acid quality suitable for use in the downstream fertilizer complex.
- Installation of a sulphuric acid plant with a low pressure (LP) steam system – to complement the steam produced from the roaster plant.

After Mazidagi's successful start-up, the operators expressed their satisfaction with the smooth operability of the plant. The project detailed in this case study demonstrates Metso Outotec's proven abilities in developing and improving roasting, gas cleaning and sulphuric acid technologies with every new plant design. ■

Table 2: **Mazidagi project: gas cleaning plant process data**

Gas flow from roasting units	152,000 Nm^3/h
SO_2 concentration	12.6 vol%
Temperature	350°C

Source: Metso Outotec

Table 3: **Mazidagi project: sulphuric acid plant process data**

Sulphuric acid production: 2,080 t/h
Sulphuric acid quality: As < 0.1 mg/kg acid, Hg < 1 mg/kg acid
Plant emissions: <2 kg SO_2 / t acid
Low pressure (LP) steam (HEROS™): 20 t/h (7bar(g), 170°C

Source: Metso Outotec

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THYSSENKRUPP UHDE

Small scale sulphuric acid plants – availability first

Dr Zion Guetta, Dr Holger Thielert, Dr Dirk Koester

Small-scale sulphuric acid plants offer an environmentally, technically and commercially feasible way of converting sulphur-containing off-gases (acid gases) into a valuable product. The sulphuric acid produced in these plants can be used directly as a feed material to produce marketable fertilizers, such as ammonium sulphate or potassium bisulphate.

A small-scale sulphuric acid plant will produce approximately 10-200 t/d of acid. In the design of large-scale acid plants, heat recovery is the focus, as this significantly impacts on plant profitability. Small-scale sulphuric acid plants, in contrast, require a plant design that provides maximum availability, trouble-free operation and minimal maintenance. This allows operators to focus on their core product – the production of coke or pulp, for example.

In this article, we highlight an alternative process design for small-scale sulphuric acid plants, along with recommendations for specific equipment. This draws on the long-term experience gained from running a small-scale sulphuric acid plant. This reference plant has been on-stream and operating trouble-free for almost 40 years. Under continuous operation, its catalyst service time, without screening, is higher than 15 years.

General approach

For acid plants, process and mechanical design should focus on known criteria which affect plant availability, for example:

- Corrosion allowances, type of alloys and fouling allowances – as these have a direct impact on the service time and maintenance type of each equipment or pipe.
- Equipment manufacturers – some have better availability of spare parts and some have longer service time.
- Mechanical design – particularly the handling of the cold spots, as these can induce acid condensation and ultimately result in corrosion.

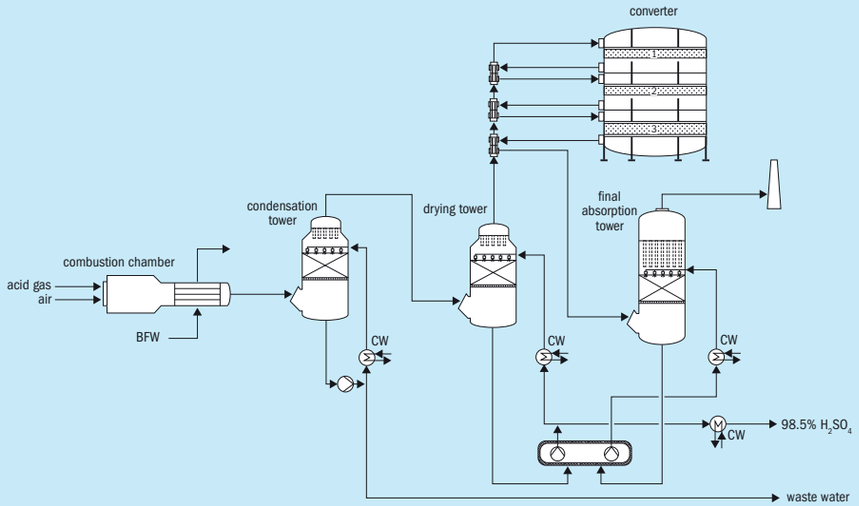
Given that the above criteria are the bread and butter of plant design, even more can be achieved at process level.

Alternative process design

Conventional sulphuric acid plants consist of combustion, conversion and absorption sections. The small-scale alternative process design (Figure 1) also includes an additional post-combustion gas cleaning step. Gas cleaning can be carried out dry or wet, although wet cleaning is most efficient.

In the alternative sulphuric acid process, acid gas and air are combusted in a chamber to form SO_2. The resulting heat of combustion is recovered by the medium pressure (MP) boiler. Downstream of combustion chamber, the gas enters the condensation tower to remove water vapour and wash out any dust. The cleaned gas is then completely dried in the drying tower (using sulphuric acid) before entering the converter where it is reacted with oxygen over a catalyst to form SO_3. The final acid is produced in the final absorption tower downstream of the converter. Typically, the off-gas leaving the final absorption tower will not require additional treatment.

Fig. 1: **Process flow diagram for thyssenkrupp Uhde's alternative sulphuric acid process – strong acid from wet acid gas**



Source: thyssenkrupp Uhde

This alternative process design offers clear advantages in terms of availability, compared to plants without gas cleaning, as has been demonstrated by the long-term operational history of a reference plant. The plant's operators report that no catalyst screening or change in catalyst has been necessary in 15 years of operation. For this plant design, therefore, the availability of the converter section is six times higher than for a conventional system.

Advantageously, the alternative process design also avoids specific or proprietary equipment or material design. This allows generic repairs or replacements to be arranged with appropriate local service providers and manufacturers.

A small drawback of the alternative process is the reduced potential for heat recovery, compared to a conventional process. This is because recovered heat is mainly required to preheat dry gas before it enters the converter, while in conventional processes it can be recovered for steam production. Despite this, in small capacity plants, the heat recovery potential is negligible, and more than offset by the equipment savings and the value gained from higher availability and lower maintenance costs.

Equipment maintenance

Pumps and acid coolers – similar to the catalyst in a conventional plant – do require frequent maintenance in the alternative process design. This can be compensated for by adopting equipment redundancy (duplication) to ensure full availability. Indeed, '1+1' equipment redundancy has been successfully applied as common practice at the reference plant, i.e. while one item is in operation a replacement item is always held in stock.

Additionally, the combustion burner process unit requires regular maintenance due to the corrosion associated with acid gas combustion. The presence of corrosive as well as solidifying components, like ammonia with hydrogen sulphide and naphthalene, respectively, are a particular challenge. Nevertheless, the burner developed for the reference plant by Uhde and its partners shows no requirement for wear parts after 10 years in operation. This burner features a special mechanical design as well as its own dedicated control system.

Summary

Process design should always match up to long-term project requirements. In many ways, therefore, selecting the optimum sulphuric acid process for a specific project is similar to the everyday choice between a bicycle, car or truck: as different types of sulphuric acid process serve different purposes and fulfil different expectations regarding efficiency and availability. For projects focused on high availability and low maintenance costs, thyssenkrupp Uhde's alternative sulphuric acid process design offers key advantages. ■

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Continuous concrete pour to construct the 313-foot-tall South headframe at the Esterhazy K3 potash expansion project, Saskatchewan.

PHOTO: MOSAIC

Successful fertilizer plant start-up

What lessons can be learnt from the successful commissioning and start-up of major fertilizer industry construction projects? Recent case studies from the nitrogen, phosphate and potash industries provide some interesting answers.

NITROGEN: CFCL THIRD AMMONIA/UREA PROJECT, INDIA

KBR's most energy efficient ammonia plant

In January 2019, Chambal Fertilisers and Chemical Ltd (CFCL) successfully commissioned its third ammonia-urea unit (G3AU Project). This 2,200 t/d capacity ammonia and 4,000 t/d capacity urea plant is located at Gadepan near the city of Kota in Rajasthan, India[1]. Since its commissioning, CFCL's Gadepan complex has become India's largest urea production site (*Nitrogen+Syngas* 364, p34).

Due to the high cost of natural gas in India, CFCL specified that the new plant should have the lowest possible energy consumption. The plant also needed to be self-sufficient in medium pressure (MP) steam.

To meet these requirements, the plant was configured with a gas turbine driving the process air compressor with the hot exhaust gas from the turbine used as preheated combustion air for the primary reformer (Fig. 1). This configuration improves the thermal efficiency of the gas turbine from around 30 percent to over 95 percent. It provides steam export to the urea plant for its turbine-driven CO_2 compressor, and also eliminates the need for a forced draft fan and combustion air preheater. The newly-commissioned ammonia plant, due to these unique features, has become the world's most energy efficient plant using KBR's *Purifier*™ ammonia technology.

Project execution

Japan's Toyo was awarded the engineering, procurement and construction (EPC) contract for the entire CFCL ammonia-urea plant, including outside battery limits. Toyo, in turn, awarded contracts to KBR for the ammonia plant license, basic engineering design and the supply of proprietary equipment.

To guarantee safety and quality, and ensure consistency in overall plant design, KBR also supported Toyo/CFCL in other activities, including:

- The review of the critical documents
- Critical equipment inspections
- Participation in Hazop
- 3D model reviews
- Supervision during catalyst loading of the reformer, ammonia converter etc.

Challenges and lesson learned

Examples of several challenges faced during plant commissioning and start-up – and how these were overcome – are provided below:

Purifier hydrogen leak

No leakage was initially detected from the purifier during a pre-start-up check with syngas at 30 kg/cm² pressure. Nevertheless, a minor hydrogen leak was subsequently observed after commissioning the purifier during routine leak checks at plant. This was issuing from the sample point of the expander duct.

The hydrogen concentration of approximately four percent was diluted to about two percent by increasing the nitrogen flow to the duct. Nitrogen was also introduced at the vent point to avoid an explosive mixture. The leak from the flange in the expander compartment was ultimately reduced by cutting the syngas compressor suction pressure by 1.0 kg/cm², which had the effect of increasing the load on the syngas turbine.

Cooling water pressure drop

The plant uses a plate-type heat exchanger to cool lean solution. During commissioning, cooling water flow through the lean cooler was found to be below design specification due to high pressure drop across the plates. This was discovered to be due to the installation of the wrong type of plates. After discussion with the vendor, the problem was resolved by replacing these and fitting the correct type of plates instead, as well as installing 20 percent extra plates to add more cooling capacity.

Valve faults

Purifier outlet valve: During start-up, a load limitation was being created by a high pressure drop (5 kg/cm²) observed between the expander outlet pressure and syngas suction pressure. To resolve this, the purifier outlet valve was replaced with a manual isolation valve during a short shutdown of the plant.

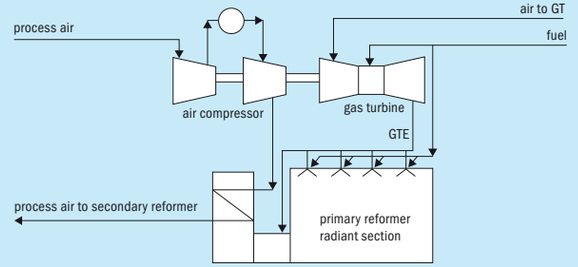
On checking, the purifier outlet valve was found to be stuck at 40 percent open position, so causing a high pressure drop, because the disc had disconnected from the stem.

Expander bypass valve: This was not operating smoothly during stroke checking. An inspection check by the vendor found that the valve stem had bent due to the actuator weight. It was discovered that the support for the valve actuator had not been fitted properly during the valve's installation, causing bending of the valve stem. The valve was returned to normal operation by replacing this stem.

Anti-surge valve malfunction: An open anti-surge valve caused the ammonia plant to trip due to low air flow to the secondary reformer actuation. This resulted in low process air flow to the secondary reformer and ultimately prompted a full plant trip due to MP steam header fluctuation. The root cause of this malfunction was a heat leak from the control valve body. This was rectified by proper insulation of the valve body to avoid the heat leak to instruments.

The CFCL plant was successfully commissioned and became the world's lowest energy ammonia plant despite the problems listed above. ■

Fig. 1: **Efficient configuration of the gas-driven ait compressor at CFCL's third ammonia-urea plant**



Source: KBR

PHOSPHATE: SERRA DO SALITRE PROJECT, BRAZIL

Brazil's growing phosphates supply/demand deficit over the next decade will have to be met by more imports and/or increases in domestic production capacity. The latter is set to receive a substantial boost with completion of the Serra do Salitre project this year.

PHOTO: YARA

Yara's flagship Serra do Salitre phosphate project, Minas Gerais, Brazil.

Flagship investment project

The BRL 2.6 billion ($470 million) flagship project is the largest ever private sector investment in Minas Gerais state and ideally located, being close to Brazil's major fertilizer-consuming markets. The project, originally a joint venture between Yara International and Brazilian producer Galvani, has been 100 percent Yara-owned since October 2018 (*Fertilizer International* 488, p45).

The Salitre project represents a major commitment by Yara to the growing Brazilian market, and a significant expansion of its in-country operations. The company invested $229 million in the project in 2020 following similar substantial investments in 2018 and 2019.

"The Serra do Salitre Mining-Industrial Complex is one of the largest private investments underway in Brazil and will double Yara's fertilizer production capacity. The project allows the country to replace the import of 950 thousand tons per year of phosphate fertilizers, thus reducing the dependence on imports and the deficit in the sector's trade balance, in addition to generating jobs and income for the national industry and supporting food production," commented Leonardo Silva, vice president of production at Yara.

Two project phases

The Serra do Salitre project is divided into two phases. The initial phase, which came onstream in 2018, involved the completion of a 1.2 million tonne capacity phosphate rock mine and associated beneficiation plant. This delivered its first 150,000 tonnes of mined rock in early 2018. A one million

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tonne capacity production plant for finished phosphate products is now scheduled to be completed during the second half of this year, as part of the project's second phase.

Building a fully integrated fertilizer production plant in Brazil is a costly, complex and highly ambitious venture. Almost inevitably, there has been some slippage in the project's timetable, partly due to the Covid-19 pandemic, with finished phosphate production originally due to start-up in the first-quarter of 2020. Nevertheless, the scale of the project is such that it will increase national P_2O_5 production by around 20 percent when it finally starts up.

Once operational, Serra do Salitre will generate:

- 900,000 tonnes of sulphuric acid
- 1.2 million tonnes of phosphate rock
- 250,000 tonnes of phosphoric acid
- One million tonnes of granulated finished phosphate products
- More than 1.2 million tonnes of gypsum
- 1,500 jobs during the operational phase
- Around 29 MW of energy.

Output from Salitre's mine and beneficiation plant will also ensure that Yara's Paulínia production plant in Sao Paulo state is self-sufficient in P_2O_5 by providing a dedicated supply of phosphate rock.

Successful completion of phase one

Salitre's transition-to-operation (TTO) began in 2017. This set 20 milestones and was vital to ensuring the successful on-time delivery of phase one of the project (Figure 2). The project's TTO required the achievement of the following critical and sequential objectives:

- Extraction of 150,000 tonnes of phosphate rock during the mine development stage
- The first ore drop at the homogenisation yard
- Commissioning of the dry processing route
- Obtaining a preliminary operating license
- Process plant start-up
- Tailings dam operation start-up
- Production of first tonnages of phosphate rock concentrate
- Storage of 10,000 tonnes of phosphate rock concentrate at the coarse phosphate rock silo
- First-ore-on-truck (FOOT) to Paulínia
- First-ore-in- Paulínia (FOIP) processed
- First fertilizer lot produced at Paulínia using Salitre rock.

With the completion of the first phase of the project, phosphate rock is now being extracted and upgraded using froth flotation to produce a phosphate concentrate. This is currently supplying Yara's Paulínia production plant in Sao Paulo state.

Serra do Salitre's phosphate mine has an estimated life of 25 years. Friable ore is extracted by excavators and transported using a fleet of five 30-tonne Volvo trucks and 13 35-tonne Mercedes-Benz trucks. The ore is crushed at the mine before being transported to the beneficiation plant via a two-kilometre belt conveyor. Apatite-bearing ore with a P_2O_5 content of 4.7 precent is then upgraded in the beneficiation plant to produce a high-grade phosphate concentrate containing 33 percent P_2O_5.

Phase one of the project involved the successful installation and commissioning of a range of mineral processing equipment, including: crushers, conveyors, mills, pulp, water and vacuum pumps, hydrocyclones, flotation columns, magnetic separators, thickeners and a filter press.

Final stages of phase two

Following successful completion of the first phase in 2018, construction of the project's second phase is now scheduled to finish in the second half of 2021. Once operational, Serra do Salitre will ramp-up to annual production of 1.2 million tonnes of phosphate concentrate and 1.5 million tonnes of finished phosphates (SSP equivalent). Its product mix will include diammonium phosphate (DAP), monoammonium phosphate (MAP), nitrophosphate (NP), single superphosphate (SSP) and triple superphosphate (TSP).

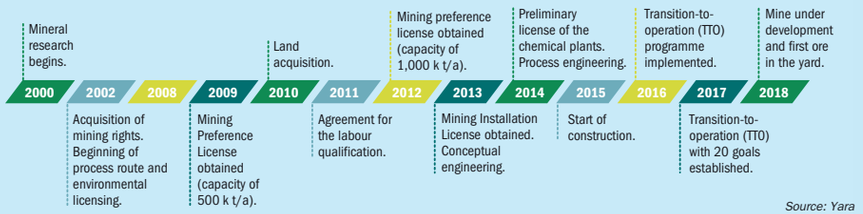
Phase two of the project is now approaching the final stages of completion with the fertilizer production complex expected to enter operations within the next six months. Construction peaked in August 2019 when 3,800 workers were engaged on the project.

The Serra do Salitre complex includes a sulphuric acid plant, phosphoric acid plant and a fertilizer granulation plant. This has required the installation of major items of complex and interlinked process equipment such as boilers, heat exchangers, reactors, absorption towers, cooling towers, granulators, dryers and belt conveyors.

The amount or piping alone provides some indication of the scale-up in construction work between phases one and two of the project. "To have an idea of how challenging the works in phase two are… in phase one, [mineral] processing consumed 700 tonnes of piping," commented Gustavo Horbach, Yara's former project director. "Now, in phase two, there are three thousand tonnes."

Once operations begin later this year and production then ramps-up in 2022, granulated fertilizers will be stored on site in two purpose-built 180,000 tonne capacity warehouses constructed from treated eucalyptus wood and reinforced concrete. These conical shaped and 30 metre-deep structures are partly underground and feature a fully-automated loading and unloading system. Materials enter the upper part of each warehouses and exit at the base, via a conveyor built within an underground concrete tunnel. ■

Fig. 2: **Timeline for delivering phase one of the Serra do Salitre project, 2000-2018**



Source: Yara

POTASH: ESTERHAZY K3 EXPANSION PROJECT, CANADA

North and South Headframes, K3 expansion project, Esterhazy, Saskatchewan.

PHOTO: MOSAIC

Mosaic operates one of the world's largest potash mining sites at Esterhazy, Saskatchewan, Canada. The site, which has been in operation since 1961, consists of the K1 and K2 potash mines, their respective K1 and K2 mills, and the under development K3 mine shafts. The Esterhazy complex produces a range of muriate of potash (MOP) products, including crystal, ag white, granular, and standard. The end-users for these products are primarily agricultural, supplemented by some industrial customers.

Ambitious expansion plans

Mosaic's large-scale expansion plans for Esterhazy have involved increasing plant capacity at the K1 and K2 sites and building the new underground K3 operations. Upon completion, the ambitious K3 development will create one of the largest underground potash mines in the world (*Fertilizer International* 490, p43).

The objective of the K3 expansion is to install massive hoisting capacity at Esterhazy's operations – which in turn will enable production of finished potash products on a much greater scale. K3, which is scheduled to be fully operational in 2022, will eventually replace the older K1 and K2 mines (Figure 3).

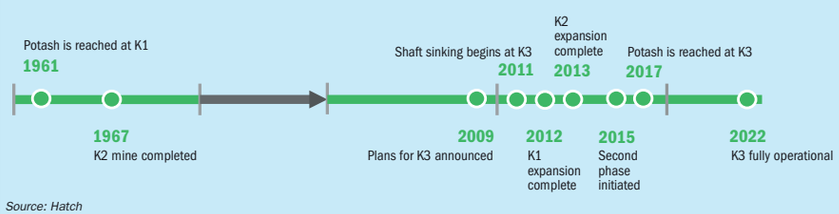
Hatch has been Mosaic's long-term engineering partner at Esterhazy, dating back to the original project to expand the capacity of the K1 and K2 mills. Mosaic engaged Hatch as their full engineering, procurement, and construction management (EPCM) services partner following Hatch's successful completion of the scoping, prefeasibility, and feasibility studies for this project.

By 2013, the K1 and K2 expansion projects had been completed below budget, with minimal negative impact to operations and an excellent safety record. Successful advances were also made in process automation and new production controls.

Massive state-of-the art operations

The current phase of the Esterhazy expansion is the construction of K3. This highly ambitious engineering project involved sinking twin shafts to a depth of just over 3,280 feet, and slip-forming two headframes with a design height of over 380 feet.

Fig. 3: **Esterhazy expansion project: key milestones**



Source: Hatch

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Hatch has participated in the K3 project from its initiation in 2008, starting with scoping-level studies all the way through to project development. Indeed, Hatch will continue to partner with Mosaic until K3 is fully commissioned and operational in 2022.

The Mosaic Company approved the first stage of development at K3 in 2009. This gave the go-ahead for the detailed design and construction management of two production shafts, headframes, and hoisting systems.

The North K3 headframe, the tallest structure in the province, houses and operates the massive hoists and skips that will transport potash to the surface from more than half a mile underground.

Shaft sinking

Saskatchewan's geology is complex and also features high water pressures at depth. Hatch and Mosaic addressed these challenging conditions by using unique shaft-linings techniques when sinking the two 20-foot diameter shafts through water-bearing geological formations.

To accomplish this, both shafts were frozen to hold back groundwater while the permanent liner was installed. "To control water inflow from the Blairmore formation, we used unique technology to freeze the ground surrounding the shafts to a depth of 1,600 feet," explains Scott Williamson, Hatch's shaft manager. "The shaft is lined with concrete and steel in various configurations based on the geology encountered." The permanent shaft liner consisted of support concrete, as well as a composite steel liner to prevent water ingress, where required.

K3 has two shafts. The first is used for both production and service, while the second is dedicated to production. The two pairs of production skips each have a 60-ton payload.

Following shaft sinking, the next hurdle was the slip-forming and mechanical fit-out of the North headframe. This structure towers more than 380 feet above the prairies and houses two massive hoists – the Koepe and Blair. The Koepe hoist moves potash to the surface from underground, while the Blair hoist carries a cage for people and equipment. Hatch's globally-responsive team of experts from Canada, Australia, and South Africa – working closely with Mosaic – designed the overall hoisting systems. These use leading-edge technology, state-of-the-art automation, and unique hoists.

Construction in two stages

Construction at K3 – comprising foundations, an electrical substation, ground freezing, shaft sinking and hoists – was scheduled in two stages. The first construction stage included:

- Site preparations
- Sinking and lining of the two shafts
- Hoist equipment and systems in the North shaft
- Egress hoist and headframe, bottom steel, surface facilities
- Preliminary mine development.

This phase of the project was completed in 2018.

The ongoing second construction stage involves:

- Replacing the temporary sinking headframe in the South with a production headframe and hoisting system
- Completing the underground development
- Debottlenecking the K2 mill to achieve the final desired capacity of the Esterhazy complex.

Shaft construction was performed using an unusual working platform – a five-level, shaft-sinking Galloway (see photo). An excavator suspended from the Galloway removes blasted muck to large buckets, which were then hoisted to the surface. Also, to reduce underground construction time, the steelwork of the shaft load-in station was modularised. To reduce shaft hoisting times and assembly times underground, innovative work practices were also used to lower the large quantity of heavy mobile equipment and bulk material handling systems.

Meeting major milestones

Years of careful planning were finally realised in February 2017. This was the date when the team celebrated a crucial K3 project milestone – the shaft finally reaching potash at a depth of 3,350 feet (Figure 1). Other major project milestones have been achieved in the four years since.

In May 2017, the team broke through the connection drift between the North and South shafts, located some 450 feet apart. This achievement was followed shortly after by the completion of the North shaft potash-level station.

PHOTO: HATCH/MOSAIC

Galloway shaft sinking platform and potash layer, Esterhazy.

The completion of the South shaft potash station, including the equipment assembly bay and electrical substation excavation, was subsequently completed in July that year. Then, in October 2017, another significant project objective was attained – the lights were turned on underground and a new, fully-assembled drum miner chassis, weighing 60 tons, was lowered into the mine.

The hoisting systems in the North shaft were commissioned in May 2018. This enabled K3 to enter operations and the ramp-up of production to begin. The next stage during 2019 was to finalise the design of the South headframe and associated equipment, before starting construction to replace the temporary headframe.

The South headframe

In August 2020, contractor Hamon Custodis Cottrell Canada, Inc commenced a continuous slip-form concrete pour to construct K3's 313-foot-tall South headframe. The new headframe replaced the smaller temporary structure previously used for shaft sinking and the installation of shaft bottom steel in the mine.

The continuous pour would take a massive 784 concrete trucks and 24 back-to-back days to complete. Incredibly, the structure grew upwards at a rate of six and a half inches per hour. Concrete trucks arrived every 45 minutes – delivering a total of 4,350 cubic meters of concrete. The headframe also incorporated three million pounds of rebar (reinforcing steel).

Once the South headframe was completed, outfitting began to prepare it for operation, with a focus on the hoist infrastructure that would be required to raise millions of tonnes of potash ore from K3 to the surface. The South shaft is solely dedicated to hoisting potash ore, unlike its sister North shaft which moves both people and materials. Indeed, the South headframe will double hoisting capacity at K3 – from 36,000 tonnes to 72,000 tonnes – once it becomes fully operational in 2022.

Work continued on the South headframe during the latter part of 2020 to add a roof penthouse, internal stairways, wall covers and a permanent 65-tonne overhead bridge crane for servicing the Koepe hoist. Mosaic reported further progress on the South shaft headframe in April this year. This included outfitting with piping, electrical trays, cable, lighting and other components.

A priority during the first half of 2021 will be the massive 2,000 tonne steel floors required to support the Koepe hoist and the 60-tonne skips used to raise ore to the surface. These steel floor will be assembled at ground level in modules and then raised to their final position using a hydraulic jacking system. Concurrently, the Koepe hoist, elevator and all the electrical/mechanical infrastructure will also be installed.

The next big milestone will be rope-up and installation of the large 60-ton skips. This is scheduled for autumn of 2021, with commissioning to follow.

Ramping up production

K3 continues to break records – setting a new daily tonnage record in February this year. Mosaic is now consistently hoisting ore through the North shaft and expects the average daily tonnage to continue increasing as they move into the second half of the year.

Underground engineering to support the production ramp-up is continuing – including work on the south surge, coarse ore bins and the mainline conveyor systems. The sixth four-rotor mining machine commenced cutting underground at K3 in January, while the first two-rotor mining machine was also available to start development work in February. As well as a further new machine added in April, Mosaic expects to deploy three more mining machines to the K3 fleet when the South headframe becomes operational next year.

All these new mining machines can run autonomously. In fact, Esterhazy's engineering team is working towards automating the entire ore flow process – tracking potash as it moves underground from mining machines to conveyors to bins, before being hoisted upwards to the surface and then moved by overland conveyor to the K1 and K2 mills. These operations will be monitored from a state-of-the-art Integrated Operations Center (IOC). Mine automation at K3 is a part of Mosaic's wider plans to revolutionise its business by adopting digital technology. ■

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Essential magnesium: fertilizer sources

The Dead Sea provides a source of brine for the world's largest magnesium chloride production plant.

PHOTO: TSAIPROJECT/FLICKR

Magnesium, a key constituent of chlorophyll, plays a vital role in plant photosynthesis and carbohydrate production. Commercial sources of this essential crop nutrient include Epsom salt, kieserite, langbeinite, magnesium chloride and magnesium nitrate.

Magnesium (Mg) is an essential, if frequently overlooked, plant nutrient. It is instrumental in many plant functions, being present in vegetative dry matter at between 0.2-0.4 percent concentration.

Mg is a key component of chlorophyll (Figure 1), with each molecule containing 6.7 percent magnesium. It is therefore vital for photosynthesis, as well as playing an important role in the synthesis of starches, sugars, amino acids, proteins, vitamins and oils.

Essential for plant growth

Mg increases plant productivity by boosting photosynthesis, mobilising carbohydrates, promoting the uptake of other nutrients including phosphorus (P), and functioning as an enzyme activator. Additionally, it acts as a P carrier in plants and regulates cellular respiration. Mg also helps create strong root systems, and increases resistance to pests, fungal attack and disease in leaves, seeds and fruit. Overall, Mg creates stronger, healthier and nutrient-rich crops with increased yields (*Fertilizer International* 455, p19).

According to a recent review of the role of magnesium fertilizers[1]: "Magnesium is involved in many physiological and biochemical processes. It is an essential element for plant growth and development and plays a key role in plant defence mechanisms in abiotic stress situations."

Mg release from soil minerals is generally small compared with the amounts needed to sustain crop yield and quality. This makes the application of Mg fertilizers crucial in many farming systems (see box). An optimal supply of Mg improves the stress tolerance of crops and increases the yield and quality of harvested products[1].

Mg deficiency

As already indicated, Mg is an activator for many critical enzymes. Without sufficient Mg, photosynthesis and enzyme activity within the plant decreases and chlorophyll begins to degrade in the older leaves of plants (see photo). This causes the main symptom of Mg deficiency, chlorosis – shown by yellowing between leaf veins which remain green (*Fertilizer International* 455, p19).

As The Mosaic Company notes: "Magnesium is mobile within the plant and easily translocated from older to younger tissues. When deficiencies occur, the older leaves are affected first. Loss of colour occurs between the leaf veins, beginning at the leaf margins or tips and progressing inward."

This can give the leaves of Mg-deficient plants a striped or marbled appearance.

Magnesium (Mg) is an essential, if frequently overlooked, plant nutrient. A key component of chlorophyll, it is vital for photosynthesis

Other signs of Mg deficiency include:

- Leaves that becoming more brittle and thinner than normal and show cupping or curve upwards
- Reddish-purple leaf tips and edges in cases of severe deficiency, especially in cotton
- Older leaves die (necrosis) and drop off after prolonged deficiency.

Magnesium deficiency occurs most frequently in low pH, sandy soils where Mg can be easily leached away. Soil testing to identify potential deficiencies is therefore recommended. Mg assimilation by plants is also depressed in the presence of high levels of soil aluminium (Al^{3+}) which have a detrimental effect on root growth. Excess potassium (K) can also negatively affect Mg availability[2]:

"The competition between these two cations for root uptake appears to be the primary cause, although high K may also impair Mg translocation [movement] within the plant. Low forage Mg concentrations following K fertilization have been linked with low Mg in the grazing animals (grass tetany) where it is essential for certain enzyme and metabolic reactions."

When Mg deficiencies are detected via soil or plant tissue analysis, soluble magnesium sources can be applied to crops via the soil or through fertigation. Relatively small doses of Mg can also be applied to growing crops through foliar fertilization to prevent or correct deficiencies. In soils, the application of Mg before crops are planted or begin active growth is generally the preferred approach.

Magnesium fertilizers and crop requirements

A number of different Mg fertilizer options are available to meet crop demands (Table 1). These are typically divided into semi-soluble and soluble sources. For semi-soluble Mg fertilizers, particle size largely determines their dissolution rate in soils.

Magnesium removal by crops depends on soil Mg supply, growing conditions, crop type and target yields. At the top end, high-yielding sugarbeet and forage crops can remove Mg at rates of 90 kg/ha and 56 kg/ha, respectively. In general, cereal crops remove smaller amounts of Mg at harvest compared with root crops and many fruit crops[2].

While Mg is essential for all plants, the following crops are said to be especially responsive to Mg fertilization: alfalfa, blueberry, beet, broccoli, cabbage, cauliflower, celery, clover, conifers, corn, cotton, cucumber, eggplant, lettuce, onion, pepper, potatoes, pumpkin, spinach, squash, tobacco, tomato, and watermelon. Applying Mg fertilizers to grassland, wheat and potatoes has been shown to be particularly beneficial[1].

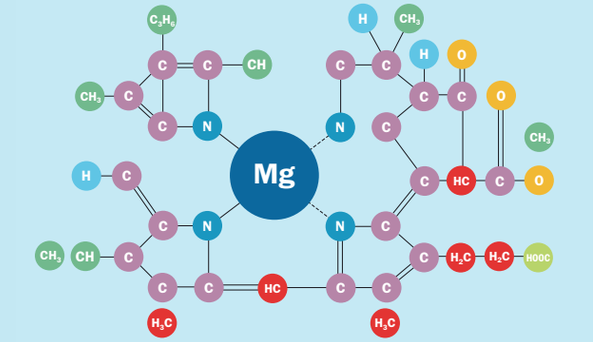
Mg fertilizer applications are necessary to ensure balanced nutrient supply to both **pasture** and animals. The removal of soil Mg without sufficient resupply generally cause significant decline in available Mg in grassland soils.

Mg is important for both the quality and yield of **wheat** and other cereals. Carbohydrate translocation and therefore optimal grain filling is supported by available Mg. Thousand-grain weight, one of the most important wheat-grain quality parameters, is generally negatively affected in Mg-deficient soils. Processing properties, such as milling behaviour during flour production, are also known to be directly related to plant Mg content.

Mg is known to be a key determinant of **potato** quality and yield. It has a direct effect, for example, on starch content and therefore the 'mealiness grade' of cooking potatoes. Tuber firmness is a major quality parameter – because it prevents bruising and various forms of discolouration during harvest, transport and storage – and is improved by Mg supply. Mg is also thought to decrease the incidence of black spot and prevent the discolouration of pulp during potato processing.

Leading magnesium fertilizer products and major producers are highlighted below.

Fig. 1: **Hidden in the heart of each molecule of chlorophyll is an atom of magnesium. This makes magnesium vital to photosynthesis**



Source: Mosaic

Potassium magnesium sulphate (SOPM)

Potassium magnesium sulphate ($K_2Mg_2(SO_4)_3$, SOPM, 11% Mg) is manufactured by extracting and processing naturally-occurring deposits of the mineral langbeinite. SOPM is valued as a fertilizer for its magnesium and sulphur content, as well as being a chloride-free source of potassium.

SOPM has been mined in the United States for over 70 years from what **The Mosaic Company** calls "the world's largest and purest deposits of langbeinite ore" at Carlsbad, New Mexico. Two producers, Mosaic and Intrepid Potash, mine and manufacture SOPM at Carlsbad and market this under the brand names *K-Mag*® and *Trio*®, respectively.

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Mosaic offers *K-Mag®* in three formulations:

- *K-Mag® Premium* (0-0-22.5+10.5Mg+21S) is suitable for high-quality blending due to its uniform particle size
- *K-Mag® Granular* (0-0-22.5+10.5Mg+21S) is typically used in bulk blends
- *K-Mag® Standard* (0-0-22+10.8Mg+22S) is suitable for direct application and as a key ingredient for granulation.

The granulated premium grade is less abrasiveness, has a lower bulk density, more uniform particle size, and a larger SGN number, making it ideal for blending.

K-Mag® is recommended for chloride-sensitive vegetable and fruit crops requiring high fertilizer application rates. It typically benefits crops with a high potassium and magnesium demand that are also sensitive to chloride, such as tobacco.

According to Mosaic, *K-Mag®* is an excellent source of non-chloride potassium, water-soluble magnesium and sulphur. With less than three percent chloride content, the risk of fertilizer 'burn' is also minimal. The combination of magnesium and potash in *K-Mag®* improves plant resistance to winter kill and insects. The product's magnesium content also activates the enzymes that synthesise chlorophyll, while the sulphur it supplies boosts amino acid formation.

Mosaic produces around 600,000-700,000 tonnes of *K-Mag®* annually from around 3.0-3.4 million tonnes of mined ore. Traditionally, about half of the finished *K-Mag®* products are sold within the US, with the other half destined for international markets where the product is also known as *Sul-Po-Mag* or *S-P-M*. Reserves at the company's Carlsbad mine are sufficient to yield a further 32 million tonnes of langbeinite concentrate (average grade 22% K_2O), equating to a mine life of 46-47 years at projected rates of production.

Intrepid Potash markets its SOPM brand *Trio®* as: "A long-lasting, readily-available source of low-chloride potassium, magnesium and sulphur ideal for fruit, vegetable and row crops grown in magnesium-deficient soils." *Trio®* is offered in four main grades:

- Premium (0-0-21.7+10.9Mg+21.8S, 3.0% Cl)
- Granular (0-0-22.1+11.2Mg+22.2S, 1.4% Cl)
- Standard (0-0-22.1+11.2Mg+22.2S, 1.5% Cl)
- Fine standard (0-0-21.7+11.0Mg+22.2S, 2.0% Cl).

These are all OMRI-listed and approved for organic farming.

Intrepid's East Mine at Carlsbad has the capacity to produce around 400,000 t/a of *Trio®*, after being converted into a *Trio®*-only operation with the cessation of potash production in 2016. The company produced 228,000 tonnes of finished product in 2019 from 935,000 of mined ore, according to Intrepid's latest annual report. *Trio®* is mainly sold into the domestic US market with only 19-28 precent being exported on average over the last three years. The product generated around $28 million in sales for the company in 2019.

Table 1: **Magnesium fertilizers: selected mineral/chemical sources of magnesium and their solubility at 25 °C**

Mineral Solubility	Chemical formula	Mg content %	Mg content g/L
Soluble sources:			
Magnesium chloride	$MgCl_2$	25	560
Kieserite	$MgSO_4.H_2O$	17	360
Langbeinite	$2MgSO_4.K_2SO_4$	11	240
Magnesium nitrate	$Mg(NO_3)_2.6H_2O$	9	1,250
Magnesium sulphate (Epsom salt)	$MgSO_4.7H_2O$	9	357
Semi-soluble sources:			
Magnesium oxide	MgO	56	-
Magnesium hydroxide	$Mg(OH)_2$	40	-
Dolomite	$CaMg(CO_3)_2$	20	-
Hydrated dolomite	$MgO.CaO/MgO.Ca(OH)_2$	18-20	-
Struvite	$MgNH_4PO_4.6H_2O$	10	-

Source: Mikkelsen (2010)

Magnesium nitrate

Magnesium nitrate ($Mg(NO_3)_2.6H_2O$, 9% Mg) is widely used in the horticultural sector to supply water-soluble Mg alongside nitrogen (N).

Commercial grades are typically manmade products synthesised by reacting nitric acid with magnesium metal or magnesium oxide. Magnesium hydroxide and AN also react to form magnesium nitrate, releasing ammonia as a by-product (*Fertilizer International* 455, p19).

Haifa Chemicals of Israel supplies water-soluble magnesium nitrate (11-0-0+16MgO) under the *Magnisal™* brandname. The product is marketed at a range of crops, including barley, citrus, cucumber, deciduous fruit trees, grapes, mango, olive, potato, tomato and winter wheat.

According to Haifa, *Magnisal™*:

- Prevents and cures magnesium deficiencies.
- Is free of chloride, sodium and other detrimental elements.
- Dissolves quickly and completely in water.
- Is ideal for fertigation and foliar spray.

Magnisal™ is extremely soluble in water. The white or yellowish-green flakes dissolve quickly and do not precipitate, even at low temperature.

Providing magnesium in nitrate form offers distinct advantages, claims Haifa: "Plants absorb the magnesium from *Magnisal™* more readily, due to the interaction between the magnesium and the nitrate anion. *Magnisal™* is up to three-fold more effective than magnesium sulphate in preventing and curing magnesium deficiencies, and therefor enables considerably lower application rates."

ICL Specialty Fertilizers offers the fully water-soluble magnesium nitrate product *Select Magnific* (11-0-0+15.5MgO). This crystalline fertilizer, provided in whitish flakes, is designed for fertigation and foliar

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use, and is recommended for field crops, orchards, flower crops, as well crops grown under protection in polytunnels or greenhouses.

Magnesium chloride

Magnesium chloride ($MgCl_2$, 25% Mg) is sold as both a water-soluble and liquid fertilizer.

ICL Group operates the world's largest magnesium chloride production plant at its Dead Sea Works (DSW) complex in Israel. About 170 grams of magnesium chloride is present in every litre of Dead Sea water. These waters are concentrated by solar evaporation to yield a solution containing around 420 grams of $MgCl_2$ per litre, equivalent to 33 percent concentration. This concentrated liquid is then converted into pellets or flakes using a heating process. The end-product contains about 47 percent magnesium chloride and is supplied as uniform quality white flakes or pellets. These are used in the following applications:

- Special fertilizer mixtures
- Animal feed additive
- De-icing and dust control
- The formulation of abrasives
- The manufacture of Sorel cement for industrial 'spark-free' flooring
- As a catalyst in textile finishing processes
- The treatment of sewage and industrial effluents.

Compass Minerals is the only US producer of naturally occurring magnesium chloride, harvesting this from the Great Salt Lake in Utah. The company markets this as an early-stage plant nutrient for wheat crops. It is also sold in North America as stand-alone de-icer or de-icing additive, and as a dedusting/stabilising agent for gravel roads.

Kieserite and Epsom salt

Germany's **K+S** is the leading international producer of magnesium fertilizers derived from naturally occurring kieserite ($MgSO_4.H_2O$, 17% Mg) and Epsom salt ($MgSO_4.7H_2O$, 9% Mg)

ESTA® Kieserit (25% MgO, 50% SO_3) contains water-soluble magnesium and sulphur in plant-available form. It is effective for all crops and all soil types and certified for organic farming. The kieserite-based product is suitable for use in agriculture, horticulture, special crops, plantations and forestry. It is recommended for amelioration of soils with poor magnesium status and is typically applied after harvest or prior to sowing.

ESTA® Kieserit is available as either a granulated or fine product. For annual crops, it is applied as a basal dressing in autumn or late winter. Early spring application as a basal or top dressing is recommended on sandy soils and/or under high rainfall conditions. Sub-surface fertilization, alongside nitrogen and phosphate fertilizers, has proved to be effective for maize.

The granular variant, *ESTA® Kieserit gran*, has excellent spreading properties due to its close particle-size distribution and granule hardness. It can be applied accurately and efficiently with all modern fertilizer spreaders. The best application

Fertilizer specialities with magnesium

Prof **Jóska Gerendás**, Dr **Matthias Rott** and Dr **Heike Thiel** of K+S Minerals and Agriculture GmbH highlight the role magnesium plays in crop nutrition. They share insights on the benefits of magnesium fertilization, based on extensive experience gained with the company's unique portfolio of magnesium- and sulphur-containing speciality fertilizers.

K+S is mainly known as a potash producer. But there is much more to the company than potash-containing products. The unique deposits in Germany also contain valuable magnesium and sulphur in the form of kieserite. This has allowed K+S to create a speciality fertilizer portfolio with a wide range of plant nutrient formulations, most of them certified for organic farming, as described in the main article. These nutrients are highly concentrated, fully water-soluble and directly available for uptake by the roots and leaves of plants. In this article, we focus on the function of magnesium, its role in plant growth and its necessity for high yielding and best quality crop production.

Essential for chlorophyll, vital for photosynthesis

Magnesium (Mg) belongs to the group of macronutrients like N, P, K, S and Ca. Yet its importance for a high-quality yield is not nearly as well-known as its counterparts.

In fact, Mg is one of the essential components of chlorophyll, and thus plays a pivotal role in the first step of photosynthesis – the absorption of sunlight. In subsequent steps of photosynthesis, Mg is also essential for the conversion of light into the biochemical energy used to synthesise carbohydrates from CO_2 and water. Additionally, Mg is the catalyst for energy transformations in general, and plays an important role in protein and carbohydrate metabolism (Figure 2).

The capacity for assimilates in storage organs (e.g. grain, beet, tuber, etc.) is significantly affected by the Mg content of the plant. Because magnesium deficiency is directly associated with a lower photosynthesis rate during the growing phase, it reduces the yield and quality of the harvest products. Furthermore, Mg promotes root growth and enables the plant to access more water and nutrients in the soil.

While Mg should be a central part of the fertilizer regime in all crops, special attention should be paid to heavily Mg-dependent crops like oil seed rape, oil palm and maize – or to acidic soils where Mg is less efficiently retained.

Helping crops combat climate change

The factor with the largest impact on crop yield which cannot be controlled by growers is the weather. Extremes of weather, such as drought conditions, are increasing due to climate change. Under these circumstances, Mg becomes even more important.

Plants suffering from Mg-deficiency react much more sensitively to high solar radiation and temperatures than plants well supplied with magnesium. This is because energy from photosynthesis not used for sugar production when Mg is lacking, but instead forms reactive oxygen species, which ultimately kills cells and lead to visible necrosis. Damage by sunlight is therefore a foreseeable consequence if the Mg content of leaves is not maintained within the optimum range.

Overall, an insufficient supply of Mg will disturb and disrupt crop growth. Such deficiency effects are also intensified by heat. Root growth is greatly inhibited on the one hand, and shoot growth is reduced on the other. Consequently, magnesium deficiency – particularly when combined with heat-stress – results in yield losses by impairing water uptake and restricting nutrient uptake and transport.

Magnesium enhances root growth

Optimising root growth offers the best security for plant production. Yet Mg deficiency often remains undetected until it is too late – as less visible impacts on root growth occur much earlier than the more visible effects on shoot growth. This makes it very difficult to recognise the early symptoms of reduced root growth in the field.

Fortunately, deficiency can be prevented through the pre-emptive application of magnesium-containing soil fertilizers. Products such as *ESTA® Kieserit, Kornkali®*, and *Patentkali®* promote root length and improve the root mass of plants from the start by improving nutrient and water uptake from the lower soil levels.

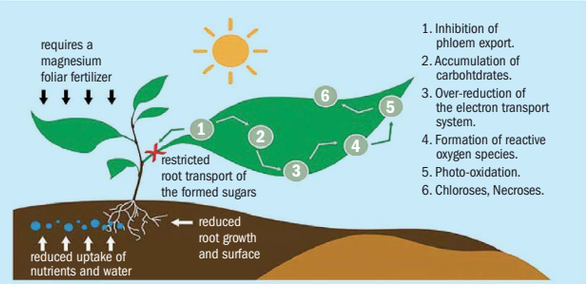
Magnesium and sulphur for better nutrient use efficiency

The longer roots and bigger root systems promoted by Mg also increase the uptake of other nutrients such as nitrogen and phosphorus from the soil. Nevertheless, optimal nitrogen uptake and utilisation can only be ensured by combining Mg with plant-available sulphur (S).

Sulphur is particularly crucial for nitrogen use efficiency. If plants are S deficient, the formation of (S-containing) proteins is impaired and consequently the amount of soluble nitrogen compounds in the plant increases, including nitrate levels. This, in turn, inhibits further nitrate uptake from the soil. The resulting accumulation of amino acids also makes the plant highly susceptibility to pathogens.

The adequate supply of sulphur to crops is important, as the failure of the plant to convert nitrate, so-called nitrate stagnation, occurs very early on during latent S deficiency. Nitrate accumulation in plants does need to be guarded against, as it is a subtle and non-visible symptom that can only be identified in the field using nitrate test strips on sap.

Fig. 2: **Magnesium deficiency: damage in leaves and effects on root growth and root nutrient and water uptake**



Source: K+S, adapted from Cakmak & Kirkby *(2008)*

Magnesium for successful crop production

Magnesium and sulphur have an impact on both crop yield and quality. For example, in cereals, with the beginning of flowering, Mg is translocated from the green plant organs (mainly flag leaf and spelt) into the grain. Here, Mg is essentially needed for grain filling with assimilates, and is also held in reserve for the seedling.

For this reason, foliar application of Mg to the flag leaf with the *EPSO®* family of products helps to prevent deficiencies in cereals – due to suboptimal translocation of assimilates to the storage organs – by prolonging photosynthesis output until maturation. This results in higher thousand grain weights and increased carbohydrate and protein contents. Similarly, magnesium beneficially affects starch content in maize, and oil content in oilseed rape and oil palm.

Basic Mg and S needs should always be included in the fertilization strategy. Crop needs can be covered by their respective soil fertilizers like *ESTA® Kieserit, Kornkali®* or *Patentkali®*.

Additionally, crops can be supported during different growth stages by applying a foliar fertilizer such as of *EPSO Top®* – which contains Mg and S in combination with micronutrients like manganese, zinc or boron. Early applications of *EPSO Top®* promote root growth, while applications during later growth stages support the transport of assimilates from the leaves to the storage organs such as grain, roots or tubers. In this way, multiple *EPSO Top®* applications offer the best insurance for maintaining optimal Mg and S supply – and helping guarantee the highest crop yields as well as the best quality harvested produce. Foliar *EPSO®* applications are also ideal as a fast-acting Mg and S supplement in situations where deficiency symptoms are observed in the crop.

Conclusions

Magnesium is an undervalued yet irreplaceable macronutrient for crop production due to its many beneficial effects on ecological and physiological processes that control plant growth, yield and quality. Mg is both essential and of central importance due to its roles in carbohydrate production and transport and root growth, all of which influence the uptake of nutrients from the soil. It is an especially valuable plant nutrient under climate change conditions too – when plants are subjected to drought, strong radiation and heat stress, etc.

In summary, magnesium clearly helps plants cope with unfavourable environmental conditions. In our experience, balanced magnesium fertilization – when supplied together with sulphur and micronutrients in combination with potassium – also leads to the best crop production results. ■

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time for perennial crops is prior to the main growth period.

Patentkali® (30% K_2O, 10% MgO, 42.5% SO_3) is a speciality potassium fertilizer with a high magnesium and sulphur content due to its kieserite content. It is certified for organic farming. Nutrients are present in sulphate form and are fully water-soluble. The product is unaffected by pH and therefore suitable for all soil types. It also has good spreading properties due to its uniform particle size distribution.

Patentkali® can be safely applied until shortly before the drilling or planting date. On light soils, it should be applied in the spring to avoid potential nutrient losses over the winter. The product is particularly well-suited for chloride-sensitive agricultural, horticultural and forestry crops due to its low chloride content (3% Cl maximum). It is recommended for application to potato, vegetables, fruits, grape and sunflower.

Korn-Kali® is a potash and magnesium fertilizer that combines potassium chloride (40% K_2O), kieserite (6% MgO) and sodium chloride (4% Na_2O). It also supplies sufficient sulphur for most crops due to its high sulphate content (12.5% SO_3 = 5% S). All these nutrients are fully water-soluble and therefore directly available to plants independent of soil pH.

The product also has good spreading properties in the field due to its uniform particle size distribution.

Korn-Kali® is recommended as a potassium fertilizer for chloride-tolerant crops which also have a requirement for the other nutrients supplied – such as sulphur for oil crops and magnesium and sodium for sugar beet. Suitable crop types include cereals, oilseed rape, sugar beet, maize and forage crops. The product is generally applied during the autumn.

Magnesia-Kainit® (9% K_2O, 4% MgO, 35% Na_2O, 9% SO_3) is a crude kieserite-containing potash salt. It is marketed by K+S as a cost-effective organic fertilizer for grassland and forage crops. The product significantly improves the palatability of pastureland due to its high sodium content. By increasing magnesium and sodium accumulation of the fodder, it contributes to good animal health, growth and fertility. It should be applied in early spring before vegetative growth begins.

K+S offers a range of four organic-approved fertilizers containing Epsom salt. All nutrients are fully water-soluble and are present in sulphate form

EPSO Top® (16% MgO and 32.5% SO_3) is a quick acting magnesium and sulphur fertilizer for foliar application. It dissolves rapidly without a residue in water, making it well-suited for foliar spray applications and for fertigation through irrigation systems. These can supplement soil applications during periods of peak demand, particularly if magnesium deficiency is observed. The product is recommended for a range of crop types, including cereals, oilseed rape, sugar beet, potatoes, hops, asparagus and softwood.

Magnesium deficiency in Tomato. Interveinal chlorosis (yellowing) on older, lower leaves.

EPSO Microtop® (15% MgO, 31% SO_3, 0.9 % B, 1% Mn) is micronutrient-enriched foliar fertilizer recommended for sugar beet, oilseed rape, brassica, potatoes, sunflower, maize and grapevines. The product is designed to rapidly alleviate magnesium, sulphur, boron and manganese deficiencies in growing crops. It is particularly suitable as a preventive application, helping to avoid deficiencies before they occur.

EPSO Combitop® (13% MgO, 34% SO_3, 4% Mn, 1% Zn) is a quick-acting, micronutrient-enriched foliar fertilizer containing magnesium, sulphur, manganese and zinc. It has been specifically developed to meet the nutrient needs of cereals, maize and leafy crops, being able to satisfy high demand for manganese in combination with magnesium and sulphur. The product is particularly suitable as a preventative application.

One or two applications should completely meet magnesium and sulphur demands and provide a full maintenance dressing of manganese and zinc. Autumn application to winter barley has been shown to improve winter hardiness.

EPSO Bortop® (12.6% MgO, 25% SO_3, 4% B) is a new foliar product from K+S. It targets crops with medium-to-high boron demand such as rapeseed, sugar beet, sunflower and corn. The combination of sulphur, magnesium and boron helps with efficient nutrient uptake by the plant. This can be further improved by split applications. A special feature of the product is its ability to lower the pH of spray solutions by up to two units. It quickly alleviates boron deficiencies, aiding plant physiological processes such as starch and sugar formation, cell development and winter hardiness.

Chinese producer

Founded in 2000, privately-owned **Sinomagchem** (Yingkou Magnesite Chemical Ind Group Co Ltd) is based in Dashiqiao – the so-called 'magnesite metropolis' – in China's Liaoning Province. The company extracts magnesite from Dashiqiao's large-scale deposits to manufacture up to 500,000 t/a of magnesium sulphate and 200,000 t/a of magnesium oxide. Its fertilizer, feed and industrial product lines are offered in more than 100 different specifications.

Unsurprisingly, given the scale of its operations, Yingkou Magnesite is China's largest manufacturer and exporter of chemically-produced magnesium sulphate fertilizers. Its product range includes fertilizer-grade:

- Magnesium sulphate (kieserite).
- Magnesium oxide.
- Boron-and zinc-enriched magnesium fertilizers (Mg plus B, Mg plus Zn).

As China's leading producer, Yingkou Magnesite drafted the country's national standard for magnesium sulphate and 'Mg plus B' fertilizers. Operating under the Sinomagchem brand internationally, the company successfully exports high quality magnesium products to more than 60 countries globally, complying with the EU's REACH certification and operating to ISO9001. ■

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CRU Phosphates 2021

More than 560 delegates participated in CRU's Phosphates 2021 Virtual Conference, 23-25 March 2021. To highlight this successful event, we report on keynote and selected commercial and technical presentations.

Phosphate market outlook

Glen Kurokawa gave the CRU view on phosphate market developments. He attributed the strong upward phosphate price sentiment of recent months to a host of supply- and demand-side factors, including:

- High crop prices
- Big demand increases in the US, Brazil, India and China
- Low stocks, e.g. in the US and India
- Impact of Covid-19 on supply (China, India, Peru)
- Production issues in Saudi Arabia.

The imposition of US import duties on Moroccan and Russian phosphate fertilizers has also had a major market impact, both on the US market and global trade flows. Both Russia and Morocco have essentially stopped exporting to the US, causing domestic phosphate shortages and price hikes.

To make up the domestic shortfall, the US is expected to import more phosphate products from producers in Saudi Arabia, Australia, Mexico, Jordan and Egypt in future.

"US countervailing duties are likely to remain through 2025, perhaps longer, and phosphate trade will consequently remain disrupted," commented Kurokawa.

On the back of strengthening demand, Brazilian phosphate prices have risen extremely fast compared to other benchmarks – a situation that is likely to continue throughout 2021 and beyond, says Kurokawa.

Meanwhile, despite recent increases, Chinese phosphate demand is expected to eventually resume its downward trajectory. "Chinese phosphate demand will likely continue declining, after rising in 2020 and 2021, reverting to that long term trend because its phosphate application rates are very, very high," Kurokawa predicted.

Summing up the outlook, Kurokawa concluded:

"Prices are expected to decline in 2021 and into 2022, but generally rise after that to 2025. There will be cost inflation, with costs like energy and wages rising, in addition to raw materials price hikes, helping push up phosphate prices to 2025."

Outlook for global agriculture

Crop prices globally have improved significantly due to below-trend crop production and strong demand in China, explained Nutrien's **Robert Mullen**.

Expectations on crop prices have shifted enormously over the last 6-8 months, said Mullen:

"I recall the expectation that corn could fall below three dollars [per bushel]. I can't believe that I'm even admitting that I was saying that late last summer. But that was the trajectory of commodity prices at the time. Now we're talking about prices that we haven't experienced in a little under a decade. If you're looking at the 2021 crop corn, today we're trading at 4.75 [dollars per bushel]."

In his view, price expectations for corn and soybean have been primarily driven by historically tight supply/demand balances, as shown by low stocks-to-use ratios:

"The run up to soybean was even more impressive than what we experienced in corn. It's not just those two commodities either. We've seen a pretty good appreciation in the cotton price. Wheat has experienced a pretty good bump in price too."

This was not just a US domestic phenomenon either, Mullen added:

"We've also experienced this internationally. Brazil has had a tremendous run up in [soybean] prices. Palm oil is moving up to record levels. That's an impressive run in last 6-8 months – corn, soybean, wheat, cotton, palm oil, and canola too for our neighbours in the north [Canada]."

The soybean trade is emblematic of the wider agricultural market conditions, with very tight supply due to Chinese demand. In Brazil, for example, record soybean exports in 2020 – with 73 percent destined for China – forced the country to increase imports from Paraguay and Uruguay to meet its own internal demand. Brazil's 2021 soybean exports are expected to reach near-record levels again.

New EU FPR regulation

The European Commission's **Johanna Bernsel** provided an update on the introduction of the EU Fertilising Products Regulation (FPR). This will enter into force in July next year.

Bernsel highlighted the main implications for the European fertilizer market:

"When we talk about an EU fertilising product – [I mean] a fertilising product that is compliant with the FPR and is CE marked. This is a new concept we have introduced in the FPR.

"A fertilising product is not only a plant nutrient, it's a wider concept that encompasses many categories. Not only will we open the market for secondary raw materials, it will also include a much broader portfolio of categories of products."

These categories will include biostimulants for the first time.

Bernsel also emphasised that introducing mandatory limits for critical contaminants and pathogens was a big step forward for protecting EU citizens:

"In the future there's going to be mandatory cadmium limit values for phosphate fertilizers – it's going to be at 60 ppm."

In advance of the regulation's introduction, the European Committee for Standardization (CEN) is developing harmonised standards for fertilising products. Bernel expect these to be ready by next spring.

China ag market spotlight

Developments in Chinese agricultural commodities markets were outlined by **Rosa Wang** of Shanghai JC Intelligence.

China's food strategy is based on absolute self-sufficiency in food grains and high

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self-sufficiency in other grains. Because of this, the country takes precautions by maintaining high stocks.

In terms of production of the three major grains in China, the current policy aims are to expand the corn acreage – which previously fell from 44.5 million hectares in 2016 to 40.2 million hectares in 2019 – while stabilising soybean and paddy rice acreages.

While Chinese wheat planting has increased in recent years, high-quality wheat acreage still represents less than 10 percent of the total, leaving the country with a significant supply gap. Wheat is mainly used for flour-making in China, although more is being used in animal feed due to the hike in the corn price.

Chinese grain demand continues to grow too, as Wang pointed out: "China imported over 10 million tonnes of corn in 2020, far exceeding its tariff-rate import quota of 7.2 million tonnes." The country imports corn from multiple sources although the Ukraine and the US account for 56 percent and 38 percent of imports, respectively.

Looking ahead at price trends in 2021 and 2022, Chinese grains are now at the bottom, concludes Wang:

"The price trend is to go up, particularly in grains for food consumption. The hike of government prices for wheat and paddy rice stockpiling provides a barometer for price trends. Corn, after a hike of over 60 percent in 2020, will stay at high level in 2021."

Risks and challenges in China

CRU's **Isabel Chen** highlighted some of the risks and challenges in the Chinese phosphates market.

On the demand-side of the equation, Chinese demand did recover in 2020-2021, although this is likely to prove a short-term respite, explained Chen: "Chinese phosphate demand will continue to rise in 2021, amid a longer term declining trend. It is expected to revert back next year."

On the supply-side, China is facing a combination of near-term shortage and medium-term oversupply. 2020 domestic phosphates production was down by one million tonnes due to production cuts by major producers – the so-called 6+2 group – and Covid-19 stoppages last spring.

The 6+2 group operates 65 million tonnes of China's total phosphates production capacity of 212 million tonnes. These larger, lower cost producers are leading the way due to their operational flexibility and price discipline. The big are also getting bigger, said Chen, with the 6+2 producers increasing their market share:

"Benefiting from a much tighter global market, Chinese producers are likely to remain highly profitable this year. But over the longer term, oversupply will still be the key risk and challenge for Chinese producers – and keep pushing them to figure out solutions for survival and development."

Chinese industry reforms are partly regulatory driven, suggested Chen: "Environmental regulations are expected to remain strict. So the cost of producers to comply with requirements will be higher and will still be an important driver for capacity changes in the near-term."

With domestic demand contracting, the shift away from commodity phosphates (TSP, DAP and MAP) to value-added products – such as industrial- and food-grade phosphates and water-soluble fertilizers – will be vital, Chen concluded:

"Phosphates producers will need to do more on diversification of their downstream to remain competitive, especially as the fall in domestic fertilizer demand is irreversible. More value-added fertilizer products in their capacity list will be the key for profitability in the Chinese phosphates industry."

Selected technical programme highlights

Gary Fowler and **James Byrd** of JESA Technologies explained the potential for synergies between beneficiation plant and phosphoric acid plant design.

Phosphoric acid pilot testing, for example, does not usually consider the grade-recovery or capex/opex optimisation of the beneficiation plant. Beneficiation plants, meanwhile, usually maximise phosphate recovery for a client-set phosphate grade. However, treating phosphate rock grade as a variable instead would provide more scope for optimising phosphoric plant design for a given feed source – by looking back to the beneficiation plant for improvements.

Both presenters concluded that, when beneficiation plant and phosphoric acid plant designers collaborate, a larger picture emerges that benefits the economics of both plants. By working together to common goals, an integrated design approach can offer phosphate project clients substantial benefits, in their view.

Yariv Cohen and colleagues from Easy Mining updated delegates on the progress of *Ash2®Phos*, a value-added process that recycles phosphorus from incinerated sewage sludge.

The process dissolves ashes containing around 10 percent P_2O_5 in acid, recovering 90-95 percent of available phosphorus while eliminating more than 96 percent of the heavy metals present. Phosphorus is recovered as 'clean' precipitated calcium phosphate (PCP). Typically, the process can generate around 15,000-45,000 tonnes of PCP from 30,000-90,000 tonnes of ash.

Several *Ash2®Phos* pilot projects are currently underway in Europe, including a 30,000 t/a capacity project for Gelsenwasser in Germany. This project is expected to enter commercial operation in 2024. A similar pilot is also at the basic engineering stage in Helsingborg, Sweden. *Ash2®Phos* production at 300,000 t/a scale is expected in Germany by the end of this decade.

Ricardo Sepulveda of PegasusTSI outlined the potential for green methanol and green ammonia production via carbon capture and hydrogen generation at phosphate fertilizer production sites.

A typical one million tonne capacity phosphoric acid plant, for example, will generate 150,000 t/a of CO_2.

Flue gas from these plants contain 4-10 percent CO_2, while fertilizer granulation plant flue gas also contains 0.3 percent CO_2. Carbon dioxide can be captured from these gases by CO_2 absorption in amine solution using proprietary systems such as *CANSOLV*.

Waste heat from on-site sulphuric acid production, meanwhile, can also be captured and converted to medium pressure steam with a heat recovery system (HRS) – and then used to generate electricity. This, in turn, can generate hydrogen from water using an alkali electrolysis unit.

These two recovery processes can provide feedstocks for two different production routes. Firstly, captured carbon dioxide and electrically generated hydrogen can be combined to manufacture green methanol. Alternatively, hydrogen can be combined with nitrogen in ammonia synthesis to manufacture green ammonia. Pegasus TSI has calculated investment costs and the revenue potential for both routes. ■

Further reading

A set of abstracts highlighting key conference technical presentations can be found in the CRU Phosphates 2021 preview in our January/February issue (*Fertilizer International* 500, p33).

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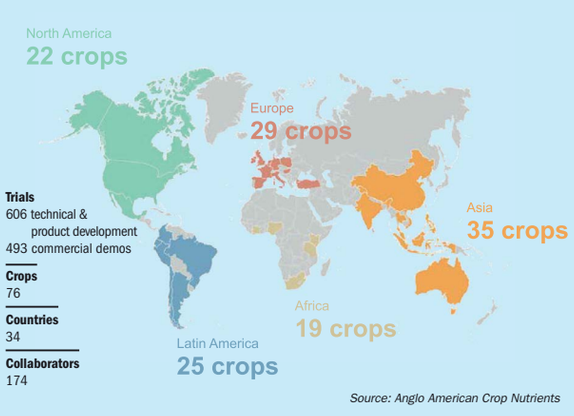
POLY4 corn trial in South Africa. Sulphur and other nutrients present in the polyhalite product POLY4 can improve corn growth and yield.

The agronomic advantages of *POLY4*

Maya Rehill of Anglo American Crop Nutrients discusses the latest crop trial findings for the polyhalite product *POLY4* with the company's regional agronomists. These highly positive trial results add to an already extensive evidence base on *POLY4*'s crop benefits.

Fig. 1: ***POLY4* global crop science programme as of April 2021**



Source: Anglo American Crop Nutrients

Anglo American Crop Nutrients is continuing to expand its worldwide crop science programme. Agronomic trials of its polyhalite product *POLY4* have now grown to encompass North America, South America, Europe, Africa, the Middle East, China, India, Southeast Asia and Australasia.

To date, a total of 606 technical and product development trials, as well as 493 commercial demonstrations, have been carried out across the world (Figure 1). As a consequence, the evidence base on the agronomic benefits of polyhalite continues to grow – underpinning the company's commercial efforts and supporting global *POLY4* sales.

Wide-ranging and positive *POLY4* trial results, for many different crop types, have undoubtedly helped boost contracted fertilizer market sales. In advance of first production, Anglo American has now signed offtake agreements with leading commercial suppliers totalling 13.8 million tonnes per annum.

Growing global

"Since the early greenhouse trials in 2013, the scope of the *POLY4* agronomy programme has expanded significantly, both in terms of geography and crop types," says Ross Mitchell, Head of Agronomy and Technical Services at Anglo American Crop Nutrients. "Up to now, we have tested *POLY4* on 76 crops and in 34 countries."

Mitchell adds: "The foundation upon which we build our trials is understanding the current farming systems in each region – and how *POLY4* can support, enhance, and sometimes even reshape local fertilizer programmes to improve crop performance,"

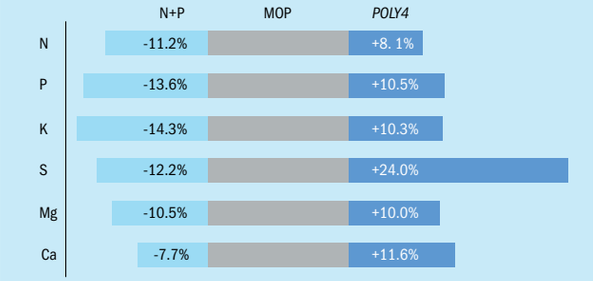
Many factors need to be assessed before *POLY4* trials commence. These range from the variety of crops grown to factors that affect fertilizer practices. The latter can include farm economics, fertilizer availability, soil conditions, agronomic advice and application recommendations."

POLY4 is a flexible product and its use can be fine-tuned to meet regional requirements. Whether higher crop yields or better crop quality are required – sometimes both – or if longer-term benefits such as soil improvements are desired, the application of *POLY4* can be tailored to meet the specific needs of farmers and growers.

Each *POLY4* trial assesses yield results while also focussing on other improvements that complement what farmers are doing already. "Of course, yield is king – yield drives profit for a large majority of farmers," says Mitchell, while adding:

"But besides the advantageous output factor, *POLY4* also offers broader benefits related to inputs in the farming system. The convenience factor, for example, where farmers do not need to spread more fertilizers or can decrease the number of field passes, yet achieve the same or even better results, will be of value."

Fig. 2: **Improvements in macronutrient uptake with *POLY4***



Source: Anglo American Crop Nutrients

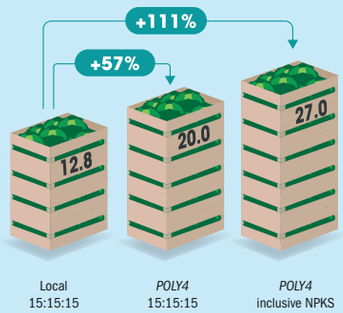
Broad benefits

POLY4 is a multi-nutrient product offering multiple benefits. These notably include better nutrient recovery and uptake by crops and a sustained dissolution rate – characteristics which, in turn, fuel crop yield improvements.

"Comparatively, the effectiveness of different fertilizers can be judged by measuring their nutrient use efficiency," says Robert Meakin, Head of Crop Science and Product Development. "We have analysed and compared apparent nutrient recovery in up to 70 *POLY4* global trials."

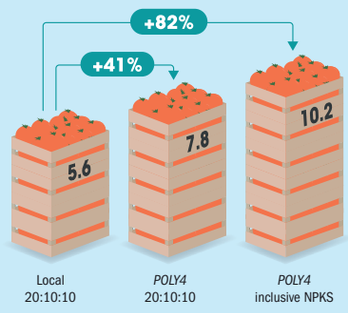
The findings are shown as a series of bar charts in Figure 2. As Meakin explains, the central bars represent 100 percent nutrient uptake (in above-ground crop biomass) by a crop supplied with nitrogen (N) and phosphorus (P) together with muriate of potash (MOP) as a potassium (K) source. The N+P bars (left) show the impact of completely removing the potassium source. The *POLY4* bars (right), meanwhile, show the impact of switching the potassium source from MOP to *POLY4*. This substitution clearly supports higher nutrient uptake. For example, potassium uptake in the *POLY4*-fed plants increased by 10.3 percent

Fig. 3a: **Average cabbage marketable yield (t/ha)**



Source: Anglo American Crop Nutrients

Fig. 3b: **Average tomato marketable yield (t/ha)**



Source: Anglo American Crop Nutrients

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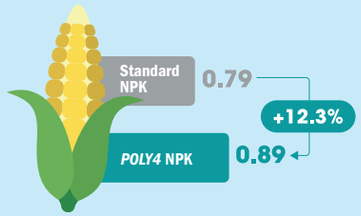
Fig. 4: **Corn relative yield (t/ha)**

Source: Anglo American Crop Nutrients

Fig. 5: **Grain S (g/kg)**



Source: Anglo American Crop Nutrients

compared to the MOP-fed crop. The benefits do not end there either. Many other nutrients as well as potassium show higher nutrient use efficiency with *POLY4*.

"Moreover, with supply of sulphur, magnesium, and calcium, *POLY4* promotes nutrient release and improves the nutrient uptake by up to 24 percent. This results in marked improvements in both crop yield and quality," confirms Meakin.

Field focus

The agronomy programme continues to generate a strong body of evidence showing *POLY4* performing consistently well on both broad-acre and high-value crops in various agroecological zones.

POLY4 supplies four of the six macronutrients a plant needs – potassium, sulphate-sulphur, magnesium and calcium. Because these are released in a gradual and sustained way, the product is able to meet the nutrient needs of crops over a longer time period, rather than delivering an immediate hit.

The task of the agronomy team at Anglo American Crop Nutrients is to understand and make sure that complex crop nutrition supplied by *POLY4* is used correctly in all agricultural areas throughout the world. It is equally important to find out:

- When is the right time to use it
- What is the right amount to put on
- What is the right rate of application.

Below, our expert regional agronomists, who work with farmers and researchers across the world, highlight the performance of *POLY4* in recent crop trials.

Innovative crop nutrition

Crop yields in Nigeria are generally low, despite the country's huge agricultural development potential and the fact is has one of the fastest growing populations in the world.

"By supplying 95 percent of all locally produced food, smallholder farmers are the backbone of Nigerian agriculture," says Candice Pienaar, Africa Regional Agronomist. "Horticultural crops can make an enormous impact on rural livelihoods due to increased income for farmers and the high nutritional value of vegetables for local communities."

Two farms in Northern Nigeria were selected as trial sites to evaluate the effects of *POLY4* blends on dry-season cabbage and tomatoes: one with a clay soil near Kaduna, and the other with a sandy soil near Kano. Results at both farms showed significant and consistent yield and quality improvements, independent of their very different soil types.

The application rates for the blends all followed local smallholder farmer practices, explains Pienaar: "Fertilizer application rates for smallholder agricultural production in Nigeria is low, but the *POLY4*-based blends were designed to give these farmers maximum yield and quality improvements even when applied at low rates."

On average results showed:

- **Cabbages:** the standard 15:15:15 fertilizer yielded 12.8 tonnes of cabbage per hectare, while the use of a *POLY4*-inclusive 15:15:15 increased the yield to 20 tonnes per hectare, a 57 percent yield increase. Additionally, the new crop-specific *POLY4*-inclusive NPKS blend achieved the highest cabbage yield of 27 tonnes per hectare. (Figure 3a).
- **Tomatoes:** while the local 20:10:10 fertilizer yielded 5.6 tonnes of marketable tomatoes per hectare, a *POLY4*-inclusive 20:10:10 increased the yield to 7.8 tonnes of marketable tomatoes per hectare, a 41 percent yield increase versus local practice. Furthermore, the use of a new crop-specific *POLY4*-inclusive NPKS blend at the same 60 kg/ha N application rate resulted in an even greater marketable tomato yield of 10.2 tonnes per hectare, delivering an 82 percent yield advantage (Figure 3b).

These trials demonstrated that Nigerian farmers can easily adopt *POLY4* into their farming practices, concludes Pienaar: "Innovative and improved fertilizer solutions such as balanced crop nutrition with *POLY4* can have a significant positive impact on the yields, quality, income and livelihoods of local vegetable farmers."

Superhero sulphate-sulphur

Farmers in the United States, because they are already at a high crop productivity level, focus more on improving the efficiency of their operations and making better use of inputs such as fertilizers to ensure a successful return on their investment.

"*POLY4* can potentially be used as a sulphur source replacing certain alternative products like ammonium sulphate," explains Brad Farber, Lead Regional Agronomist in North America. "For example, corn has a high sulphur need. The demand for yields increases, when combined with decreasing sulphur deposition from the atmosphere, means the soil organic matter can no longer meet the crop's high sulphur needs."

Farber continues: "15 research and commercial farm trials on corn in Iowa, Illinois, and Minnesota between 2015 and 2019, showed that *POLY4* programmes improved the average yield by 620 kg/ha – an increase of almost five percent compared to the standard NPK programme where K was provided by MOP. Yield increased because crops had both more kernels and larger kernels: the number of kernels per square metre actually increased by five percent, while the thousand kernel weight increased by more than one percent on average."

> **Of course, yield is king – it drives profits – but *POLY4* offers broader benefits too.**

"Sulphur uptake can be a significant contributor to crop growth and eventual yield," sums up Farber. "*POLY4* increased grain sulphur by more than 12 percent."

The results of these corn trials are shown in Figures 4 and 5.

There are two major fertilizer seasons in the North American Midwest – autumn and spring – as Matt Wiebers, North America Regional Agronomist, explains:

"Sulphur containing fertilizers are usually applied in spring, and not before, because they contain both nitrogen and sulphur – two nutrients that are leachable and therefore move with water. Corn growing areas are primarily rainfed and, with current weather events being somewhat unpredictable, in a heavy rainfall nitrogen and sulphur tend to leach down into the soil profile away from the crop roots."

As a source of sulphate-sulphur for corn, the sustained nutrient delivery profile of *POLY4* ensures a continuous supply of nutrients throughout the growing season that matches the crop's needs.

Farmers are innovators and are therefore generally open to new products and technologies, if they offer convenience and increase efficiency, says Wiebers:

"Every farmer can appreciate the convenience of simplifying on-farm operations and fertilizer applications while still increasing productivity. *POLY4* provides an effective solution with its gradual and sustained release of sulphate-sulphur, plus it can be safely blended and applied to fields in autumn with the other P and K fertilizers farmers are already applying.

"This improves efficiency by reducing the number of field passes – covering more acres in less time – and saving the hassle during a busy time of the year. Furthermore, with *POLY4* you have a crop nutrition product that emulates many of the properties of specialty fertilizers but can be produced in bulk and at scale making it available to all farmers when it enters the market."

Nutrition on demand

Indian agriculture provides more people with livelihoods than any other sector in the country. Indeed, some 70 percent of rural households in India still depend primarily on agriculture for their livelihood, with 82 percent of farmers being smallholders.

The use of *POLY4* can help Indian farmers overcome many challenges, says Satendra Upadhyay, India Regional Agronomist:

"*POLY4* can help strengthen crop productivity in India by offering balanced crop nutrition while avoiding overuse of fertilizers. Poorly balanced use of fertilizers, especially chemical products, encourages land to become less productive rather than more productive and degrades the soil health and quality hence causing soil pollution."

Upadhyay highlights the promising performance of *POLY4* on some of the key crops produced in India, such as wheat and potatoes:

"Amalgamation of trial results have shown that *POLY4* increases both wheat yield and biomass. In trials conducted by the India Agriculture Research Institute in New Delhi, supplying 50 percent of recommended potassium with *POLY4* increased grain yield by seven percent, versus crops that received their full K recommendation from MOP.

"Furthermore, when compared to the common farmer practice of applying N and P from urea and DAP, *POLY4* achieved a 21 percent increase in yield."

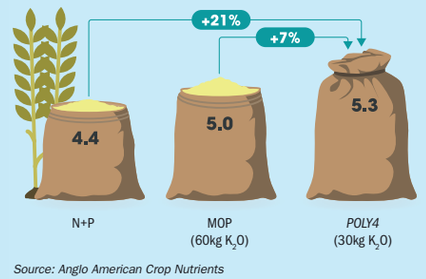
These results are shown in Figure 6.

The performance of *POLY4* on potatoes was also assessed, as Upadhyay explains:

"The majority of Indian potatoes are grown in the northern state of Uttar Pradesh, where we carried out three-year trials with the Sardar Vallabhbhai Patel University of Agriculture and Technology based in Meerut.

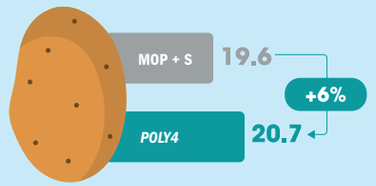
"These trials demonstrated that a *POLY4* fertilizer programme offers potato farmers more benefits than a conventional MOP and elemental sulphur treatment. The

Fig. 6: **Wheat grain yield (t/ha)**



Source: Anglo American Crop Nutrients

Fig. 7: **Potato tuber dry matter (%)**



Source: Anglo American Crop Nutrients

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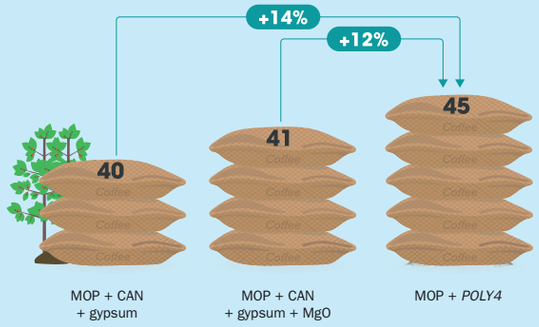
Fig. 8: **Average coffee yield (kg/plot)**



Source: Anglo American Crop Nutrients

marketable potato yield increased by an average of 13 percent with *POLY4*."

This programme also improved potato quality (see Figure 7), adds Upadhyay:

"By offering a better balance of nutrients, including calcium, as well as a reduced chloride dose, *POLY4* helps to improve quality of tubers. Tuber dry matter content was increased by six percent in the *POLY4*-treated potato crop, compared to MOP plus sulphur, thus improving the frying quality of potatoes."

"*POLY4* can also help resolve the well-known antagonism between soil potassium and magnesium that limits yield for potato growers," concludes Upadhyay. "It can do this thanks to two helpful characteristics – its sustained dissolution rate and the ability to supply magnesium alongside potassium."

Magic of magnesium

Latin America accounts for nearly 60 percent of worldwide coffee production, with Brazil and Colombia being the leading producers. Colombia ranks as the second largest coffee producing country in the region with an average annual production of almost 14 million 60-kilogram bags.

The majority of coffee in Latin America is produced by smallholder farmers whose livelihoods fully rely on the high quality of their crop to achieve a high price, says Lino Furia, Regional Agronomist in Latin America: "In Colombia, coffee is grown by approximately 900 thousand farmers on 700 thousand hectares, meaning that on average a coffee grower operates on less than one hectare of land."

Colombian coffee is mainly exported to Europe, with quality criteria and standards greatly influencing the way coffee is produced, including:

- European quality standards
- The demand for certified organic coffee
- The implementation of good agricultural practices (GAP)
- Fair Trade principles
- Demand for low carbon footprint products.

Furia says that to receive higher scoring on quality certification, and consequently a higher price, farmers aim to harvest consistent and uniform coffee cherries based on size, colour and maturity:

"Compared to Brazil, where the quality of coffee is lower due to mechanical methods of harvesting and industrialised assessment of quality, Colombian coffee is used as a benchmark for a superior coffee quality. In Colombia, the fruit is harvested from the same trees six times a year when only the mature and large cherries are handpicked each time.

"Colombia grows mostly Arabica beans which are considered to be of a better quality. Arabica beans are large and extended in shape and offer a more refined taste.

"Coffee crops demand a large supply of nutrients. Usually, 200 kilograms of potassium is applied per hectare – more than two times soybean requirement, for example. However, high levels of chloride in currently used fertilizer sources negatively affect the size and density of the fruit.

"And this is where *POLY4* can help to achieve higher quality of coffee by providing low-chloride potassium as well as a balanced nutrition of soluble magnesium, sulphur and calcium.

"Coffee trees traditionally are fertilized three times a year with the standard local practice of 20:5:20 NPK blends. Kieserite is added to meet the crop's magnesium demand. Gypsum is also applied where soil aluminium levels are high or when a small amount of sulphur is required."

Cenicafé, a member of the Colombian Coffee Growers Federation, has assessed the performance of *POLY4* on coffee at two sites over four years, explains Furia:

"In these *POLY4* trials, standard N and P rates were applied and demand for K was met by mixing MOP with *POLY4*, consequently replacing up to 35 percent with low-chloride potassium and increasing Mg supply. The *POLY4* plan consistently increased yield across the four years of trials – by up to 14 percent on average – while also maintaining the coffee cup quality. In contrast, application of non-*POLY4* sources of S, MgO or CaO gave less yield."

These results are shown in Figure 8.

The acidic, weathered tropical soils common in Latin America frequently harbour toxic levels of aluminium, particularly at depth, says Furia:

"An additional benefit of *POLY4* fertilization is the detoxification effect of its $CaSO_4$ and $MgSO_4$ elements. These have the ability to counteract and improve resistance to aluminium toxicity, encouraging more expansive root growth deeper in the soil profile.

"The use of lower carbon footprint products like *POLY4* with its simple production process (mining + crushing + granulation with starch) is also valued by both the international coffee market and farmers. Low carbon footprint products improve quality certification scores making it easier to sell coffee at a higher price."

Combined, these characteristics make *POLY4* a highly-attractive, natural, multi-nutrient option for crop fertilization, Furia concludes, one that can greatly improve farmer economics. ■

About the author

Maya Rehill is the customer marketing manager at Anglo American Crop Nutrients.

PHOTO: PRAYON/PROFILE

The latest filtration technology

Vacuum filtration is a key process step in phosphoric acid production. We highlight the main equipment options and recent project installations.

Above: PROFILE's model 30-220 tilting pan filter with a total surface area of 220 m². Installed at OCP's Jorf Lasfar phosphates production complex in Morocco.

Thickening, clarification and filtration are integral to the phosphoric acid production process. In phosphoric acid plants, thickeners are used to concentrate phosphate rock slurry prior to the reactor stage, while vacuum filtration, in combination with clarifiers, removes gypsum from the phosphoric acid product (Figure 1).

Thickeners and filtration equipment are also used to dewater phosphate tailings (see separate article on page 55).

For new plants, selection of the phosphoric acid process is the primary design consideration, as is production output – with an industry trend towards constructing larger capacity phosphoric acid plants (1,000-1,500 t/d P_2O_5) since the early 2000s. Once the production process has been selected, and the scale of operation decided upon, the selection of suitable vacuum filtration equipment then becomes a vital technical and economic matter for any phosphoric acid plant[1].

Filtration options

Essentially, there are three options when it comes to selecting vacuum filtration equipment for phosphoric acid plants:

- Table filters
- Tilting pan filters
- Horizontal belt filters.

Although they vary in terms of capital outlay, operating/maintenance costs and performance characteristics, all three types of filter can produce phosphoric acid efficiently and economically (*Fertilizer International* 487, p43).

It can be tempting to select the lowest capital cost equipment. However, a range of other factors – such as filtration performance, equipment quality, installation cost, and ongoing operational and maintenance costs – also need to be considered when selecting filtration equipment[1].

Horizontal belt filters

Horizontal belt filters have become increasingly commonplace due to their operational flexibility, large throughput and ability to handle corrosive slurries. They have become a popular alternative to table filters and tilting pan filters in many industrial applications.

The horizontal belt filter combines a perforated rubber drainage belt, travelling continuously in a loop around two rollers, with an underlying longitudinal vacuum box (Figure 2). The top of this box forms a moving seal with the bottom of the belt. Slurry is fed onto a filter cloth overlying the drainage belt.

Most manufacturers offer a choice of belt materials including natural rubber, SBR (HT or LT), EPDM, Chlor-Butyl and Neoprene. Pneumatic systems for lowering and raising the vacuum box are also

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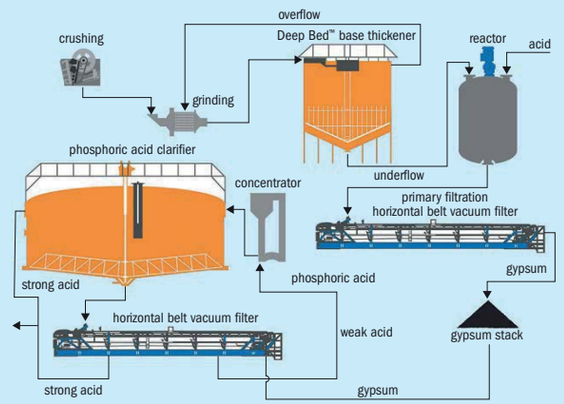
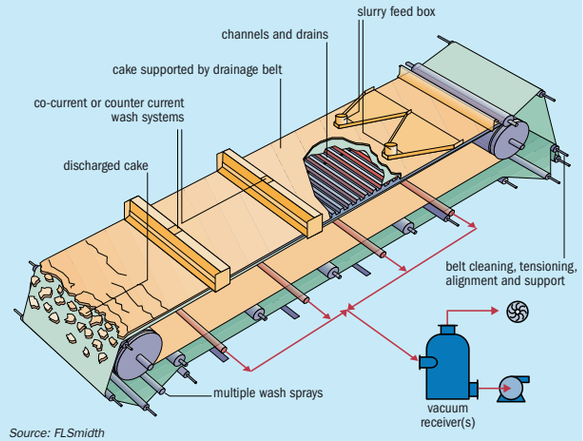
Fig. 1: **Thickening, clarification and filtration* in phosphoric acid production**



*Although horizontal belt filters are shown in this example, tilting pan filters and table filters are also widely used within the industry.

Source: WesTech

Fig. 2: **Schematic of FLSmidth's EIMCO® Extractor® horizontal belt filter**



Source: FLSmidth

commonplace, enabling fast and reliable maintenance and cleaning.

Filtrate is drawn down through the filter cloth under vacuum, entering channels holes in the drainage belt, and then flows into the vacuum box beneath. Spray nozzles or a flood weir box are used for filter cake washing. The filter cake eventually separates from the cloth surface at the far end of the filter as the belt moves downward over the discharge roller.

Horizontal belt filters are used to filter calcium sulphate from phosphoric acid (counter-current washing) and to dewater phosphate rock (co-current washing).

Notable manufacturers (*Fertilizer International* 487, p43) include:

- ANDRITZ
- TAKRAF/DELKOR
- FLSmidth/EIMCO
- Hasler/Filtres Philippe
- Gaudfrin
- Outotec/Larox
- WesTech.

DELKOR, part of TAKRAF Group, has been manufacturing horizontal belt filters (see photo) for more than 40 years, supplying more than 950 units globally over this period with a combined filtration area of 37,500 m². The solid/liquid separation company is also the supplier of the world's largest individual horizontal belt filter unit. DELKOR has often led the way in horizontal belt filter design and was the first manufacturer to introduce:

- Ripple curbing with superior vacuum sealing and longer life
- Wear strips and wear belts for vacuum sealing.

DELKOR recently installed a large horizontal belt filter (110 m² area) at a phosphoric acid plant on behalf of Coromandel International Limited, India's second largest phosphate producer. The filter was successfully commissioned at the company's Visakhapatnam plant in Andhra Pradesh in February 2020, ahead of schedule.

The belt filter was supplied to Coromandel as part of an engineering, procurement and construction (EPC) package. This covered the design, engineering, supply, construction and commissioning of the horizontal belt filter and ancillary equipment – including filtrate pumps, wash pumps, air blowers, valves and piping. This 'Industry 4.0' filtration system comes ready equipped for advanced control technology.

The highly corrosive nature of phosphoric acid means DELKOR needs to design and manufacture belt filters using corrosion resistant materials, such as stainless steel for the frames, vacuum boxes, feeders and air boxes, an EPDM rubber transporter belt and GRP (glass-reinforced plastic) for the fume hood.

Detailed planning and scheduling substantially reduced the on-site equipment erection time. This included a mock assembly of the major components of the belt filter and plant piping at DELKOR's India fabrication plant in Bangalore.

At the inauguration of 450 t/d expansion to the Visakhapatnam plant, Vinay Kumar Sandur, DELKOR's vice president, projects, said: "The safe and successful implementation of such a complex project

DELKOR horizontal vacuum belt filter.

PHOTO: DELKOR/TAKRAF

Fig. 3: **PROFILE tilting pan filter**

Source: Prayon/PROFILE

clearly demonstrates our horizontal belt filter capabilities. With this achievement, we continue to entrench ourselves as a leading global provider of dewatering equipment."

Tilting pan filters

Tilting pan filters consist of series of independent trapezoidal pans mounted on a rotating circular support structure (Figure 3). Pans are kept horizontal and under vacuum as they rotate during the filtration cycle. The cake is washed counter-currently during filtration, generally in three stages, with filtrates collected by separate vacuum receivers. The cake is eventually discharged dry at the end of the cycle. Following cake discharge, pans are tilted through 180 degrees and pass over radial manifolds fitted with high pressure jets which clean the cloth and dislodge any remaining cake.

Prayon, through its PROFILE equipment division, is a leading supplier of tilting pan filters to the phosphates industry. Around 250 of the 300 tilting pan filters sold by Prayon since the 1950s have been installed in phosphoric acid production plants worldwide.

According to Prayon the main benefits of tilting pan filter include:

- High level of reliability due to their robust design, with some 1960s filters still in operation
- On-stream factor of over 95 percent
- Excellent capacity/extraction yield ratio, due to batch filtration and a high maximum vacuum level
- Energy efficiency
- Cake discharged contains very little free water
- Prayon's proven track record with very large filters, e.g. the PROFILE *30-240* filter with a surface area of 275 m².

Prayon has improved its tilting pan filter design over the years. The main developments are:

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- A special compact vacuum box for separating gases and filtrates
- A fast-drain filtration cell (pan) to increase filter capacity and filtration yield
- An automatic system to keep the pans horizontal
- A new tilting-track design for higher rotation speed and filtration capacity
- Support rollers designed for heavy loads
- A robust rotating frame with a replaceable wear plate
- A new waterproof cloth-fixing system for quick cloth replacement
- A high filter surface-to-base-area ratio.
- Stainless steel rotating frame with replaceable wear plates
- Fibre-reinforced plastic (FRP) hood and side protective barriers

Paul-Henri Legros, the general manager of Prayon's PROFILE division, explains the company's approach and ambitions:

"PROFILE wants to remain the showroom for excellency in performance and engineering in P_2O_5 filtration, so we decided to refocus our resources on the Prayon tilting pan filter. The actual production trend in the market is for large capacity (surface area) filters – and we clearly keep the edge with our tilting pan filter, in comparison with the belt filter where the available surface is limited by mechanical contingencies."

Demand for large capacity filtration equipment in the phosphates industry, says Paul-Henri, is being driven by two main factors:

- The ability to increase production throughput provides a quicker return on capex
- As the quality of available phosphate rock decreases, larger volumes need to be handled and treated to achieve comfortable investment returns.

"We continue improving every aspect of our equipment, and are also developing and investing for the future," comments Legros. "We are currently designing and engineering a new filter model with 36 filtration cells, for example, and are also optimising the design of tilting pan filters by carrying out studies on the flow of liquids within filtration cells in collaboration with the University of Liege."

He continues: "One of Prayon's main objective is sustainability and modifying our impacts on nature – a subject which will guide my team and myself in upcoming years. To deliver on this, the questions are: how can we spare expensive raw materials, how can we save on spare parts, how can we decrease the movement of goods and people worldwide?"

PROFILE has secured a number of major phosphate industry equipment contracts in recent years. These include a large-scale project with OCP Group for its Jorf Lasfar production complex in Morocco. This involved the supply of:

- Eight *30-220* model tilting pan filters (four lines at 1,500 t/d P_2O_5) for the ODI project
- Eight *30-220* model tilting pan filters (four lines at 1,500 t/d P_2O_5) replacing the eight existing table filters at MP3 and MP4
- Four *30-220* model tilting pan filters (two lines at 1,500 t/d P_2O_5) for Line E and Line F at MP3 and MP4.

As part of this project, PROFILE manufactured 18 filters between mid-2011 and end-2014, then shipped four filters every six months from mid-2012 to end-2014. These were then erected ready for start-up of the different production lines between 2013 and 2018.

> **"No single type of vacuum filter can outperform all others in every application. Table, tilting pan and horizontal belt filters all have strengths and weaknesses.**

The last two filters were manufactured in 2018 and shipped in 2019. Their erection has been finalised although start-up is currently on hold.

PROFILE successfully overcame multiple challenges to deliver this large-scale filtration project for OCP, as Paul-Henri Legros makes clear:

"The replacement, in the same footprint, of table filters by tilting pan filters without major modification of the civil work of the building is an engineering challenge. There's also the procurement and organisational challenge of following up manufacture with on-site erection in parallel.

"Finally, the logistical challenge was the supply and storage of more than 800 boxes of equipment with a combined volume of 12,500 metres cubed and weighing 3,200 tonnes. To repeat a famous slogan: yes we can and yes we did!"

Table filters

Table filters, also known as horizontal pan filters, are designed for continuous vacuum filtration of relatively coarse, granular, fast-settling solids. Their main applications include the filtration washing of slurries in bauxite and phosphate processing.

Table filters consist of a circular filtration surface rotating in a horizontal plane. The filtration surface is excellent for both cake washing and drying. After moisture has been reduced by an applied vacuum, the cake is removed by a wear-resistant cake discharge scroll.

Originally developed in the early 1960's, the *UCEGO*® filter marketed by Technip is specifically designed to filter phosphogypsum slurry generated by the dihydrate (DH) and hemihydrate (HH) production processes. The filter has been adopted throughout the global phosphates industry with worldwide sales to some 28 countries. More than 90 *UCEGO*® filter units have been installed in plants responsible for over 35 percent of the world's phosphoric acid production.

The *UCEGO*® filter is also suitable for retrofits at existing plants. Its compactness and high per-unit-area filtration capacity helps to optimise throughput for a given space. According to Technip, replacing certain types of tilting pan filter with an *UCEGO*® filter can increase filtration area by up to 100 percent for the same construction footprint. Such retrofits only require a short shutdown and the installations costs are minimal, suggests Technip.

Summary

No single type of vacuum filter can outperform other types in every application. All three kinds – table filters, tilting pan filters and horizontal belt filters – have their own strengths and weaknesses (*Fertilizer International* 487, p47). Instead, vacuum filtration equipment needs to be selected according to individual plant needs using the best engineering solution available, while aiming for the lowest lifecycle cost[1]. The main considerations when choosing equipment are:

- Equipment quality
- Service quality
- Spare parts availability
- Expected equipment life
- Capital, installation, operating and maintenance costs. ■

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Tailings filtration: Looking upstream to optimise the filter

Filters can be a common bottleneck in overall plant operations. **Jerold Johnson** and **Brad Bentley** of WesTech outline how upstream modernisation or upgrades to the thickener can have significant benefits for the efficiency of filter operations downstream. Results are applicable to the dewatering of phosphate tailings and other fine particle tailings.

Filters are increasingly being used for the final dewatering of tailings. The dual benefits of water recovery and lower impoundment risks are making filtration equipment a more attractive option. Technology improvements, particularly larger filter sizes and higher pressure gradients, also means filters are becoming practical for dewatering phosphate tailings and other fine particle tailings.

There is a need to look at tailings dewatering operations as a whole, as improvements made upstream may have negative consequence downstream by changing the volume and characteristics of the tailings being produced. Increased tonnes-per-hour throughput, or even finer particle-size distribution, will adversely affect the filter.

WesTech high-density thickener (HDT).

PHOTO:WESTECH

Looking upstream for downstream benefits

Equipment upgrades and operational improvements can achieve several goals – identifying common bottlenecks in the dewatering stages being one of these. Typically though, optimising one bottleneck simply reveals the next one. While the filter stage can often appear to be a bottleneck, upstream thickeners – which affect the downstream filter – often provide greater scope and flexibility for optimisation.

Installed filters, once they reach capacity, can certainly limit overall plant optimisation. In these circumstances, turning attention upstream of the filters can yield significant benefits.

Filter sizing and capacity are based on dry solids throughputs (ex. kg*m²/h). When optimising filters, however, attention should turn to the water volume in the feed. Indeed, models that predict filtration operations and filter rates show there is a clear potential for reducing filtrate volume[1].

For installed systems, the filtrate's volumetric flow rate is a set parameter – for a given pressure differential and cake thickness. Consequently, reducing the water volume in the filter feed provides a direct reduction in the time taken for the filter cake to form. This reduction is beneficial to the design of greenfield plants as well as helping optimise existing operations.

It is the thickener upstream that dictates the hydraulic load on the filters. Therefore, improving control strategies, modernising the feedwell, and installing paste-type thickeners can all improve water recovery at the thickener – and ultimately benefit filters downstream.

Thickener modernisation

Thickener optimisation has been a focus at WesTech for many years. This has resulted in significant advances in feedwell design and bed level detection for thickener control.

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Experience has shown that running the thickener with a constant solids inventory results in a predictable, steady-state operation. Allowing the bed level to rise and fall, in contrast, reduces water recovery by causing swings in the weight-percent discharge.

Underflow variations of just two percentage points, for example, could send eight percent water, or more, to the filter. Nevertheless, poor bed level detection methods in the industry have often limited the success of thickener control, forcing many plants to rely on manual control. Unfortunately, manual control is notorious for inconsistent operation.

WesTech recently introduced the *MudMax*™ – an instrument that directly measures the thickener bed level – to address this specific issue. The instrument's sensor is mounted on the rake arms of the thickener, turning in sync with the mechanism[2]. This instrument, by providing steady, accurate, continuous measurements, allows much greater thickener control. The target bed level is maintained using discharge pump speed as a control. This steady bed level gives confidence that operations are being optimised close to the thickener limits. Without swings in operation, the operational target for the thickener can be set much less conservatively. Instead, the thickener can be operated at deeper bed levels, resulting in greater weight percentage solids underflow. The thickener can also be confidently operated closer to torque alarms, with dewatering at an even greater dry tonnes per hour (tph) throughput as a result of this optimisation.

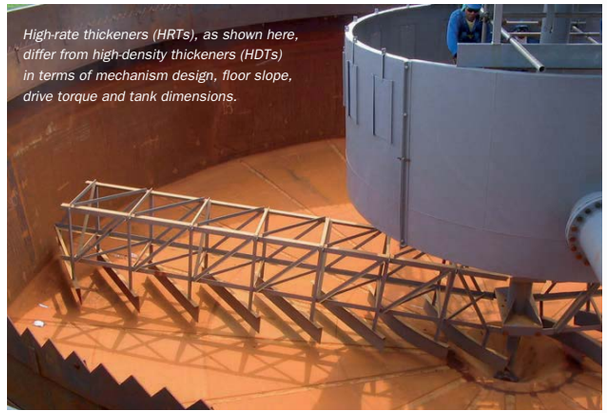
The heart of the thickener is the feedwell[3]. Indeed, many of the poor thickener performance issues start here.

Yet conventional feedwells suffer from two glaring design flaws: short circuiting flows and poor mixing. That is generally because feed momentum is poorly managed in tangentially-fed feedwell designs. Consequently, large short-circuiting flows develop, prematurely exiting the feedwell and carrying with them poorly flocculated solids. This results in solids in the overflow and can produce uneven loading in the bed.

Feed momentum is still needed, however, as it is the source of energy for mixing in the feedwell. Most feedwell designs have a relatively small area where the mixing is optimum. This is often near the inlet, leaving the rest of the feedwell volume insufficiently mixed. This leaves the operator with only one recourse – increasing the flocculant dosage to try and compensate for these design flaws. The resulting overdosage in the thickener can be counterproductive as underflow density is reduced because the excess flocculant inhibits solids compaction[4].

Flocculation within the thickener must balance three objectives: clarity, settling rate, and the ability to compact. Proper flocculation also relies on dosage and mixing working well together. Any improvement in mixing, for example, reduces the dosage requirement.

WesTech introduced the *EvenFlo*® feedwell to address common feedwell issues. This feedwell design incorporates two stages. The first stage receives the feed stream, manages feed momentum and then directs the feed radially out into the second stage. This radial flow prevents short-circuiting and distributes solids evenly into the thickener. It also creates an optimal mixing zone around the entire periphery of the second stage feedwell. In summary, this simple design eliminates short circuiting and greatly improves the mixing needed for flocculation. The improved mixing significantly reduces dosage, improving operating costs and increasing the weight percent solids in the underflow.



High-rate thickeners (HRTs), as shown here, differ from high-density thickeners (HDTs) in terms of mechanism design, floor slope, drive torque and tank dimensions.

PHOTO: WESTECH

Table 1: **Fine tailings: filter cake form times from vacuum filter bench-scale leaf tests at two different feed concentrations. Results show that form times are reduced by lowering the water content of the feed.**

Filter feed type	Feed (wt%)	Vacuum form time (mins)
Red mud	27-30	1.25
	39-40	0.75
Iron ore slimes	44-45	7.60
	54-55	5.10
Coal fuel	46-47	3.00
	56-57	1.50

Source: WesTech

Thickener types

Not all thickeners are created equal either. Some designs produce a slurry underflow, such as high-rate thickeners (HRTs). Other designs produce non-Newtonian (significant yield stress) underflow, like the high-density paste-type thickeners (HDTs). Both thickener designs are commonly used in combination with filters. Recently, however, the HDT type has emerged as the thickener of choice.

HDTs differ from HRTs in terms of mechanism design, floor slope, drive torque, and tank dimensions (see photos). HDTs, with their low-profile mechanism with dewatering pickets and high torque drives, are designed to produce and discharge the non-Newtonian underflow. Advantageously, the HDT will produce a greater weight percent solids underflow, yielding a 15 percentage points increase or higher.

Differences in the weight percent solids obtained by a HRT and a HDT can be compared in case studies where these two thickeners dewater the same material as part of a two-stage thickening process. Full-scale installations initially use HRT to dewater plant tailings. This saves on pumping costs due to the smaller volume of HRT underflow obtained, relative to the total tailings volume. The HRT underflow is next pumped, sometimes over long distances, to a HDT located at the tailings storage facility. The HDT then completes the final dewatering needed to enable the tailings to be surface stacked.

The two thickeners dewater the same solids and, in both cases, the slurry must be diluted to optimal feed concentration with the solids then flocculated. Data from mine sites reveal that the HDT recovers more water, producing an underflow with 40 percent less water present, compared to the HRT underflow.

HDTs also meet a key requirement for the filter feed, i.e. it is fluid enough to fill the filter chamber or spread easily over the filter cloth. Valuably, HDTs are designed to produce a low yield stress underflow that is still fluid and easily fills the filter chambers or spreads on the cloth.

Benefit of reduced water in the feed

Reducing the water content of the feed shortens the filter cake form time in the filtration cycle. Table 1 demonstrates the benefits of this for phosphate and other fine particle tailings. It provides a comparison between weight percent solids in the filter feed of red mud, iron ore slimes and coal fuel tailings. These are all known for their fine particle-size distributions. For each type of tailing, the form times from vacuum filter bench-scale leaf tests are shown for two different feed concentrations. Results demonstrate that form time was reduced due to a higher solids weight percentage of about 10-percentage points By reducing the water in the feed, the form time was in fact reduced by around 36-50 percent.

Filters can be a common bottleneck in the overall plant operation. The form time in the filter cycle is particularly dependent on the volume of water that needs to be removed. A cost-effective way to optimise the filter, therefore, is to optimise the thickener preparing the filter feed. Consequently, modernising or upgrading the thickener, as described in this article, can have significant benefits on the filter operation. This applies to the dewatering of phosphate tailings and other fine particle tailings. ■

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Phosphogypsum in a circular economy

Philippe Malsan of Technip Energies explains how high recovery *Diplo* phosphoric acid technology can generate phosphogypsum suitable for industrial reuse. Industrial cases studies for Senegal and Austria show how phosphogypsum from this process has been successfully recycled on a large scale for cement, plaster and other end uses.

Until recently, phosphogypsum (PG) produced from the wet phosphoric acid process, was mostly managed as a waste, stacked on land or rejected into the environment. Industrial practice is, however, evolving fast.

A recently published study by the International Fertilizer Association (IFA) reveals that up to 25 percent of phosphogypsum produced annually is now reused for a range of applications, such as mine restoration, agriculture, plaster and cement manufacture[1].

While other usage estimates are less optimistic, there remains a clear upward trend with more PG recycling over the last decade. This trend is expected to continue in the 2020s, along with new regulations and industrial technologies promoting more sustainable resource use.

While phosphogypsum for construction – in plaster, cement and other building materials – is one of the main reuse options, this market imposes strict limits on certain contaminants such as phosphorus (P_2O_5), fluorine and radionuclides. That places additional constraints on phosphoric acid producers looking to reuse PG.

In the future, such quality considerations may favour phosphoric acid production technologies offering high P_2O_5 recovery from phosphate rock. These technologies could help reduce the residual P_2O_5 content of PG, and levels of other unwanted contaminants, so avoiding or minimising the need the need for purification treatment prior to reuse.

This article highlights Technip Energies' high recovery di-hydrate (DH) technology – particularly its ability to generate high quality PG suitable for industrial reuse. This is illustrated by industrial cases studies for Senegal and Austria. These show how PG from this DH process has been successfully recycled commercially on a large scale for cement, plaster and other end uses.

Processing phosphate rock

There are several options for producing phosphoric acid from phosphate rock via the wet process route. Differences between these process options are mainly determined by calcium sulphate (gypsum) crystallisation conditions. Generally, gypsum is either precipitated in di-hydrate (DH) or hemihydrate (HH) form, or as a combination of both in successive steps. Crystallisation is a particularly important parameter when selecting a process technology that generates 'clean' gypsum as the desired by-product.

Standard single step DH process

The single-step DH process is widely used to produce phosphoric acid. The phosphate rock is treated with sulphuric acid to precipitate calcium sulphate as DH in one step in a reactor under agitation. A large recycling flow is achieved by agitation and/or by external circulation associated with a flash cooling system.

The single-step DH process is a long-standing and mature industrial-scale technology that has been implemented since the 1950s. This process is by far the most flexible, compared to other phosphoric acid production routes, especially in terms of tolerance to phosphate rock impurities. Because of this, the DH process can handle a wide range of phosphate rock types. Its flexibility, together with low capex and high operability, are probably the main reasons why a large majority of the world's phosphoric acid plants utilise the DH route.

It is generally accepted that the standard DH process achieves recovery yields of approximately 95-96 percent – this corresponding to typical reaction yields of 96-97 percent P_2O_5. If left untreated, with no removal of soluble impurities, this leaves approximately 0.8-1.1 percent residual P_2O_5 remaining in the gypsum, unfortunately exceeding the quality standards for plaster or cement production.

The hemihydrate (HH) process

The single-step HH process has been successfully implemented in different countries around the world as an alternative to the DH route. The HH route presents several advantages, such as the production of higher strength acid (39-42 percent) containing less impurities. But the process does have a lower P_2O_5 recovery (typically around 92 percent) compared to the DH route.

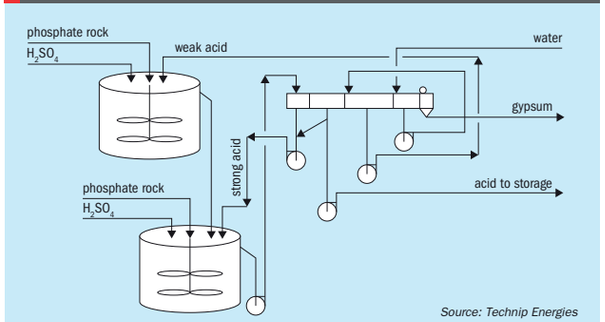
The PG produced from the HH route also contains more P_2O_5 and more impurities, compared to PG produced via the DH route. The fact that HH gypsum reverts to the DH form, at a certain point post-production, is another constraint limiting the purification of PG. For these reasons, the HH route is generally not an option when there is a need to recover phosphogypsum for industrial applications.

Recrystallisation processes: DH-HH and HDH

Those technologies based on recrystallisation – either Hemihydrate to Di-Hydrate (HDH) or Dihydrate to Hemihydrate (DHH) – offer the highest P_2O_5 recovery. This is due to the liberation of the co-crystallised P_2O_5 during recrystallisation. These processes can also produce acid at higher strength compared to DH.

These advantages are offset by other factors, particularly the lack of flexibility of recrystallisation processes towards impurities. Because of this, their performance can depend strongly on the nature of the phosphate rock used as a raw material. Plants based on recrystallisation processes, being more complex and requiring more equipment, have lower plant availability, higher capex and higher maintenance costs, compared to DH plants. Neither do recrystallisation processes provide significant advantages in terms of contaminant levels in phosphogypsum (fluorine, sodium, organic matter etc.). This makes additional treatment of PG necessary before further use.

Fig. 1: **Simplified flowsheet for Technip Energies' high recovery two-step *Diplo* phosphoric acid production process**



Source: Technip Energies

The two-stage *Diplo* process

In the 1980s and 1990s, a new approach to the DH method was developed by the French company Rhône Poulenc, the phosphoric acid technology predecessor to Technip Energies. The main purpose of this evolution in DH technology was twofold: firstly, to obtain higher P_2O_5 yields and, secondly, to increase the concentration of the dilute acid produced at filtration.

This new approach successfully generated both higher P_2O_5 yields and acid concentration, while keeping the original operational advantages of the DH route. This was of particular interest to producers in Europe who were sourcing from the merchant rock market and facing strong economic pressure to reduce their operating costs.

In the *Diplo* process, phosphate rock is digested using two reactors in series, with each reactor being fed phosphate rock, sulphuric acid and recycled phosphoric acid in set proportions (Figure 1). The conditions of the reaction – including temperature, P_2O_5 concentration, and concentration of free sulphate in the acid – are optimised at each stage. In doing so, the *Diplo* process allows overall process performance to be optimised, according to the requirements of the producer, while still retaining most of the advantages of the traditional DH process.

As already stated, higher acid concentration and higher P_2O_5 recovery can be obtained through this process, compared to the usual DH approach. These performance advantages depend on the nature of the phosphate rock:

- Enhanced P_2O_5 recovery occurs with reactive sedimentary rocks.
- Higher concentrations of phosphoric acid, exceeding 35 percent P_2O_5, can be produced from some phosphate rocks such as Togo or Taiba.

Another advantage of the *Diplo* process is the high stability offered by its optimal two-stage reaction/filtration treatment step. This reaction-filtration system offers higher performance stability relative to the traditional DH system.

Diplo process for high P_2O_5 recovery

When targeting high P_2O_5 yields, 70-90 percent of the phosphate rock is reacted in the first reactor. The first reactor is operated at lower P_2O_5 concentration, higher temperature and with higher excess sulphuric acid. Combined, these conditions tend to reduce co-crystallised losses in gypsum. The remaining phosphate rock is reacted in the second reactor, increasing the P_2O_5 concentration of the acid. Excess sulphuric acid in the second reactor slurry is typically regulated close to 25-28g/l. This limits unreacted P_2O_5 losses and avoid excess sulphate in the phosphoric acid produced.

Impact of PG impurities on plaster and cement production

Residual contaminants present in phosphogypsum obtained after filtration can be detrimental to PG reuse and may have to be removed or reduced below certain limits (Table 1).

Impact of the phosphate rock

The phosphate rock used in phosphoric acid production is the main source of residual impurities present in the phosphogypsum generated. For this reason, the composition and purity of phosphate rock raw materials have an important impact on the quality of the phosphogypsum.

Igneous phosphate rock types, such as apatite ore from Kola, Russia, and Phalaborwa, South Africa, and calcined rock have lower impurity levels and organic content compared to sedimentary rocks. The phosphogypsum produced from these rock types, depending on the phosphoric acid production technology used, can be sufficiently pure to avoid further treatment, or only require simple washing of the re-pulped gypsum to reach the required purity. However, these phosphate rock types only represent 15-20 percent of overall world production and are generally more expensive compared to sedimentary phosphates.

Sedimentary phosphate rocks, in contrast, generally contain higher levels of mineral and organic impurities relative to their igneous counterparts. Consequently, when sedimentary rocks are consumed as raw materials for phosphoric acid – as is the case in most plants globally – the amounts of impurities remaining in the phosphogypsum are correspondingly higher, and a purification step is therefore generally necessary.

Regardless of the technology used for phosphoric acid production, some contaminants, such as soluble impurities and organics, will still affect the quality of phosphogypsum and therefore need to be removed prior to reuse.

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Table 1: **Impacts of phosphogypsum impurities on plaster and cement quality**

Type of impurities	Contaminant	Impact on product quality	Action required
Plaster and wallboard			
Water soluble acidic impurities	Water soluble P_2O_5, water soluble fluorine, sodium, potassium	Unwanted acidity, blistering	Need to be removed or neutralised
Potentially acidic compounds	Precipitated F, Al, SiO_2, Na_2SiF_6, K_2SiF_6, Co-crystallised P_2O_5	Unwanted acidity, blistering	Must be controlled and reduced to acceptable levels
Radioactive elements	Radium, thorium	Generate radioactivity	May need to be controlled and reduced to acceptable levels, depending on regulations and recommendations
Organics		Result in unwanted coloration at the surface of wallboard due to diffusion of water-soluble organics during painting	Need to be controlled and reduced. Water-soluble organics need to be removed
Inerts	Silica, unreacted P_2O_5	Coarse particles affect the quality of final product in those applications requiring fine and homogeneous products	Coarse particles need to be removed for some applications
Others (iron, other metals)		Might lead to unwanted coloration of the product	Needs to be controlled
Cement additives			
Soluble P_2O_5	Water soluble P_2O_5 and co-crystallised P_2O_5	May affect settling time and mechanical resistance of the product	Need to be controlled and neutralised. Water soluble P_2O_5 + co-crystallised P_2O_5 <0.5%
Soluble fluorine			Needs to be controlled and neutralised. Water-soluble F <0.1%

Source: Technip Energies

Case study: reuse of PG for cement in Senegal

Industries Chimiques du Senegal (ICS) is the largest producer of phosphate fertilizer products in sub-Saharan Africa and the third largest producer on the continent. The company began mining phosphate rock in 1960 and later started producing phosphoric acid in 1984.

Following the acquisition of ICS by Indorama in 2014, a rehabilitation programme has improved phosphoric acid output with levels expected to recover to 600,000 t/a P_2O_5. ICS Indorama currently operates two phosphoric acid trains – Darou 1 and Darou 2 – both based on Technip Energies' technology.

Darou 2, the second train, was started in 2002 with a nameplate production capacity of 1,200 t/d (reaction-filtration), and a nominal capacity for 53 percent phosphoric acid of 1,015 t/d. This unit, which is based on Technip Energies' two-stage *Diplo* technology, is designed to consume a blend of Taiba rock phosphate concentrate and slimes. This allows Darou 2 to achieve a reaction yield of 97.7-98 percent P_2O_5 recovery. The corresponding 2-2.3 percent P_2O_5 reaction losses represent insoluble P_2O_5, this consisting of a 50:50 mixture of unreacted P_2O_5 and co-crystallized P_2O_5 locked in the gypsum. The total insoluble P_2O_5 remaining in the gypsum is below 0.5 percent.

At ICS Indorama, the PG produced by the phosphoric acid plant is discharged dry and stacked, where it is then exposed to the prevailing weather including both rain and sun. Under these repeated wetting and drying conditions, a decrease in mainly soluble P_2O_5 and fluorine occurs. The residual humidity – an important factor for the economics of phosphogypsum reuse – is also reduced below ten percent free water due to natural drying.

Aged phosphogypsum is reclaimed and directly used as an additive for clinker production without further treatment. An analysis of ICS phosphogypsum sampled from various depth in the stack is provided in Table 2.

ICS Indorama is exploring other potential markets for phosphogypsum, including use as an agricultural soil amendment and use in the remediation of saline soils. The company has developed a new phosphogypsum formulation for soil amendment purposes. This granulated product functions as a calcium source, and contains residual P_2O_5 and useful secondary elements such as magnesium and sulphur, all of which contribute to soil fertilization.

This use of phosphogypsum as a constituent in roadbed construction is another potential application being targeted by ICS Indorama. As a result of these efforts, industrial and agricultural sales of phosphogypsum have increased substantially in recent years, generating additional revenues for the company.

Historic case study: reuse of PG for plaster production in Austria

Donau Chemie was a major European phosphoric acid producer in the 1980s and 1990s. The Austrian company combined production of phosphoric acid for fertilizer production with the manufacture of plaster from phosphogypsum. The latter was sold into the local European market as wallboard and other high-quality products.

Donau Chemie converted its phosphoric acid plant to the high recovery two-stage *Diplo* DH process in 1987. This sourced sedimentary phosphate rock as a raw material from various countries such as Algeria, Jordan, Syria and Israel. The converted *Diplo* plant achieved its expected performance levels, with a reaction yield slightly above 97.7 percent P_2O_5, as well as generating phosphogypsum suitable for plaster production.

The phosphogypsum underwent a treatment process prior to plaster production. This involved repulping PG from the phosphoric acid filter, energetic washing and screening, and two- or three-stage hydrocyclone separation, before being filtered in a final dewatering step (Figure 2).

This treatment process separates off soluble impurities, impurities such as organics absorbed at the surface of crystals, and insoluble impurities that concentrate in the coarse and fine fractions. The treatment also successfully reduced the radioactivity of the final gypsum product, enabling it to meet the Austrian standard for building materials.

This simple and robust treatment process was successfully operated in-line with the phosphoric acid plant. This enabled Donau Chemie to send the purified gypsum by-product obtained directly to the plaster plant for calcination.

Table 3 compares the performance of two different phosphogypsum treatment processes: a simple filtration process with counter-current washing versus hydrocyclone size separation plus filtration.

Table 2: **Average composition of phosphogypsum sampled from old parts of the stack, ICS Indorama, Senegal**

	Weight %*
H_2O	21-25
P_2O_5 Total	<0.6
P_2O_5 water soluble	<0.1
P_2O_5 water un-soluble	<0.5
P_2O_5 co-crystallised	0.29-0.40
P_2O_5 unreacted	0.16-0.36
SiO_2	6-14.5
Fe_2O_3	0.10-0.35
Al_2O_3	0.1-0.55
FeO	0.20-0.90
CaO	37.5-38
SO_3	31.5- 52
Organic C	0.45-0.56
CO_2	0.00
Fluorine	0.12-0.4

**Dry basis (120°C)* *Source: ICS Indorama*

Conclusions

In a circular economy, where greater reuse of phosphogypsum will be expected, phosphoric acid production via the DH process offers the most promise. This process route is adaptable to most commercially-extracted phosphate rock types globally, whether low- or high-grade, being more tolerant to raw material impurities.

While the HDH and DHH recrystallisation processes deliver high rates of P_2O_5 recovery, they have several drawbacks compared to DH. They are less accepting of variations in phosphate rock quality, especially more impure lower-grade rock. Higher capex, increased maintenance costs and lower plant availability also tend to offset their other advantages.

When using sedimentary phosphate rock as a raw material – and independent of whether a HDH, DHH or DH process is used – a phosphogypsum purification step is generally recommended to ensure product quality reaches an acceptable standard.

The high recovery, two-step *Diplo* process from Technip Energies combines significant P_2O_5 recovery with the typical advantages of the DH route, such as the flexibility to accept different sedimentary phosphate rock types. Depending on the phosphate rock source, the process can solubilise around 97.5-98.5 percent of the P_2O_5 during the reaction step. The *Diplo* process can also be easily combined with a simple phosphogypsum purification process, avoiding the need to consume costly high-quality phosphate rock. Other benefits include: process simplicity, ease of operation, low maintenance cost, high plant availability and low capex.

Currently, most phosphoric acid plants globally operate the DH process due to its advantages over other production routes. Looking ahead, the DH route is expected to remain the first option for most phosphoric acid producers in future, at least in the medium term. In this scenario, robust production processes, such as high recovery *Diplo* technology from Technip Energies, will be required to meet the challenge of greater phosphogypsum recycling and reuse. ■

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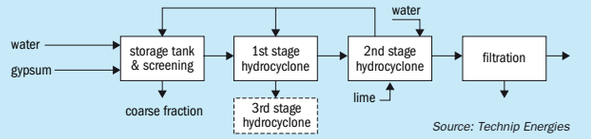
Fig. 2: **The Donau Chemie multi-stage phosphogypsum treatment process: washing, screening, hydrocyclone separation and filtration**



Source: Technip Energies

Table 3: **A comparison of two phosphogypsum treatment processes**

Purification process for removal of impurities from phosphogypsum	Filtration process	Hydro sizing and filtration process
Gypsum yield	97%	70-90%
Extraction of soluble acidic impurities	80-90%	95%
Extraction of potentially acidic impurities in solid form	No or very limited effect	Partial
Radioactive elements (thorium/radium)	No or very limited effect	Partial
Organics	No or very limited effect	Satisfactory
Inerts:		
Unreacted P_2O_5	No or very limited effect	Satisfactory
Silica	No or very limited effect	Partial
Others (iron, etc.)	No or very limited effect	Partial

Source: Technip Energies

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