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MAY-JUNE 2017

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Divestment risks

> **Societal acceptance of the energy system, as we have it, is just disappearing.**

The fertilizer industry is closely aligned with the oil and gas sector. The supply of two of the industry's essential and fundamental raw materials, ammonia and sulphur, is largely reliant on natural gas feedstocks and the refining of sour gas and heavy crude. Nitrogen fertilizer production in China is equally dependent on coal, another fossil fuel.

The recent hardening in public attitudes towards oil and gas production should therefore be a cause for concern. Divestment campaigners are urging large investors, pension funds and charitable trusts to rid themselves of fossil fuel assets. These campaigns conflate and equate oil and gas production with coal mining. The climate policies of oil and gas companies are also coming under shareholder pressure.

Worryingly, the raft of negative publicity seems to be having an effect.

In March, Royal Dutch Shell announced an $8.5 billion sell-off of its *in-situ* and undeveloped oil sands interests in Canada. It also reduced its share in the Athabasca Oil Sands Project (AOSP) from 60 percent to 10 percent. The oil and gas giant will however remain the operator of AOSP's Scotford upgrader and the Quest carbon capture and storage (CCS) project in Canada. These are located next to the Shell-owned Scotford refinery and chemicals complex.

Shell has exited oil sands in Canada for largely strategic reasons. The move is part of a larger $30 billion assets sale that will allow the company to concentrate on areas where it has global scale and a competitive advantage, such as integrated gas.

But negative public perceptions of oil and gas companies are clearly worrying Shell. And, as the world's second largest public oil company, Shell's behaviour and actions do carry weight.

A warning from Shell's chief executive, Ben van Beurden, in March that the oil and gas industry risked losing public support was therefore highly significant. van Beurden argued for more rapid progress on the transition to a low-carbon energy system globally. He also committed Shell to ramping up its annual investment in renewable energy to $1 billion by the end of the decade.

"If we're not very careful, with all the good intentions and advocacy that we have, we may, as a sector and society, not make the progress [on clean energy] that is needed," van Beurden said in Houston on 9 March.

van Beurden also singled-out public acceptance of the energy industry as the biggest challenge faced by Shell: "I do think trust has been eroded to the point that it is becoming a serious issue for our long term future. If we are not careful, broader public support for the sector will wane."

He added: "This is the biggest challenge we have at the moment as a company... The fact that societal acceptance of the energy system as we have it is just disappearing."

To help counter these perceptions, Shell announced in March that its directors will in future be partly rewarded on how well the company is managing its greenhouse gas emissions. One irony for Shell is the fact that, as a company, it has been a vocal advocate of a carbon tax. Shell has also led sector investment in developing new supplies of natural gas, the cleanest-burning fossil fuel.

Why should any of this worry the fertilizer industry? Well, one cause for concern is that divestment campaigns are creating a widespread public perception that the oil and gas sector is a fuel-producing and carbon-polluting dinosaur. This completely ignores the indispensable downstream petrochemicals sector which produces the ubiquitous plastics found in household goods, consumer electronics and vehicles. It also completely fails to acknowledge the central and global importance of natural gas as a feedstock in nitrogen fertilizer production.

The oil and gas sector does not deserve to become a climate change pariah. Viewing oil and gas as no more than fuels, and conflating their production with coal, is deeply unhelpful. For one thing, oil and gas sector expertise will be an essential part of making CCS a success in future.

The fertilizer industry clearly needs to be more vocal about how it helps feed the world. That is self-evidently in its own interest. Valuably, speaking out about fertilizers could also help change hearts and minds about the wider merits and value to society of natural gas. ■

S. Inglesfield

IFA CONVENES IN MARRAKECH

The 85th International Fertilizer Association (IFA) Annual Conference is being held at the Palais des Congrès Convention Center, Marrakech, Morocco, 22-24 May. As in previous years, BCInsight will be attending and exhibiting at what is the industry's leading showcase event. If you're attending, please do visit our stand and say hello. We are very much look forwarding to being in the beautiful city of Marrakech this May, and having the opportunity to meet with friends and colleagues, both old and new.

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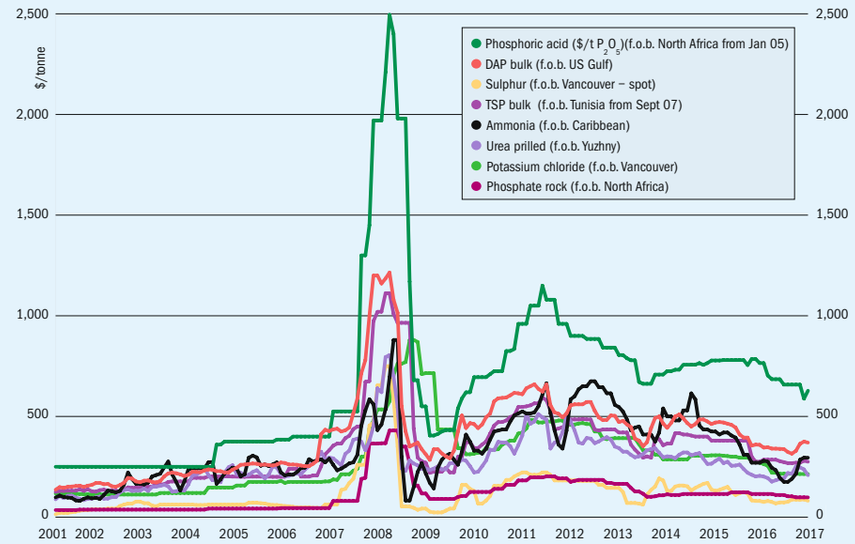
Market outlook

Historical price trends $/tonne



Source: BCInsight

Market insight courtesy of Integer Research

AMMONIA

Ammonia prices have strengthened strongly. The Yuzhny benchmark increased to a 13-month high of $315/t f.o.b. in March – up from a low of $167/t f.o.b. last October – due to supply restrictions out of the Black Sea. Adding to positive market sentiment, strong US seasonal demand for ammonia prompted a price surge across all major benchmarks. Upward price pressures have now moderated, however, significantly slowing this bull run. Trinidadian producers continue to suffer from gas curtailments, although these have eased back to a 10-15% production loss.

UREA

The global market is under pressure heading into the second quarter. The Yuzhny urea price dropped back to $234/t f.o.b. in March, after reaching a 15-month high of $253/t f.o.b. in February. Chinese urea producers accepted lower price offers under the Indian IPL market tender in March, due to weak Indian demand and ample Chinese export availability. Inventory levels at Chinese ports also continue to build, despite lower production rates. Seasonal demand in Europe, Brazil and the US has been thin, adding to price weakness in the market.

PHOSPHATES

After bottoming last year, finished phosphates prices rebounded in the first quarter, supported by a spike in global ammonia prices. Major DAP benchmarks increased by $30-60/t to average $373-383/t f.o.b. by the end of March. In India, the Nutrient Based Subsidy (NBS) for phosphate fertilizers was cut from $204/t to $185/t in April. Indian DAP imports have also been soft due to high inventories and a buying preference for domestic DAP. The $30/t rise in the Indian DAP benchmark between January and March was supported by increased production costs and higher ammonia prices. In China, low average operating rates (45-55%) and a focus on the domestic market has limited export availability and supported prices.

POTASH

Prices have been depressed but mainly stable during the first quarter. By March, the Vancouver MOP benchmark was down 15% year-on-year to $225/t f.o.b., its lowest level since the end of 2007. Other benchmarks for Israel/Jordan, Baltic and SE Asia have remained mostly flat since the middle of 2016. Brazilian spot prices, in contrast, have strengthened since last December, bolstered by strong demand.

Otherwise, the market remains stable with strong demand in key import markets, notably the US and Brazil, and even China.

On the supply side, Mosaic resumed production at its Colonsay mine in January. Turkmenhimiya also opened its Garlyk mine in Turkmenistan in March. This is the first of three greenfield potash projects due to enter production this year, the other two being K+S Legacy in Canada and EuroChem's Usolskiy mine in Russia.

SULPHUR

Global sulphur prices firmed during the first quarter to reach a ceiling in March. Limited spot availability was a key factor. North American production was disrupted by an incident at Syncrude's upgrader at Mildred Lake, Alberta, in mid-March, resulting in temporary tightness. Availability from Russia was also tight over the winter period. The upward momentum in pricing was expected to halt eventually because of limited support from the processed phosphates market. Middle East producers dropped their monthly postings to $83-88/t f.o.b. for April, in response to downward pressure from end-use markets. Chinese sulphur spot prices came under pressure during the quarter, with bids in the $80s/t cfr range, down from a level of $100/t cfr and above. Portside inventories in China fell to 1.3 million tonnes in March, as buyers turned to local stocks rather than imports. China's January-February sulphur imports were also down 13% year-on-year, a trend that is expected to continue. Sulphur supply has been in balance across most regions, allowing prices to approach $100/t in major exporting markets.

Market price summary $/tonne – End-April 2017

Nitrogen	Ammonia	Urea	Ammonium Sulphate	Phosphates	DAP	TSP	Phosphoric Acid
f.o.b. Caribbean	285	n.m.	f.o.b. E. Europe 90-100	f.o.b. US Gulf	360	n.m.	n.m.
f.o.b. Yuzhny	300-305	195-200	-	f.o.b. N. Africa	370-385	270-280	515-740
f.o.b. Middle East	400	168-213**	-	cfr India	364-368	-	570-590*
Potash	KCl Standard	K_2SO_4	**Sulphuric Acid**		**Sulphur**		
f.o.b. Vancouver	195-232	-	cfr US Gulf	35-40	f.o.b. Vancouver	73-83	
f.o.b. Middle East	192-229	-			f.o.b. Arab Gulf	74-84	
f.o.b. Western Europe	-	€430-460			cfr North Africa	70-85	
f.o.b. FSU	180-222				cfr India	87-95+	

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)*

MARKET DRIVERS

- **Ammonia:** The Yuzhny price rally of early April is expected to run out of steam as short-term supply shortages out of the Black Sea have now eased. US cornbelt demand has supported strong prices across all other major price benchmarks in recent months. However, the onslaught of new US and South American capacity expansions in 2017 is expected to cap this upward price trajectory. This new capacity will add to ammonia market oversupply and, consequently, price sentiment is expected to weaken during the second quarter.
- **Urea:** Although market players felt little downside earlier in 2017, negative sentiment began to take hold as demand softened from the end of March into April. The prospect of new production in the US has fuelled negative market sentiment by pointing to lower pricing. Demand in Europe, Brazil and the US has continued to be weak, despite the lower prices seen since February. After rising to a 15-month high in February, the Yuzhny prilled urea benchmark subsequently fell for 10 successive weeks, and is expected to remain soft through May.
- **Phosphates:** Indian import buying should increase in the second quarter in response to *kharif* season plantings and confirmation of the country's maximum retail price. Competition for market share in India is likely to drive DAP import prices below the price of domestic product. Because of this, Indian market DAP prices of $365-375/t cfr are expected, with further falls of $10-15/t likely in May. Additional capacity from Ma'aden in the second quarter will add to downward price pressures. Integer expects DAP prices to trend $15-25/t lower, quarter-on-quarter, due to increasing producer competition and the likelihood of softer ammonia prices.
- **Potash:** The demand outlook for 2017 is generally positive given that inventories need replenishing in many key markets this year, particularly China. Integer forecasts global MOP demand to increase by around 2.3% in 2017 to approach 62 million tonnes. Brazilian demand has made a strong start to the year with first quarter imports increasing by 38% year-on-year to total 2.1 million tonnes. Brazilian demand is supported by an increase in soybean acreage and record local currency prices for crops such as sugar. In contrast, US demand sentiment is mixed with applications affected by wet weather.

  The Indian outlook is less encouraging since the fertilizer ministry announced a 20% decrease in its potash subsidy level for 2017/18. This equates to a reduction of around $28/t at current exchange rates. Indian potash buyers may try to mitigate subsidy cuts by negotiating lower prices on supply contracts.
- **Sulphur:** Two new supply sources will influence the global sulphur balance in the short-term, namely the Kashagan project in Kazakhstan and the Barzan project in Qatar. Together, these could add almost two million tonnes of sulphur capacity to the export market – a potentially bearish development for sulphur pricing. Sulphur prices are expected to remain soft ahead of the start-up of these projects, although this trend is likely to stabilise as Middle East prices move closer to $80/t f.o.b. Developments in China will also be crucial to the outlook, as this key market represents over a third of globally traded sulphur. Several oil and gas projects look set to increase domestic sulphur recovery capacity in China. The country's demand growth is also expected to weaken in future. This raises questions over whether China's 11-12 million t/a import requirement will be sustained. Demand growth is expected elsewhere in 2017, largely in Africa and the Middle East, with other regions expected to be largely stable. Integer expects challenges to remain on sulphur pricing through the remainder of the year, and for this to weigh on the sulphur market, despite recent positive signs in the phosphates market.

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UNITED STATES

IFCo starts up Wever plant

The Wever nitrogen fertilizer plant in southeast Iowa finally entered production this spring, four and a half years after construction first began.

The owner, Iowa Fertilizer Company (IFCo), a subsidiary of OCI, confirmed the start-up of the $3 billion plant on 20 April. OCI marked the occasion with an official inauguration attended by the Governor of Iowa, Terry Branstad, Lt. Governor Kim Reynolds, the Lee County Board of Supervisors and others.

The 1.5-2 million tonne capacity Wever plant is one of the largest private sector construction projects in Iowa's history. Importantly, it is the first world-scale, greenfield nitrogen fertilizer plant to be built in the US in more than 25 years.

"The start of production at Iowa Fertilizer Company plant in Wever is a transformative moment for the agricultural industry," said Nassef Sawiris, OCI's CEO. "As one of the most innovative and efficient manufacturing plants in the nation, Iowa Fertilizer is leading the way in providing American farmers a stable, high-quality and domestic source of nitrogen fertilizer products. Given its location among the highest nitrogen-consuming acres globally, on the border between Iowa and Illinois, the number one and two corn-producing states in the nation, the site houses not only a premier production facility, but also an industry-leading distribution centre."

Wever will produce urea, urea ammonium nitrate (UAN), ammonia and diesel exhaust fluid (DEF). The plant will be operated flexibly, and can switch between products at short notice according to market demand. IFCo has more than 200 full-time staff operating the plant currently, having previously employed more than 3,500 workers at the peak of construction. ■

UNITED STATES

Borger plant enters production

Agrium has successfully commissioned its new urea plant at Borger, Texas. The plant completed its first production run in April, and is expected to ramp-up to full capacity by the end of June.

The new 610,000 tonne capacity plant will mainly produce urea, although 100,000 tonnes of capacity will be dedicated to the manufacture of diesel exhaust fluid (DEF), a vehicle fuel additive.

"We look forward to bringing our reliable and high quality urea and DEF products to existing and new customers in this key agricultural region of the US," commented Chuck Magro, Agrium's president & CEO.

ISRAEL

Court orders emptying of ammonia tank

There has been a new legal development in the long-running saga over the future of an ammonia storage tank at the port of Haifa owned by Haifa Chemicals.

An Israeli court ordered the storage tank to be emptied by 1st April. This was due to concerns that a breach to the storage tank could threaten life in the city.

Haifa Chemicals uses the tank to store imported ammonia consumed in the manufacture of potassium nitrate, a fertilizer product that is mostly destined for export. The company has warned that the loss of the storage tank could mean it will have to cease operations. Haifa Chemicals employs 800 people and has an annual turnover of $600-700 million.

The court order was prompted by a petition from Haifa's municipal government and follows the publication of a city-commissioned report. This concluded that ammonia operations posed a serious risk to the population – from terrorist attack as well as accidental spillage. Hezbollah leader Hassan Nasrallah threatened to target Haifa's ammonia facilities with rockets last year.

The Israeli government has been working to develop an alternative source of ammonia. This involves building an ammonia production site in the southern Negev desert near the closely-guarded Dimona nuclear site. However, a tender to build and operate the plant attracted no interest last year. The main concerns were the high price of natural gas feedstock and uncertainty over future demand for ammonia.

Haifa Chemicals, which did not take part in last year's tender, has since proposed investing $175 million in the project, asking the government to match this sum. Even if the Negev ammonia project gets the go ahead, construction would take two to three years, meaning Haifa would still require a source of ammonia in the interim. Israel's ammonia demand is around 120,000 tonnes annually, with Haifa Chemicals consuming around two-thirds of this volume.

GERMANY

New low-cost granulation process

thyssenkrupp Industrial Solutions (TKIS) has launched a new production process for ammonium sulphate (AS) granulation. This is said to deliver major cost efficiencies over conventional AS finishing. The granules obtained also have better spreading and mixing properties compared with crystalline AS products.

The new patented process begins by mixing AS solution with an additive at a specific ratio. This reduces dust formation during granulation and improves the crushing strength of the end-product. In the second step, the liquid mixture is sprayed into a fluidised bed granulator and processed into solid granules. These granules are round, very hard and highly resistant to impact and abrasion.

Conventional granulation plants are not able to process AS solutions, and instead consume relatively high-priced ammonia and sulphuric acid starting materials. In 2016, TKIS built a pilot granulation plant with a production capacity of 500 kg/h, following successful lab- and bench-scale trialling of the new process.

"All the tests have been successful so we can now scale-up the process to industrial scale with capacities between five and 20 tonnes per hour," explained Dr Jens Mathiak, whose team at TKIS developed the new process. "Fertilizer manufacturers worldwide will be able to benefit from greater cost efficiency. Granular ammonium sulphate is currently made by very few manufacturers so demand is high and there are great sales opportunities."

BRAZIL

Petrobras to sell Três Lagoas

Petrobras is negotiating the sale of its $1.2 billion Três Lagoas ammonia and urea plant in Mato Grosso to a Chinese consortium lead by Sinopec. The consortium would take on debts of around $12 million if it purchased the plant, according to reports.

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Três Lagoas has a design capacity of 760,000 tonnes for ammonia and 1.2 million tonnes for urea. Construction was suspended by a corruption investigation at the end of 2014, Petrobras says the plant is now 81 percent complete.

TURKMENISTAN

Garlyk potash mine inaugurated

Turkmenhimiya's Garlyk potash mine in Turkmenistan officially opened at the end of March.

The mine, located in the country's Lebap region, was built by Belarusian potash engineering firm Belgorkhimprom. The first production tonnages emerged in February and the project is expected to ramp-up to its full capacity of 1.4 million t/a over the next three years. The mine has already exported to Afghanistan, according to reports, in addition to making deliveries to its home market.

The government of Turkmenistan is expected to purchase several hundred thousand tonnes of potash from Turkmenhimiya every year for domestic use. This leaves the mine with spare capacity to supply other Central Asian countries, including Tajikistan and Afghanistan.

However, the Garlyk mine's remote and land-locked location remains a hindrance, and Turkmenhimiya will need to rail freight potash long-distance to Bandar Abbas in Iran, according to analysts CRU, if it is to reach full capacity and access overseas markets.

Although Garlyk is the country's only potash mine currently, the Turkmenistan government is inviting bids for the construction of a second $1.4 billion potash mine, *Reuters* reported in April.

SERBIA

Phosphea to buy Elixir feed phosphates

Serbia's Elixir Group has agreed to sell its feed phosphates business to Phosphea, a subsidiary of Groupe Roullier.

The deal will transfer ownership of Elixir's entire feed phosphates business in Central and Eastern Europe to Phosphea, including the 100,000 t/a capacity Prahovo production plant in Serbia. If approved, the move will cement Groupe Roullier's position as one of Europe's leading feed phosphates producers.

Elixir Group operates a sizable plant, animal and human nutrition business in Europe. The group had a turnover of €240 million last year and numbers 1,500 employees. The sale of its phosphates arm to Phosphea is expected to close mid-year, subject to the necessary approvals.

NORWAY

Fire at Yara's Porsgrunn plant

The ammonia plant at Yara International's Porsgrunn fertilizer complex was damaged by a fire on the morning of the 24 April.

The fire was put out on the same day and no personnel were injured, Yara confirmed in a statement. "Investigations into the cause and material damage of the fire are on-going, but the damage is limited to the ammonia plant," the statement added.

Porsgrunn produces ammonia (0.5 million t/a), NPK fertilizers (2.2 million t/a) and calcium nitrate (0.8 million tonnes). The impact of the fire on fertilizer output should be minimal, as Porsgrunn is capable of producing finished fertilizers using imported ammonia, commented Yara.

RUSSIA

Veolia to supply VolgaKaliy expansion

EuroChem Group has selected Veolia as a technology provider for the expansion phase of its VolgaKaliy potash project in Russia's Volgograd region.

The mine, which is due to enter production next year, will incorporate Veolia's crystallisation technology as part of an expansion scheduled to start-up in 2021.

Veolia's HPD PIC™ Crystallizer System will be used to manufacture two million t/a of high-purity potassium chloride fertilizer from brines extracted from conventionally-mined potash ore. Veolia Water Technologies will provide the major process equipment required, including multiple *HPD PIC™ Crystallizers*, recirculation and transfer pumps, vapour condensers and centrifuges.

"With their proven experience and talented team, EuroChem is pleased to be working with such a strong partner as Veolia," said Clark Bailey, EuroChem's head of mining "The expansion phase of our VolgaKaliy project will increase the plant's capacity to 4.3 million tonnes per year of potash, in grades suitable for both agricultural and industrial applications."

Klaus Andersen, CEO of Veolia Water Technologies, added: "We are proud to partner with EuroChem on this prestigious project. With the experience from more than 1,200 successful installations for industrial evaporation and crystallization, and over 50 references in the fertilizer market, we were able to offer a custom-built system that offers the flexibility to meet a wide range of production requirements."

UNITED KINGDOM

Sirius to begin construction

Formal construction work on the North Yorkshire polyhalite project is now scheduled to begin by the end of June, according to Sirius Minerals.

Enabling works at the Woodsmith Mine site are near completion, the developer confirmed in a quarterly update, allowing site preparation including earthworks to begin. The project also remains on time and on budget.

Chris Fraser, managing director and CEO of Sirius Minerals, said: "We are making good progress with the development of the Woodsmith Mine and associated infrastructure, having successfully secured around £1 billion in November 2016 in our Stage 1 Financing."

The update confirmed that highways works around the Woodsmith Mine have already commenced. Contracts for the highways works, geotechnical drilling at the mine site and shaft engineering have been signed and are within budget. Negotiations with AMC over the shaft sinking contract are said to be continuing.

Sirius Minerals says it is actively looking at opportunities to shorten the project timetable by speeding up some of the spending on the mine's shaft and tunnel. The process for acquiring the project's harbour site has also started and should be completed over the next 12 months.

In a further development, Sirius Minerals was successfully admitted to the main market of the London Stock Exchange on 28 April, having previously been listed on the London AIM market. The company expects to be included in the FTSE UK Index from June, based on its current market capitalisation.

New phosphorus recycling technologies

Severn Trent Water, one of the UK's largest water companies, is trialling new technologies to remove phosphorus during sewage treatment. Six technologies are being evaluated at its Packington waste water treatment works in Leicestershire:

- Membrane filtration
- Nanoparticle embedded ion exchange

China News Round-up

Courtesy of Kcomber, owner of CCM and Tranalysis

Widespread losses in 2016

Many Chinese fertilizer manufacturers suffered losses in 2016, victims of a sluggish market.

China's biggest fertilizer producer, Hubei Yihua Chemical, was not immune, after it revealed 2016 losses of $181 million. The firm's 2016 sales of $2.2 billion were down 17% on 2015.

The weak financials reflect the sluggish performance of Hubei Yihua's fertilizer business, which accounts for more than one-quarter of its total sales. Increasing production costs and falling prices have seen the firm's fertilizer profit margins fall from 12.6% previously to 3.3% in 2016.

Two other fertilizer manufacturers, Sinofert and Yunnan Yuntianhua, also posted large losses in 2016. Both companies produce a limited range of fertilizers, making them particularly vulnerable to depressed market conditions.

Joint sulphur purchasing agreement

Leading Chinese phosphate producers, Yuntianhua Group, Guizhou Kailin, and Wengfu Group, have agreed a *Strategic Cooperation Framework Agreement on Jointly Purchasing Sulphur.*

This will allow the three producers to jointly purchase sulphur together. The agreement was necessary to counteract rising sulphur prices at a time when fertilizer prices are falling, the companies said. The cost of sulphur, along with the other raw materials, accounts for about 30% of finished fertilizer production costs currently.

The agreement is highly significant as the three companies are collectively responsible for one-third of Chinese sulphur demand, about 80% of which is imported. The joint purchasing agreement will therefore strengthen the bargaining position of Chinese firms during future price negotiations with international sulphur suppliers.

Kingenta asks World Bank to invest

Leading Chinese fertilizer producer Kingenta has invited the World Bank to part-fund a $1 billion, 3-year investment programme, through the bank's International Finance Corporation (IFC) arm.

IFC has been asked to provide a finance package totalling $205 million. The package includes a $100 million loan and equity worth $105 million.

This will part-finance new crop production service centres in rural Chinese farming areas. The funds will also be invested in production upgrades to convert fertilizer plant output from conventional products to compound and speciality fertilizers instead. Kingenta plans to set up a new company to undertake both projects. It will directly own a 40 percent stake in the new firm.

Kingenta manufactures a wide range of premium fertilizer products, including compound fertilizers, slow and controlled release fertilizers and water soluble fertilizers. These are targeted at food crops, cash crops and the horticulture market.

The company, which is listed on the Shenzhen stock exchange, has a market capitalisation of $3.4 billion. Founder and chairman Lianbu Wan owns a controlling interest in Kingenta, through a direct stake of about 18.3% together with an additional 39.1% stake via Linyi Kingenta Investment Holding Ltd.

Phosphate projects announced

Two industrial phosphate projects have been announced in Weng'an County, Guizhou Province, one of China's leading phosphate mining districts. The projects will produce phosphorus trichloride and ammonium polyphosphate flame retardant.

Weng'an County is seeking to invest about $13.7 million in a 100,000 t/a phosphorus trichloride project. This will support the manufacture of a range of chemical derivatives including $POCl_3$, $PSCl_3$, PCl_5 and phosphite and phosphate esters.

A further $13.1 million project to produce 40,000 t/a of ammonium polyphosphate in Weng'an has also been announced. Output will help meet China's growing demand for fire retardants. Guangxi Sino-Linchem is also developing ammonium polyphosphate projects to supply this market.

The two new projects will be supplied by 11.5 million t/a of phosphate mining capacity. Weng'an County has estimated phosphate ore reserves of more than 3.6 billion tonnes.

Sinofert and Hubei Yihua to cooperate

Sinofert Holding and Hubei Yihua are to cooperate strategically as part of a new agreement signed in April. Both firms said they wanted to complement each other's advantages and improve their competitiveness by deepening strategic cooperation on all products. The cooperation agreement will cover 800,000 tonnes of joint fertilizer production in 2017.

Partial chemical fertilizer phase-out

China's ministry of agriculture is piloting a project to replace 50 percent of the country's chemical fertilizer usage with organic fertilizers instead. The new approach is being trialled for fruit and vegetable growing and tea planting in one hundred key cities and districts. These crops combined currently account for about two-fifths of total fertilizer use in China, consuming 24 million tonnes annually.

The ambitious new project is part of *China's zero-growth in the usage of fertilizer until 2020* strategy. If successful, the project will be rolled-out to the whole country after 2020, according to minister Han Changfu.

However, the proposed ramp-up in organic fertilizer use faces major hurdles. Organic fertilizers account for just 5% of nutrient applications currently, for example. There also are concerns about high levels of antibiotics in animal manure.

Commercial production of organic fertilizer would clearly need to be expanded massively to reach the proposed 50% substitution by 2020.

New industry-scientific coalition

China's leading research institutes and fertilizer producers have joined forces to form the National Union of Scientific and Technological Innovation for Usage Reduction and Efficiency Improvement of Fertilizer.

Institutes such as the Chinese Academy of Agricultural Science and China Agricultural are participating, as are major producers Yuntianhua, Wengfu, and Sinofert Holding.

The new organisation will help stabilise and reduce China's fertilizer usage by connecting the upstream and downstream parts of the country's agricultural industry. It will also promote scientific collaboration and research and development work. ■

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- Pile cloth media filtration
- Ballasted coagulation and clarification
- Immobilised algal bioreactor
- Absorption media reed beds

The ion exchange and algal bioreactor, both developed by Cranfield University in the UK, are being trialled for the first time.

"New legislation in the [EU] Water Framework Directive requires us to meet much tighter phosphorus limits than we have in the past and that's why we've been trialling these new types of technology," explained Pete Vale, head of technical innovation at Severn Trent. "We hope that by developing these we can get down to around the 0.1 mg/l level and greatly reduce the amount of phosphorus that goes back into our streams and rivers."

He added: "We've been using some state-of-the-art techniques to understand which technology will work for our sewage treatment sites that greatly differ in size – from very small local sites to one of the biggest in Europe. We've already… installed some new technology at three plants with another nine in the planning process."

FRANCE

Pardies plant to close

Yara International's Pardies plant is to cease production and close, the company said in a statement on 8 March. This also confirmed that a buyer for the plant is being sought.

The French technical ammonium nitrate plant has an annual production capacity of 100,000 tonnes and employs 85 workers. The main reasons for the closure were the plant's lack of scale, raw material integration and export competitiveness. Yara had previously been forced to end ammonia production at Pardies after the closure of a nearby industrial operation in 2010.

"We regret to inform our employees and other stakeholders that we are considering closing the Yara Pardies plant and seeking buyers interested in taking over the plant. I would like to assure our employees that the cessation process will be handled in a respectful and professional way, and in accordance with the relevant union agreements," said Svein Tore Holsether, Yara's president and CEO.

Holsether added: "France… remains a key market for Yara, with more than 2.5 million tonnes of product delivered and €73 million invested in 2016."

ETHIOPIA

Circum awarded mining license

The Ethiopian government has granted Circum Minerals a mining license for its Danakil potash project in northeast Ethiopia

This provides Circum with exclusive access to potash resources within a 365 square kilometre license area. The licence is for a 20-year period, initially, but is renewable indefinitely for further 10-year periods, subject to financial viability.

Circum plans to solution mine both SOP (sulphate of potash, K_2SO_4) and MOP (muriate of potash, KCl) from a large-scale shallow ore deposit. Extracted brines will be processed by crystallisation in solar ponds prior to final refining in a process plant.

In the project's first phase, production from solution mining is scheduled to commence in mid-2018 and ramp-up to two million t/a of MOP and 0.75 million t/a of SOP over the next three years. A mine life of 26 years is expected for production on this scale.

The award of the license follows the submission of a definitive feasibility study (DFS) and a project environmental and social impact assessment (ESIA). The project's DFS confirmed proven and probable KCl reserves of 107.8 million tonnes, and measured, indicated and inferred resources of 4.9 billion tonnes (18.1% KCl).

"We are delighted that the Ethiopian government has approved the mining license for this world class project. This represents a significant milestone for both the company and the country. We now have a compelling investment case that supports the development of this project," said Stephen Dattels, Circum's chairman and co-founder.

CANADA

Shell exits oil sands

Royal Dutch Shell has agreed to sell most of its Canadian oil sands assets for a total of $8.5 billion. The sale is part of a larger $30 billion assets sell-off at the company.

The move is designed to clear some of the debts incurred from Shell's acquisition of BG Group last year. But the divestment is also in response to investor pressure and concerns about carbon emissions and climate change.

Under the oil sands deal, Shell has agreed to sell its existing and undeveloped Canadian oil sands prospect to Canadian Natural Resources Ltd (CNRL) and to cut its share in the Athabasca Oil Sands Project (AOSP) from 60% to 10%. The company will, however, continue to operate the Scotford upgrader and the Quest carbon capture and storage project. Shell and CNRL will also buy and jointly own Marathon Oil Canada, which produces 48,000 bbl/d of syncrude from Alberta oil sands.

Falling oil prices have led to a partial retreat from Canadian oil sands projects in recent years. Shell abandoned its Carmon Creek project in 2015, and ExxonMobil took a write-down on its $16 billion Kearl project earlier this year.

Shell says that it is focussing more on cleaner technologies, with annual investments of $1 billion in renewable energy by 2020, a four percent share of the company's overall annual spend. In future, up to one-tenth of director bonus payments will also be tied to managing greenhouse gas emissions in Shell's refining, chemical and upstream operations.

"This announcement is a significant step in re-shaping Shell's portfolio," said Ben Van Beurden, Shell's chief executive officer. "The proceeds will accelerate free cash flow and reduce gearing and make a meaningful contribution to Shell's $30 billion divestment program."

Rail Cars arrive at Legacy project

The first 177 of 531 custom-built rail cars arrived at the Legacy project site in Saskatchewan in March, K+S Potash Canada (KSPC) has confirmed. The arrivals are enough to complete one of the three trains that will transport potash from the Legacy mine to KSPC's Port Moody potash facility in British Columbia.

"The arrival of these rail cars demonstrates how close we are to production, which is expected to begin in the second quarter this year," said Dr Ulrich Lamp, KSPC's president and CEO.

The rail cars will travel along a 30 kilometre spur recently constructed by Canadian Pacific (CP). This connects CP's main line at Belle Plaine to 14 kilometres of newly-built industrial rail line owned and operated by KSPC.

The rail cars, designed by National Steel Car, can be loaded in motion and are built to an innovative design. The new cars have the capacity to hold the same volume as a regular rail car while being slightly shorter in length. This optimises rail transport and the timely and efficient delivery of products.

"Once the trains arrive at our facility in Port Moody, they will be unloaded by automatic conveyor to our warehouse or directly onto a ship at one of the world's most modern potash handling facilities," said Steffen Brill, KSPC's senior manager for logistics and transportation.

The 531 rail cars will meet KSPC's initial requirements for weekly transportation to Port Moody, although additional cars will be required when production ramps-up later in the year, according to Brill. Part of the new rail fleet will also be used to transport product to the US market.

BULGARIA

EuroChem acquires distributor Agricola

EuroChem Group has purchased Agricola Bulgaria, the country's leading fertilizer distributor.

Agricola Bulgaria, based in Pleven, northern Bulgaria, has annual fertilizer sales of 70,000-80,000 tonnes, equivalent to a 9% share of the Bulgarian distribution market. It was previously owned by Agrium Europe.

The purchase will expand EuroChem's distribution capabilities in Bulgaria and Eastern Europe. The deal has already been approved by Bulgaria's competition regulator. The newly-purchased company will be renamed EuroChem Agro Bulgaria.

"The acquisition of Agricola Bulgaria, a well-established player in the Bulgarian fertilizer distribution market, is in line with our expansion strategy in Eastern Europe where we see strong demand for fertilizers," said Dmitry Strezhnev, EuroChem's CEO. "This acquisition will contribute to the Group's growth in Bulgaria and its neighbouring countries."

UNITED ARAB EMIRATES

Adnoc to double output at Shah

Occidental Petroleum has said that it expects output at the Shah sour gas project to double over the next decade. The project is already operating at 110% of rated capacity.

Occidental holds a two-fifths stake in the Al Hosn Gas joint venture behind the project. The Abu Dhabi National Oil Company (Adnoc), the project's majority partner, owns the remainder.

A production increase of 50 percent to 1.5 billion scf/d by 2021 has been set as an interim target, according to Adnoc CEO Omar Al Suwaidi. Foster Wheeler was awarded the front end engineering and design (FEED) contract for this first phase expansion in December 2016. The design work is scheduled to be completed by the end of this year.

Shah's sulphur output is also set to progressively increase, from its present 3 million t/a to 4.5 million t/a in phase one and then to 6 million t/a in phase two, taking Adnoc's total production to 9 million t/a.

Etihad Rail says it has now transported a total of 10 million tonnes of solid sulphur since it began operations for Adnoc in September 2014. Sulphur is transported up to 264 km from the Shah and Habshan sour gas processing plants to the terminal at Ruwais for export. Two trains travel the route daily, each carrying up to 11,000 tonnes of sulphur, with around 400,000 tonnes delivered monthly. ■

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People

James Fazzino is to step down as managing director and CEO of Incitec Pivot Limited after almost eight years in the role. He will remain with the company for up to 12 months in his current job until a successor is identified and appointed.

Company chairman Paul Brasher commented: "During his time as managing director & CEO, James has transformed Incitec Pivot from a fertiliser business on the East Coast of Australia to a global diversified industrial chemicals company."

James Fazzino added: "It has been a privilege for me to be managing director & CEO of Incitec Pivot. During my 14 years with the company… Incitec Pivot has been through a transformational journey which has resulted in the size of the group increasing six fold... I'm very proud of what we have achieved and I wish to thank the board, the executive team and all of our employees for their support and hard work."

James Fazzino steps down at Incitec Pivot.

Andreas Kreimeyer is set to take over from **Ralf Bethke** as chairman of K+S Group's supervisory board, after the company's AGM in May. **Thomas Kölbl**, Südzucker's chief financial officer, has also been proposed as a new supervisory board member.

Dr Bethke has been chairman since May 2008 and will step down when his term of office expires this May. Supervisory board members thanked Dr Bethke for his excellent leadership. The supervisory board plans to elect Dr Kreimeyer, who has served on the board since 2015, as chairman after the AGM.

Rod Humphris takes over as Chairman of Omnia.

Neville Crosse is to retire as chairman and non-executive director of Omnia Holding Limited on 31 May, triggering a number of high-level changes at the company. Mr Crosse will be replaced by **Rod Humphris**, Omnia's current managing director.

In a coordinated move, Omnia appointed **Adriaan de Lange** to the role of group managing director, with effect from the start of June. Mr de Lange, who will also join the board as an executive director, is to work closely with the new chairman to ensure a smooth handover.

The board thanked Neville Crosse for his many years of dedicated service and wished him well on his retirement. The board also welcomed Rod Humphris in his new role as chairman, and also looked forward to working with new managing director, Adriaan de Lange.

Mike Lumley, general manager for sulphur and ventures at Shell Sulphur Solutions, has been elected chairman of the board of The Sulphur Institute (TSI). His appointment was confirmed at a TSI board of directors meeting in Dublin in April. This meeting also named Jack Cohn of Savage Sulphur Services as TSI's vice chair.

"We seek to be a unified voice for the sulphur and sulphuric acid industry for all aspects of the businesses impacting our license to operate," Lumley commented. Under Lumley's leadership, TSI said it plans to demonstrate its value to members, not only in North America, but in Europe and into Central Asia, the Middle East and North Africa. ■

Calendar 2017

MAY

22-24

85th IFA Annual Conference,
MARRAKECH, Morocco
Contact: IFA Conference Service
Tel: +33 1 53 93 05 25
Email: conference@fertilizer.org
Web: www.fertilizer.org

JUNE

9-10

41st AIChE Annual Clearwater Conference 2017, CLEARWATER, Florida, US
Email: chair@aiche-cf.org
Web: www.aiche-cf.org

26-30

Nitrogen Fertilizer: Advances in Technology, Products, Safety and Global Impact, IFA-IFDC Workshop, LONDON, UK
Contact: IFDC Training and Workshop Coordination Unit
Tel: +1 (256) 381 6600
Email: training@ifdc.org
Web: www.ifdc.org

29-30

International Fertiliser Society Technical Conference, LONDON, UK
Contact: International Fertiliser Society
Tel: +44 (0)1206 851819
Email: secretary@fertiliser-society.org

JULY

10-12

West Africa Fertilizer Agribusiness Conference, ACCRA, Ghana
Contact: CRU Events
Tel: +44 (0)20 7903 2444
Email: conferences@crugroup.com
Web: www.crugroup.com

OCTOBER

24-26

IFA Crossroads Asia-Pacific Conference, SHANGHAI, China
Contact: IFA Conference Service
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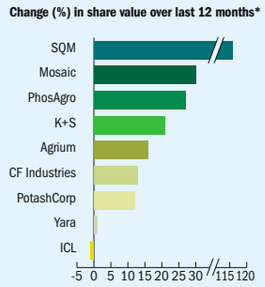
Fertilizer industry financial scorecard

Exactly how profitable was the fertilizer industry last year and who were the main financial winners and losers? The tough prevailing market conditions undoubtedly made 2016 a testing year for the sector's major players. We analyse the relative performance of leading fertilizer producers, following the publication of 2016 company results.

Fig 1: **Change in share value of major listed fertilizer producers**



* to March 2017

Source: Bloomberg/Scotiabank

* to March 2017

Source: Hannam & Partners

A clearer picture of 2016 fertilizer sector finances has emerged following the reporting of fourth quarter and full-year results. The major listed fertilizer companies disclose information on revenues, earnings, operating profits, margins and dividends each spring. Comparing and contrasting these results provides some useful insights into how the global fertilizer industry performed in 2016, and its reaction to the year's challenges.

Stocks rally

Encouragingly for the sector, there has been a general rally in fertilizer stocks over the last year (Figure 1). In recent months, this share rebound has been attributed to[1]:

- Increasing nitrogen, phosphate and potash prices moving into the Northern Hemisphere spring application season
- Potash producers, rightly or wrongly, calling the bottom of the cycle
- Current and potential nitrogen and phosphate plant closures in China
- Merger and acquisition (M&A) activity

In North America, there is also growing optimism that the US will reduce corporate tax rates and a belief that US fertilizer prices will move higher if a border adjustment tax is implemented[1].

SQM shares have risen on the back of the soaring lithium market. Both Mosaic and PhosAgro appear to be benefiting from the strong price rally in the phosphates market over the last six months. Stocks in Germany's K+S Group, which is on the verge of commissioning its new Legacy potash mine in Canada, have also risen significantly. Understandably, Agrium and PotashCorp shares have moved upwards in advance of their planned merger[1] (*Fertilizer International* 475, p16).

"What we've seen for the most part is a 10-30% rally of large fertilizer stocks over the past few months due to fertilizer prices moving higher," commented Ben Isaacson, equity analyst for global fertilizers at Scotia Capital, speaking in March[1]. "The debate in the investment community is how much of this is seasonal and how much is actually due to fundamentals."

Revenues and profits tumble

With the exception of SQM, revenues and operating profits of the major listed fertilizer producers fell year-on-year in 2016 (Figure 2). Poor market conditions and softer prices were mostly to blame.

In North America and elsewhere, benchmarks prices for urea, potash and diammonium phosphate (DAP) have fallen sharply since the start of 2015, although crop nutrient prices have since recovered from the floor levels of mid-2016 (Figure 3). Sensibly, producers such as Mosaic countered lower prices in 2016 by cutting operating costs.

"Sales [revenues] were $7.2 billion, down from $8.9 billion a year ago," noted Mosaic. "Full-year operating earnings were $319 million, down from $1.3 billion last year, as lower operating expenses were more than offset by lower sales volumes and prices in potash and lower phosphate prices."

Price falls were also highlighted by Agrium: "Wholesale sales decreased in 2016 primarily as a result of lower realised prices for all products. Retail sales

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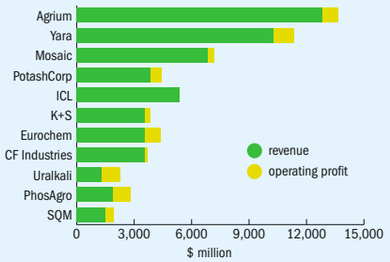
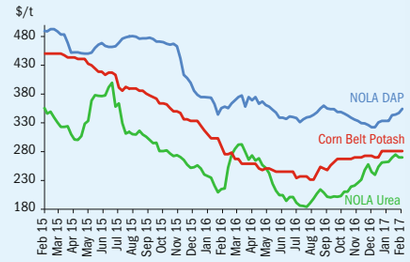
Fig 2: **Revenues and operating profits of major fertilizer producers, 2016**



Source: Hannam & Partners/S&P Capital IQ/company filings

Fig 3: **Example benchmark prices for DAP, potash and urea, 2015-2017**



Source: Green Markets, Argus, Agrium

decreased in 2016 primarily as a result of lower crop nutrient selling prices. Competitive pricing pressures and volatile commodity markets [also] affected our selling price."

Individual factors also came into play. German producer K+S partly attributed its drop in 2016 operating earnings, a 71 percent fall from €782 million in 2015 to €229 million last year, to the lower average selling price for potash. But it also cited standstills at its Werra potash plant in Germany, and the mild winter conditions affecting its salt business.

PotashCorp's performance over the last five years encapsulates some of the challenges of operating in the current market environment. Revenues at the world's largest fertilizer producer have fallen for five successive years, from $7,927 million in 2012 to $4,456 million last year. Net profits have followed a similar trend over this period, dropping from $2,079 million in 2012 to just $323 million in 2016.

Although potash, nitrogen and phosphate sales volumes at PotashCorp have all risen over the last five years – 1.4 million t/a more in the case of potash – margins have moved down significantly. PotashCorp's gross margin per tonne for potash fell from $272/t in 2012 to $53/t last year, for example.

Put simply, PotashCorp, like many of its peers in the sector, is selling more fertilizer than it was five years ago. But, due to a combination of price and cost pressures, the company is operating on lower margins and generating less earnings.

PotashCorp is acting to cut operating expenses by ramping-up production at Rocanville, its lowest-cost potash operation. The company also expects to benefit from a recovery in the potash market.

"Positive potash pricing trends from the second half of 2016 are expected to carry into [2017]," said Jochen Tilk, PotashCorp president and CEO. "Supported by healthy underlying consumption, lower global inventories and with Canpotex fully committed for the first quarter of 2017, we see a continued potash recovery."

Some of the sector's listed companies have managed to increase their profits at a time of downward pressure on revenues and earnings. PhosAgro reported a 64% rise in net profits in 2016, up from RUB 36.4 billion ($598 million) in 2015 to RUB 59.9 billion ($893 million).

Because PhosAgro's products are dollar-denominated, the higher $/RUB average exchange rate in 2016 had a positive impact on full year results. But the company was also helped by the "tremendous performance" of the Russian fertilizer market in 2016. Domestic sales grew by more than 30% year-on-year to reach 2.1 million tonnes.

"Despite the challenging environment in 2016 – a year when phosphate and nitrogen prices bottomed out at levels last seen during the 2009 financial crisis – PhosAgro continues to generate solid operating cash flows," commented Andrey Guryev, the company's CEO. Guryev also noted that PhosAgro's earnings-to-revenue margin of just under 40% was an "unachievable target" for the most integrated and largest of its phosphate fertilizer peers.

Debt worse than diversified miners

The fertilizer sector has undoubtedly become more indebted over the last five years. Net debt, as a proportion of enterprise value (EV), has risen threefold – from single digits (4%) in 2012 to over one-quarter (27%), as of March 2017 (Figure 4).

"Five years ago fertilizer companies were cash-rich, had low levels of debt and the markets were optimistic this would continue," comments Scotia Capital's Ben Isaacson. "Today the same companies have total net debt to enterprise values that are the highest they've been in years."

He continues: "When we look at balance sheets, we can generally see that fertilizer companies were caught off-guard. They took on a lot of debt to build new capacity and then the start of oversupply led to lower fertilizer prices which reduced the amount of cash available to cover that debt."

Indeed, the indebtedness of fertilizer majors has now overtaken that of diversified mining companies. Collectively, major miners such as Anglo American, BHP, Glencore, Rio Tinto and Vale have acted to half their net debt over the last two years, from two-fifths (39%) of EV in 2015 to around one-fifth (22%) currently (Figure 4).

The market capitalisation and net debt of major listed fertilizer producers are shown in Figure 5. Sector debt has risen substantially since 2012, with some companies now running net debt levels above three times earnings, although the industry average over the last 12 months has remained below this threshold. However, this still compares relatively poorly with diversified miners who, with the exception of Glencore, have debt levels of between 1.1 to 2.2 times earnings[1].

Looking ahead, Scotia Capital expects fertilizer industry debt to fall year-on-year during 2017 and 2018. Action to pay down debt in the sector will take place to avoid potential downgrades to credit ratings, in

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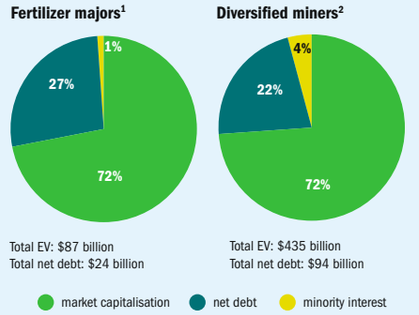
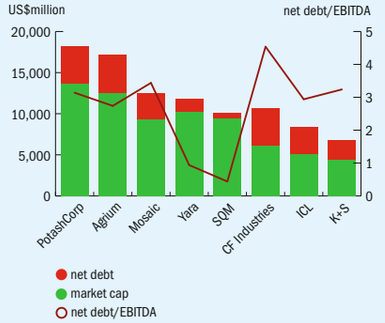
Fig 4: **Capital structure of global fertilizer and mining companies, March 2017**



1. Includes Agrium, CF Industries, ICL, Mosaic, PotashCorp and Yara.
2. Includes Anglo American, BHP, Glencore, Rio Tinto and Vale.

Source: Capital IQ

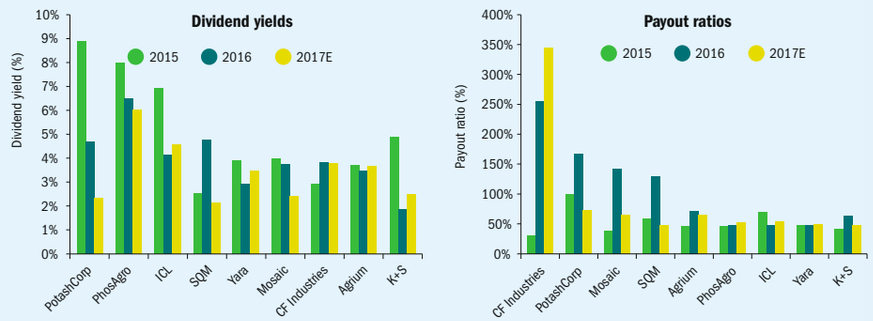
Fig 5: **Net debt of selected major fertilizer producers relative to market value and earnings, 2016**



**EBITDA*

Source: Hannam & Partners, Scotiabank, Capital IQ

Fig 6: **Dividend yields and payout ratios**



Source: FactSet, Scotiabank GBM

its view. Fortunately, the sector's debt is overwhelmingly long-term, and the majority of this does not mature until after 2021. Many companies in the sector also have the ability to fund a high proportion of their capital expenditure from earnings. Yara and SQM also managed their balance sheets particularly well in 2016, maintaining net debt-to-earnings ratios of 1.1 and 0.6, respectively[1].

Ben Isaacson explains more about the priority being given to debt reduction:

"Many fertilizer producers have debt more than three times earnings [EBITDA]. This is a very important psychological level as it's when we typically see credit downgrades or the risk of downgrades. Because of this debt scare, most companies plan to pay down debt much more aggressively with future earnings – which is why we see industry leverage improving over the next couple of years.

"Fertilizer companies on average have a capital structure of approximately 40 percent debt. Every company is different, but optimal ratios are closer to 30-35 percent."

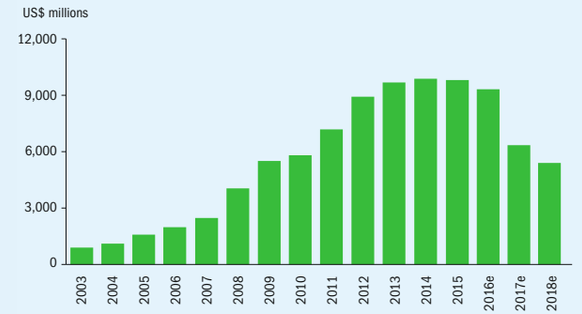
However, the downside of diverting earning to pay down debt is that it may limit the scope for dividend payments over the next few years.

Shareholder payments

Dividend yields – annual payment to shareholders as a percentage of share price – have generally fallen since 2015 (Figure 6). Declining earnings were behind dividend cuts at PotashCorp, Mosaic and others, suggests Scotia Capital. Higher company equity values, when combined with static dividends, have also driven down yields in some instances[1].

Scotia Capital's Ben Isaacson elaborates on the two reasons driving cuts to dividend yields: "When fertilizer prices moved lower, earnings dropped to levels that made dividends unsustainable and

Fig 7: **Capital expenditure by major fertilizer companies**



Source: Capital IQ

this resulted in dividend cuts. Optimism over the last few months has [also] driven equities higher – but earnings haven't improved to the point that dividends can return to previous levels."

More positively, dividend yields should rise next year, predicts Scotia Capital, although this is likely to be largely driven by lower equity values rather than higher dividends[1].

Shareholder returns can also be monitored using payout ratios. These measure the proportion of earnings paid out as dividends, with lower ratios generally preferred. A ratio above 100% indicates a company is paying out more in shareholder dividends than it receives in net income. Fertilizer sector payout ratios generally soared in 2016 (Figure 6), reports Scotiabank, mainly because dividend policies were not adjusted quickly enough in response to falling earnings[1].

Investment cycle past its peak

Since 2003, capital expenditure of listed fertilizer majors increased year-on-year for over a decade, peaking at $9.96 billion in 2014 (Figure 7). This has included investments totalling $48 billion over the last five years alone. Although the fertilizer industry's investment cycle is past its peak, additional capital expenditure of $11.8 billion is expected over the next two years. This total is highly conservative as it excludes the massive phosphate investment programmes of Ma'aden and OCP Group.

Companies are starting to see their huge investments since 2012 come to fruition. In a landmark moment, the first deliveries from K+S Group's 2.86 million tonne capacity Legacy mine are expected later this year. The CAD 4.1 billion project is Canada's first new potash mine in decades. EuroChem's $2.9 billion Usolskiy potash mine in Russia's Perm region is also scheduled to begin production in late 2017. Its $4.0 billion sister VolgaKaliy mine in the Volgograd region is due to follow suit in mid-2018.

CF's $2.1 billion expansion project at Donaldsonville is also now complete, making it the world's largest nitrogen complex. CF also successfully started-up new ammonia and urea plants at Port Neal, Iowa, last December, having invested $1.7 billion at the site. Adding to North American nitrogen capacity, Agrium commissioned its new urea plant at Borger, Texas, in April.

In Morocco, the commissioning of two further one million tonne capacity production units at the Jorf Lasfar Phosphate Hub by the end of 2017 will increase OCP Group's fertilizer production capacity to 12 million tonnes. The completion of the $7.5 billion, three million tonne capacity Wa'ad Al-Shamal phosphate complex in Saudi Arabia, jointly owned by Ma'aden, Sabic and Mosaic, is also imminent.

Acknowledgement

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Peanuts, one of many crops which respond to micronutrient applications.

PHOTO: NATTIKA/SHUTTERSTOCK.COM

Micronutrients, major impacts

The widespread problem of soil micronutrient deficiency has come under the spotlight in recent years. We look at the effects of these deficiencies on crop productivity and human health – and the range of speciality micronutrient fertilizer products currently on the market.

Micronutrients are essential for plant growth and a necessary part of balanced crop nutrition. They include boron, copper, iron, manganese, molybdenum and zinc. Although required in much smaller amounts, micronutrient availability is arguably as important to plant nutrition as primary and secondary nutrients. A lack of one or more micronutrients in soil can still limit plant growth, even when adequate levels of other nutrients are present.

Hidden hunger

Micronutrients play a vital role in crop productivity and the health of humans and animals. Yet deficiency in soils and crops has often been a neglected and hidden problem, despite its potentially pernicious effects.

Micronutrient deficiencies and accompanying yield losses in crops are easy to detect when symptoms are visible – such as the yellowing of plant leaves (chlorosis), for example. Yet deficiencies can still be present, and drive down the yield and quality of farm produce, even when crops look healthy and exhibit no tell-tale signs.

There can be major health and economic repercussions from 'hidden hunger', the name given to this invisible form of micronutrient deficiency. Although unnoticeable whilst crops are in the field, hidden hunger manifests itself post-harvest, with visible signs of deficiency finally emerging during distribution, storage and sale. This has economically damaging consequences for farmers, food processors, distributors and retailers due to greater spoilage, reduced shelf-life and higher food losses.

Hidden hunger can also have a major impact on human health, particularly for vulnerable, malnourished children. Yet the understandable priority, when it comes to feeding the world, has been to produce more calories. Consequently, the nutritional value of food has been largely ignored, as *The Economist* reported in 2011:

"Nutrition has long been the Cinderella of development. Lack of calories – hunger – is the headline-grabber. But the hidden hunger of micronutrient deficiencies harms even more people and inflicts lasting damage on them and their societies. It, too, worsens as food prices rise: families switch from costly, nutrient-rich, fruit, vegetables and meat to cheaper, nutrient-poor staples."

Widespread and growing iron and zinc deficiency in humans has been detected by the World Health Organization (WHO) in recent decades. Similarly, iodine deficiency has been on the increase globally since the 1970s. Selenium deficiency also now affects large swathes of China and Africa. Micronutrient mining of soils is partly to blame, as some of these deficiencies are linked to the depletion associated with the 'Green Revolution' – the large increase in crop production achieved in in the middle decades of the 20th Century.

Over three billion people on the planet are believed to be suffering the consequences of micronutrient deficiencies, with children being most vulnerable. Even mild cases of hidden hunger can damage mental and physical development, lower disease resistance and cause blindness and other ailments in children.

A special issue of medical journal *The Lancet* in 2008 helped reveal the true human costs of micronutrient deficiencies for the first time. This showed that more than 450,000 children under the age of five die each year in developing countries due to zinc deficiency alone.

Fertilization – a proven strategy

What is striking about tackling micronutrient deficiency and its human consequences is the range of expertise that needs to be brought to bear. It is an issue that involves international development, agronomy, geochemistry, soil science, medicine and economics.

However, the rise of innovative, speciality fertilizers able to correct micronutrient deficiencies, effectively and economically, means crop nutrition is at the vanguard when it comes to tackling hidden hunger. Indeed, agronomic biofortification – the use of measures such as crop management and crop fertilization to increase micronutrient levels in crops – is a proven strategy for tackling deficiency.

The need for speciality products to replenish micronutrients in soils is growing due to a combination of factors. High-yielding crops are removing more micronutrients from soil than before, for example. The prevalence of high-analysis NPK fertilizers, which have fewer trace impurities, also means less micronutrients are being applied.

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Table 1: **Crop yield responses to micronutrients**

Crop	B	Cu	Mn	Zn
Alfalfa	●	●	●	●
Apples	●	●	●	●
Sugar beet	●	●	●	●
Citrus	●	●	●	●
Corn	●	●	●	●
Cotton	●	●	●	●
Grain sorghum	●	●	●	●
Lettuce	●	●	●	●
Oat	●	●	●	●
Peanut	●	●	●	●
Irish potato	●	●	●	●
Sweet potato	●	●	●	●
Rye	●	●	●	●
Soybean	●	●	●	●
Tomato	●	●	●	●
Wheat	●	●	●	●

● *High*
● *Medium*
● *Low*

Source: Mosaic

Crops show a range of yield responses to micronutrients (Table 1). The following crops are particularly responsive to boron, copper, manganese and zinc:

- **Boron:** alfalfa, apples, sugar beet, cotton, peanuts, sweet potato, tomato
- **Copper:** citrus, lettuce, tomato, wheat
- **Manganese:** cotton, lettuce, oats, sweet potato, soybean, wheat
- **Zinc:** corn, grain sorghum, potato

The increases in crop yields that are potentially achievable by applying micronutrients are shown in Table 2.

Application methods

Soil application of micronutrients remains the most common application method for crops. Recommended application rates are low (usually <10 lb/acre, <11 kg/ha), making separate field applications difficult. Because of this, granular or liquid NPK fertilizers are commonly used as micronutrient carriers. Incorporating micronutrients as part of a fertilizer mix is a convenient application method as it enables uniform distribution in the field with conventional spreading equipment. There are four main methods of applying micronutrients with mixed fertilizers:

- **Incorporation during manufacture:** this results in uniform distribution of micronutrients within granular NPK fertilizers
- **Bulk blending with granular fertilizers:** this produces fertilizer grades at the recommended micronutrient rate, although segregation can result in an uneven nutrient distribution
- **Coating onto granular fertilizers:** coating powdered micronutrients onto granular NPK fertilizers decreases the risk of segregation
- **Mixing with liquid fertilizers:** fertigation has become a popular method of application although compatibility tests are required

Foliar sprays are also widely-used to apply micronutrients, especially iron and manganese. Soluble non-chelated inorganic salts are usually chosen as they are generally as effective as more expensive chelated products. Use of a sticker-spreader agent in the spray is often advised to help micronutrients adhere to foliage.

Non-chelated and chelated forms

Micronutrient fertilizers can be split into two main categories: non-chelated and chelated products. Demand for **non-chelated micronutrient products** is rising rapidly, making these products the fastest growing segment of the speciality fertilizer market globally. The largest producers are Yara, Borax, Agrichem, Cheminova, Brandt Consolidated, COMPO and Valagro[1].

Table 2: **Potential yield response to micronutrients application**

Nutrient	Crop	Application	Yield (kg/ha)
Zn	rice	soil	36
Zn	pomegranate	foliar	18
Fe	bean	foliar	133
Fe	soybean	foliar	45
Fe	soybean	soil	9
B	cotton	soil	13
B	sunflower	foliar	49
B	soybean	soil	39
Mn	maize	soil	16
Mn	bean	soil	19
Cu	rice	soil	8.5
Cu	bean	soil	32
Cu	wheat	soil	63
Mo	rice	soil	13

Source: Dimpka & Bindraban (2016)

Non-chelated products are formulated using inorganic micronutrient sources, typically oxides, carbonates, sulphates, borates and molybdates. They can be applied flexibly and incorporated into both compound fertilizers and foliar treatments. Co-formulants are generally incorporated to ensure stability and optimise performance during foliar application and seed coating. Complexing agents are used in liquid micronutrient fertilizers to produce the desired mixing behaviour.

Chelated micronutrient products, as the name suggests, benefit from the incorporation of a chelating agent. Because they are a popular choice in fertigation, growth in demand has tracked the rise in the global market for water soluble fertilizers and drip irrigation (*Fertilizer International* 475, p33). **AkzoNobel**, the current world leader in chelated micronutrients, manufactures and distributes eight trademarks globally. AkzoNobel's *Rexolin* brand is distributed worldwide by Yara International and its *Rexene* brand is distributed by SQM. France's Angibaud & Spécialitées also distributes AkzoNobel's *Ferica* brand. Compass Minerals, SQM and Mosaic also have a strong presence in this market[1].

Chelate is derived from the Greek word for claw and refers to an inorganic nutrient enclosed by an organic molecule. EDTA, DTPA, EDDHA and HBED are the most common chelating agents used. Chelation prevents micronutrients from precipitating into an insoluble form in high concentration liquid fertilizers, particularly those containing phosphate. This makes chelated products the speciality micronutrients of choice for fertigation in combination with water soluble fertilizers.

EDTA is invariably used as a chelating agent for foliar application of micronutrients, including iron. Fe-DTPA is also recommended in hard water areas. EDTA is the most common chelating agent in soil applications, although EDDHA and HBED are preferred for iron in alkaline soils. Iron is generally chelated with HEDTA, DTPA or EDTA in less alkaline and acidic soils.

Selected products and producers

Borax is the world's leading supplier of borates for agriculture, and markets the *Fertibor, Granubor, Solubor* and *Optibor* product range. *Fertibor* is a sodium borate (15.0% B) used in the manufacture of ammoniated, granulated, and suspension fertilizers. It works best in fertilizer suspensions broadcast before planting. *Granubor*

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is a granular form of sodium borate (14.3% B) for use with bulk blended fertilizers. It is suitable for dry blends broadcast prior to planting. *Solubor* is soluble form of sodium borate (20.5% B) designed for liquid fertilizers and foliar sprays. It can be dissolved in water or liquid fertilizers and be applied to soils or directly on crops, with or without pesticides. *Optibor* is a boric acid crop fertilizer.

Borax provides comprehensive agronomic support. A series of crop guides and crop recommendations for alfalfa, banana, canola, coffee, corn, cotton, fruit trees, oil palm, peanuts and soybean are available on the company's website. Its products are all organic certified.

Chile's **SQM** offers the *Ultrasol micro Rexene* range of chelated micronutrient fertilizers, *Rexene* being one of AkzoNobel's trademarks. *Ultrasol* is targeted at the fertigation market and is suitable for agricultural and horticultural crops. The range includes:

- *Ultrasol micro Rexene ABC:* an EDTA-chelated foliar fertilizer that contains Fe, Mn, Cu, Zn, Co, Mg, B, and Mo in a single microgranule
- *Ultrasol micro Rexene Cu15:* a Cu-disodium-EDTA chelate (148 g/kg Cu) for fertigation and foliar use on copper deficient crops or application to copper deficient soils as a solution
- *Ultrasol micro Rexene Zn15:* a Zn-disodium-EDTA chelate chelate (148 g/kg Zn) for fertigation and foliar use on zinc deficient crops or application to zinc deficient soils as a solution
- *Ultrasol micro Rexene Mn13:* a Mn-disodium-EDTA chelate (128 g/kg Mn) for fertigation and foliar use on manganese deficient crops or application to manganese deficient soils as a solution
- *Ultrasol micro Rexene FeD12:* a Fe-sodium-DTPA chelate (116 g/kg of iron) for fertigation and foliar use on iron deficient crops or application to iron deficient soils as a solution
- *Ultrasol micro Rexene FeQ40:* a micro-granular Fe-EDDHA chelate (60 g/kg of iron) for application to alkaline and calcareous soils as a solution

SQM also markets a number of micronutrient products as part of its *Speedfol* foliar range, including:

- *Speedfol B SP:* a polyborate formulation with high boron content (17% B)
- *Speedfol Zn SC:* a highly concentrated zinc source
- *Speedfol Zn+Mn SC:* a highly concentrated zinc and manganese source
- *Speedfol Balance SP:* an NPKS product containing 500 ppm Fe and 100 ppm each of B, Cu, Mn and Zn

SQM is also gearing up to launch *Speedfol Iodine SP*, the latest micronutrient product addition to its foliar range (*Fertilizer International* 477, p 38).

Haifa, an Israel-based global supplier of potassium nitrate and speciality fertilizers, offers water soluble chelated micronutrient products for the fertigation market and for foliar application under its *Haifa Micro* trademark. The range includes:

- *Haifa Micro Fe:* Iron-EDTA chelate, 6% or 13% Fe
- *Haifa Micro Mn:* Manganese-EDTA, 13% Mn
- *Haifa Micro Zn:* Zinc-EDTA, 4% Zn
- *Haifa Micro Cu:* Copper-EDTA, 14% Cu
- *Haifa Micro Comb:* 7.1% Fe, 3.48% Mn, 1.02% Zn, 0.76% Cu, all EDTA chelates, and 0.485% Mo as ammonium molybdate
- *Haifa Micro soilless combination:* 6.5% Fe-DTPA, 3.48% Mn-EDTA, 1.02% Zn-EDTA, 0.76% Cu-EDTA and 0.485% Mo as ammonium molybdate

North America has a healthy micronutrient market. They are often supplied in products alongside sulphur (*Fertilizer International* 476, p19). **The Mosaic Company** has led the way with its pioneering sulphur-enhanced monoammonium phosphate (MAP) product range, *MicroEssentials*. This broke through the one million t/a barrier at the end of 2013. One of the main formulations offered is the zinc-fortified *MicroEssentials SZ* (12-40-0 10S 1Zn). This combines 12% nitrogen, 40% phosphorus and 10% sulphur with 1% zinc.

The proprietary *Fusion* process used in the manufacture of *MicroEssentials* joins together nitrogen, phosphorus, sulphur and zinc to create a nutritionally-balanced granule capable of boosting crop yields by 3-7%, compared to conventional MAP or DAP.

In 2014, Mosaic also launched a new micronutrient product, *Aspire*, a boron-enhanced potash fertilizer. This first-of-its-kind premium potash fertilizer (0-0-58-0.5B) combines potassium chloride (58% K_2O) with boron (0.5%). This is uniformly distributed within granules using proprietary *Nutriform* technology. *Aspire* is being targeted at the growing micronutrient needs of crops like corn, soybeans, alfalfa and cotton.

Tiger-Sul Products, a Canadian subsidiary of Connecticut-based **HJ Baker & Bro, Inc**, is a leading and long-standing global sulphur-bentonite supplier. Tiger-Sul also manufactures and markets *Tiger Micronutrients*, a range of premium sulphur-enhanced fertilizers. These combine *Tiger 90 CR* sulphur-bentonite with micronutrients using proprietary *Microsite Enhanced* technology. The range includes:

- *Tiger Zinc* 18% (65% S + 18% Zn)
- *Tiger Manganese* 15% (63% S + 15% Mn)
- *Tiger Copper* 7% (80% S + 7% Cu)
- *Tiger Copper* 12% (72% S + 12% Cu)
- *Tiger Iron* 22% (55% S + 22% Fe)

Compass Minerals manufactures the popular *Wolf Trax DDP* (Dry Dispersible Powder) *Nutrients* line. These high-analysis products coat NPK granules during blending and include:

- 18.5% Boron DDP
- 27.0% Calcium DDP
- 57.5% Copper DDP
- 47.0% Iron DDP
- 30.0% Magnesium DDP
- 33.0% Manganese DDP
- 62.0% Zinc DDP

Wolf Trax DDP Nutrients incorporate four proprietary innovations. They use *EvenCoat* technology to coat every NPK granule in a fertilizer blend with micronutrients. Once applied, this coating does not come off during subsequent handling and transport. This ensures micronutrients are evenly distributed across the field and are available in close proximity to plant roots for early plant uptake.

The patented *PlantActiv* formulation further improves micronutrient availability by avoiding soil fixation and ensuring that particle size is the optimum for plant uptake. *Wolf Trax DPP* products also contain micronutrients in multiple forms, ensuring both immediate and longer-term availability, a property Compass Minerals calls *DUAL ACTION* availability. Finally, *Wolf Trax DPP* can be used flexibly (*FlexUse*) and applied in three different ways: as a dry fertilizer coating, mixed with liquid fertilizers, or as a foliar spray.

EvenCoat has helped solve the industry's long-standing segregation problem, as Paul Reising, senior product manager for micronutrients at Compass Minerals, recently explained to *CropLife magazine*:

"The further away dry granules get from the blender, the more segregation occurs," commented Reising. "Zinc and manganese are denser elements than the N, P, and K that they're applied onto, so if the truck drives down the road, hits some bumps or a pothole or two, they start to segregate."

Reising also says that *Wolf Trax DDP*-coated fertilizer granules are more available to plants, compared to liquid blends applied in-furrow, especially during Corn Belt planting in cold, wet spring conditions.

Compass Minerals also offers *Nu-Trax P+*, another innovative micronutrient product. Comprised of a custom blend of phosphorus, zinc, manganese and nitrogen, this P-based fertilizer improves early-season nutrition to crops. This helps plants develop a more fibrous root system, according to the company, one that is better able to handle environmental stress and helps maximise yields.

Corn Belt growers are using *Nu-Trax P+* to substitute for liquid starters. "The starter fertilizers utilised by farmers in the Midwest – where more and more they are planting into colder soils where phosphorus availability can be tricky – it's not tremendously available to the plant when it most needs it," says Reising. "This dry blend on pre-plant is a much more efficient system for some growers."

2017 will be a year of expansion for Compass Minerals. The company launched a new *Wolf Trax* product, *Statesville Manganese*, in February. This will target corn growers in the Mid-South of the US, as Reising explains: "This product will feature three sources of manganese and is oriented toward those corn growers in, say South Georgia or the Carolinas, where humidity issues tend to pop up throughout the spring."

Following the recent purchase of Brazil's Produquímica, Compass Minerals is also planning to expand its plant nutrition portfolio in North America later this year. Vatren Jurin, senior product manager for plant nutrition, told *CropLife*: "In 2017 we plan to introduce a complete line of soluble nutrients for seed treatment, foliar nutrition, fertigation, hydroponics and more."

Norway's **Yara International** occupies a leading position in the overlapping water soluble fertilizer, fertigation and micronutrient product markets. Its *YaraTera KRISTALON* water soluble NPK product range contains a full spectrum of micronutrients in chelated form. These are suitable for drip, tape, sprinkler or pivot irrigation systems. The company's *YaraTera REXOLIN* product range also incorporates fully water soluble chelated micronutrients. These are suited for soil, foliar and hydroponic applications, and ensure micronutrients remain available to crops, without the risk of precipitation or fixation. A third chelated micronutrient product, *YaraTera TENSO COCKTAIL* is a wettable powder that can be tank mixed with other water soluble fertilizers to address micronutrient deficiencies in hydroponic and fertigation applications.

A range of micronutrient formulations are also offered as part of the company's *YaraVita* product range. The foliar fertilizer *YaraVita BEETRAC*, for example, is designed to prevent micronutrient deficiencies in sugar beet (*Fertilizer International* 467, p24) and contains manganese, sulphur, boron, copper and zinc. *YaraVita BRASSITREL PRO*, a liquid suspension for foliar application to oilseed rape (*Fertilizer International* 477, p15), brassicas (*Fertilizer International* 472, p40) and legumes, contains manganese, magnesium, boron and molybdenum.

Two other foliar liquid suspension products, *YaraVita BUD BUILDER FL* (Mg, Zn, N, B and P) and *YaraVita GRAMITREL* (N, Mn, Mg, Cu and Zn) are targeted at soft fruit flowering and cereal yields, respectively. A formulation of the *YaraMila* NPKS fertilizer incorporating magnesium, sulphur, boron, iron, manganese and molybdenum is also available in either prill or granule form.

An attractive global market

The higher performance of chelated micronutrients, relative to their non-chelated counterparts, means they can be sold at a higher price in the market. The nutrient and water efficiency of fertigation – a key market for chelated micronutrients – also generates enough cost savings to support this price differential[1].

Although the size of the segment is relatively small in volume terms, higher value and better margins make micronutrients a very attractive global market – one which looks set to grow at a very fast rate for the foreseeable future[1].

In North America, there is a view that any softening in the pricing of N, P and K fertilizers could also leave more farm dollars available for spending on micronutrients. If true, higher zinc and sulphur applications to corn, and manganese applications to soybeans, are likely to be the main beneficiaries. ■

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Advances in sulphuric acid plant design

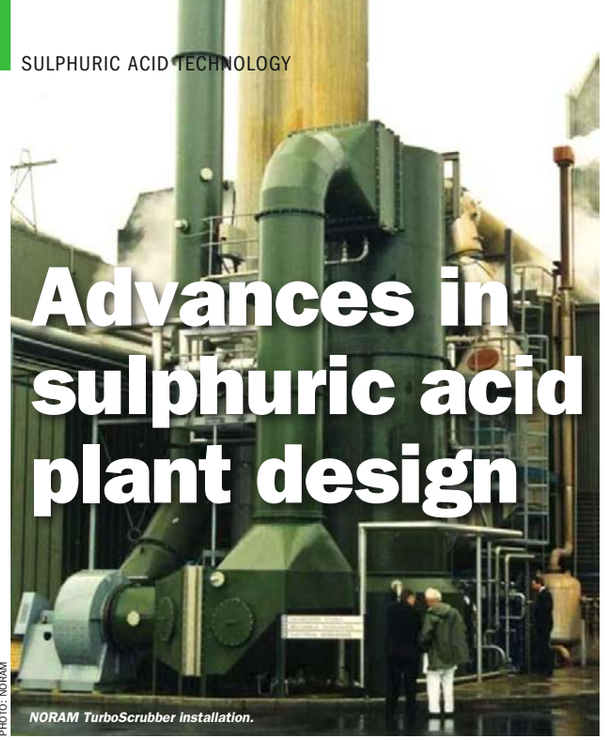


PHOTO: NORAM

NORAM TurboScrubber installation.

Innovative technologies from MECS, Outotec, NORAM, Chemetics and Shell are helping transform the economics of sulphuric acid production and reduce emissions. New sulphuric acid plant designs are combining novel technologies in new process line-ups.

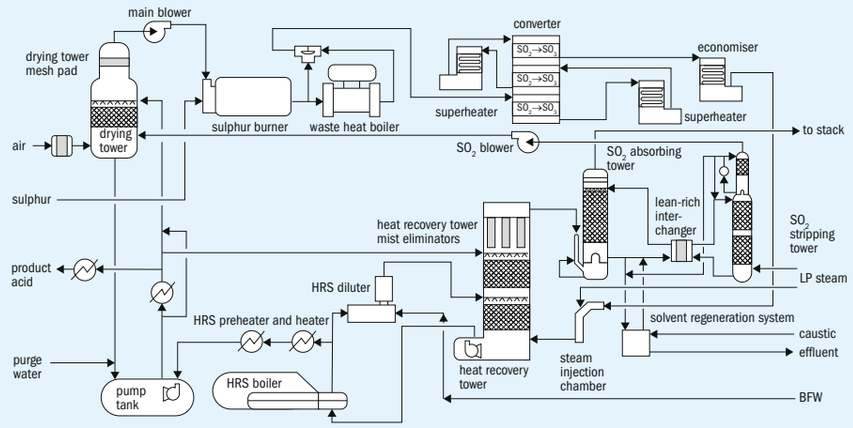
Gradually, year-by-year, incremental advances in technology are steadily improving the performance of sulphuric acid plants. Better catalysts are helping to cut emissions, for example. Developments in heat recovery technology are also improving plant energy efficiency. But small, incremental improvements are unlikely to satisfy an industry that is increasingly seeking a step-change in plant costs, energy use and environmental protection.

An integrated solution from MECS

Valuably, the MECS® *MAX3*™ process achieves what incremental improvements cannot. It combines two innovative technologies (*SteaMax*™ and *SolvR*®) into a single technology to provide an integrated solution that addresses the future cost, energy recovery, and emissions needs of sulphuric acid plants.

The *MAX3*™ sulphuric acid plant process simplifies the conventional sulphuric acid plant flow scheme while recovering more energy than conventional *HRS*™ technology and achieving best-in-class stack emissions. *MAX3*™ combines MECS' proprietary *SolvR*® regenerative SO_2 absorption system with *SteaMax*™ technology to shift to a single absorption plant arrangement (Figure 1), eliminating equipment and reducing cost.

Fig 1: **The MECS® *MAX3*™ process**



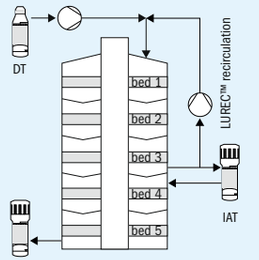
Source: MECS

Table 1: **Key data for *MAX3*™ compared to conventional sulphuric acid plant technology**

Export / import	Double absorption	Double absorption with *SteaMax*™	*MAX3*™
HP steam (40 barg, 400°C), kg/h	133,700	132,800	146,500
t/t	1.3	1.3	1.5
IP steam (10 barg, saturated), kg/h	13,000	29,000	19,000
t/t	0.13	0.29	0.20
SO_2 emissions, ppmv	140	140	30
Cooling water, m^3/h	3,200	850	1,200
Power use, kWh	5,500	5,500	3,200
Relative TIC	100	110	100
Chemicals, $	0	0	250,000

Source: MECS

Fig 2: **Principle of *LUREC*™ recirculation**



Source: Outotec

The *MAX3*™ process also moves beyond the historic approach of maximising intermediate-pressure steam (e.g. 10 bar) in favour of producing more high-pressure steam. By optimising energy recovery, the *MAX3*™ process reduces, and can even eliminate, cooling water consumption. Finally, MECS' proprietary SO_2 regeneration solvent provides a significant improvement over existing technologies, especially in terms of steam consumption, materials of construction and effluent treatment. Table 1 summarises the key data for *MAX3*™ compared to conventional sulphuric acid plant technology.

Outotec sulphuric acid technologies

Outotec has been a provider of sulphuric acid production technologies for more than 80 years. Outotec's *LUREC*™ and *HEROS*™ technologies can be combined in highly-efficient sulphuric acid production configurations.

Outotec *LUREC*™ process

Oxygen enrichment used in modern copper smelting processes produces a strong SO_2 off-gas. The *LUREC*™ process was developed to process these strong off-gases from continuous processes such as Outotec flash smelting or flash converting.

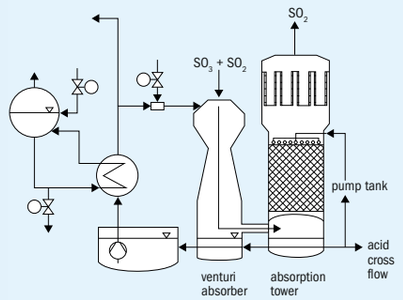
Reducing the total gas flow in an acid plant is advantageous as it lowers opex and capex costs due to the power savings in the main blower and the reduction in equipment size. Lower gas flows can be achieved by operating acid plants at high SO_2 concentrations. However, a conventional acid plant (inlet temperature of 420°C) is limited to a SO_2 concentration of 12 vol-% by the maximum catalyst operating temperature.

The principle of Outotec *LUREC*™ recirculation is shown in Figure 2. The technology limits the outlet temperature of bed 1 by recirculating some of the SO_3-rich gas from the exit of bed 3 to the feed gas of bed 1. This delivers significant capex and opex benefits by allowing operation at much higher SO_2 inlet concentrations than is possible with conventional plants.

Another advantage of operating at high SO_2 concentrations is that the excess heat generated is suitable for high-pressure steam production. By increasing SO_2 concentrations above 12 vol-%, the amount of excess heat that must be removed from the system increases significantly, enabling stand-alone power generation from high-pressure steam.

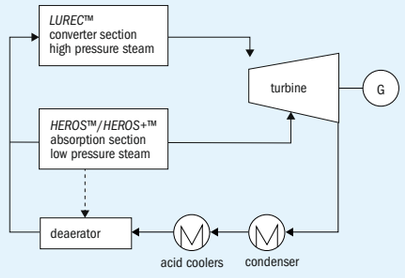
In principle, SO_3 gas recirculation allows SO_2 gas to be processed at concentrations of up to 25 vol-%. However, in the

Fig 3: **Typical Outotec heat recovery system (*HEROS*™)**



Source: Outotec

Fig 4: **Enhanced power generation in a *LUREC*™ acid plant combined with *HEROS*™ designs**



Source: Outotec

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Table 2: **Technical comparison of a conventional plant with different solutions for power generation** (all *LUREC*™ process solutions in the table use 18 %-vol SO_2)

Basis 4,250 t/d	Conventional 12 vol-% SO_2	*LUREC*™	*LUREC*™ with *HEROS*™	*LUREC*™ with *HEROS+*™
Gas flow to converter, Nm^3/h	330,000	220,000	220,000	220,000
Power consumption, kWh/t H_2SO_4	55	43	45	46
LP steam generation: 100 kPa, saturated, t/h	-	-	62	72
HP steam generation: 400 kPa, 480°C, t/h	-	46	46	53
Power generated, MW	-	12	21	24
Net power export, MW	-	4.5	13.1	16.1
Emissions, kg SO_2/t H_2SO_4 (basis 250 ppmv)	1.1	0.75	0.75	0.75

Source: Outotec

case of copper smelter off-gas, the practical concentration range is between 16 and 18 vol-% SO_2 due to the amount of oxygen required for conversion.

Outotec *HEROS*™ Process

A large amount of heat is released by the absorption of SO_3. Outotec's *HEROS*™ process (Figure 3) generates saturated low-pressure steam by capturing the absorption energy released at the intermediate absorption step. Most of the SO_3 absorption takes place in a co-current venturi at high temperature and is used to produce low pressure steam in the *HEROS*™ boiler. The remaining SO_3 is absorbed in the intermediate absorption tower downstream of the venturi. The intermediate absorption tower is a conventional full capacity design capable of handling all SO_3 when the *HEROS*™ is not in operation.

Outotec's *HEROS+*™ process is able to maximise power generation by increasing the production of valuable high-pressure steam. This integrated concept improves efficiency of the standard *HEROS*™ system by using energy recovered in the acid coolers to pre-heat boiler feed water.

Combining *LUREC*™ and *HEROS*™

A combination of *LUREC*™ and *HEROS*™ technology is beneficial for treating off-gas from a continuous Outotec flash smelter and Outotec flash converter. This makes a perfect gas source for heat integration because of its strong and continuous flow. The design basis for the described 4,250 t/d *LUREC*™ acid plant is a strong 18 vol-% SO_2 gas with 14 vol-% O_2.

Figure 4 shows the key elements of the combined technologies: High pressure steam from a *LUREC*™ converter section and low pressure steam from a *HEROS*™ section are fed into a turbine. This is combined with the pre-heating of boiler feed water in the acid coolers.

Compared to a conventional plant, the low gas flow rate of a *LUREC*™ plant reduces the size of the extra recirculation blower and reduces the overall power consumption of the plant. Table 2 shows the difference in gas flow between a conventional (330,000 Nm^3/h) and a *LUREC*™ plant (220,000 Nm^3/h). The reduced specific power consumption per tonne of sulphuric acid for the *LUREC*™ design is a direct consequence of this lower gas flow. Table 2 also shows the potential for steam production when combining a *LUREC*™ plant concept with *HEROS*™ or *HEROS+*™.

Further advantages of *LUREC*™ technology include reduced SO_2 emissions (based on SO_2/t H_2SO_4) and lower cooling water consumption. The increase in net power export for all three combinations in Table 2 also clearly demonstrate the efficiency gains relative to a conventional plant.

To achieve the most economic plant concept, plant designs for specific projects are tailored to individual customer requirements. The combination of the *LUREC*™ process with either *HEROS*™ or *HEROS+*™ is a perfect fit when it comes to optimising plant efficiency.

NORAM *TurboScrubber*® process line-ups

The *TurboScrubber*® fluidised bed technology licensed by NORAM has been successfully applied to a wide range of SO_2 applications. In the sulphuric acid industry, *TurboScrubber*® can potentially be used to great effect in new process line-ups which eliminate sub-micron sulphuric acid mist as well as scrub SO_2 gas. It is a flexible technology that can be used for both gas cleaning and tail gas scrubbing.

Gas cleaning

NORAM's *TurboScrubber*® system can replace the conventional gas cleaning section of a sulphuric acid regeneration or metallurgical acid plant. Replacing the venturi scrubber, the cooling tower and/or one stage of wet electrostatic precipitation (WESP) with *TurboScrubber*® both simplifies the process line-up (Figure 5) and provides net savings in pressure drop. Additional benefits include:

- Continuous as well as start-up scrubbing of particulates, dust, condensed metals and sub-micron sulphuric acid mist
- The scrubber is non-fouling
- Cost savings from elimination of the expensive WESPs
- Different operating modes depending on the mist and dust loads

The following common combinations of gas cleaning equipment can be replaced by the *TurboScrubber*® system:

- High pressure drop fixed-throat venturi scrubber and cooling tower
- High pressure drop variable-throat venturi scrubber and cooling tower
- Reverse-jet scrubber and cooling tower/froth column
- Radial flow scrubber and cooling tower

Such replacements are possible because *TurboScrubber*®:

- Achieves particulate and aerosol removal with high efficiencies
- Is countercurrent, which is important for heat transfer, cooling and water removal
- Does not foul in dirty service

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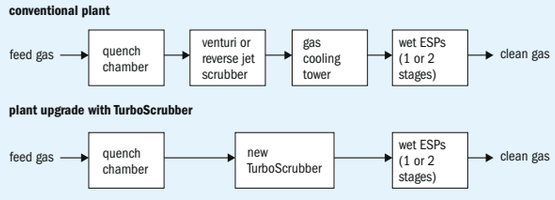
Fig 5: **Gas cleaning process line-ups**



Source: NORAM

- Has a potentially lower pressure-drop of about 20 inch WC, compared to 25-50 inch WC for other equipment combinations

Tail gas scrubbing

NORAM's *TurboScrubber®* system can also be installed as a tail gas scrubber at the tail end of a sulphuric acid plant. Environmental regulations governing SO_2 emissions are becoming ever tighter around the world. This holds true for plants in the start-up phase and in continuous operation.

Installing a *TurboScrubber®* after the final absorption tower of an acid plant significantly reduces stack emissions during both start-up and continuous operation. Plants often experience an acid plume from the stack during start-up, due to cold acid not being able to fully absorb SO_3.

One key feature of the *TurboScrubber®* is that it allows the liquid-to-gas ratio to be modified during both start-up and normal operation. This flexibility enables one single piece of equipment to be used for two very different operational phases:

- SO_2 and acid plume removal during start-up
- SO_2 removal during normal operation

In addition to removing SO_2, the *TurboScrubber®* also has the ability to remove fine acid mist downstream from the final absorption tower. *TurboScrubber®* allows the high efficiency mist eliminator – typically candles – in the final absorption tower to be replaced with a low pressure drop mesh pad. It can therefore be installed without adding pressure drop to the plant.

Case study: TurboScrubber acid mist reductions

The following case study is based on a sulphur burning plant producing up to 600 t/d of sulphuric acid. The stack emissions during continuous operation are approximately 310 ppmv SO_2.

The plant has an upstream final absorption tower (FAT) with Brownian diffusion (BD) candles. The acid tower operates with an acid inlet concentration of 98.5 wt-% and inlet temperature of 80°C. The BD candles operate with a 10 inch WC pressure drop. The purpose of the BD candles is to remove acid mist to meet the emissions limit, which generally in the US is 0.075 kg H_2SO_4/t H_2SO_4. There are three sources of acid mist stack emissions:

- Acid spray and mist
- H_2SO_4 vapour
- SO_3 slippage

Acid spray is generally formed by mechanical splashing or by spray nozzles and are >3 microns in size. Acid mist is generally <3 microns and is produced by gas phase condensation during gas cooling. Even smaller mist particles can be formed from a gas phase reaction. The last source of acid emissions is SO_3 slippage. In a correctly designed and operating acid tower, the absorption efficiency should be 99.9% or higher.

Table 3: **Comparison of estimated acid emissions**

	FAT with BD candles			FAT with mesh pad			FAT with mesh pad + TurboScrubber		
	Inlet to FAT mist eliminator	**Removal efficiency**	**Outlet of FAT BD candle**	**Inlet to FAT mist eliminator**	**Removal efficiency**	**Outlet of FAT mesh pad**	**Inlet to TurboScrubber**	**Removal efficiency**	**Outlet of TurboScrubber**
Acid mist	700 mg/m³	-	4.2 mg/m³	700 mg/m³	-	112 mg/m³	138 mg/m³	-	11.7 mg/m³
<1 micron	30 wt-%	98%	4.2 mg/m³	30 wt-%	60%	84 mg/m³	75 wt-%	89%	11.4 mg/m³
1-3 micron	40 wt-%	100%	-	40 wt-%	90%	28 mg/m³	25 wt-%	99%	0.3 mg/m³
>3 micron	30 wt-%	100%	-	30 wt-%	100%	-	-	100%	-
Overall removal efficiency	-	99.4%	-		84.0%	-	-	96.3%	-
Total acid mist	47 kg/h 1.940 kg/t		0.3 kg/h 0.012 kg/t	47 kg/h 1.940 kg/t		7.5 kg/h 0.310 kg/t	9 kg/h 0.382 kg/t		0.8 kg/h 0.032 kg/t
Acid vapour	1.5 kg/h 0.06 kg/t		- -	1.5 kg/h 0.06 kg/t		1.5 kg/h 0.06 kg/t	- -	-	-
SO_3 slippage	0.3 kg/h 0.011 kg/t		- -	0.3 kg/h 0.011 kg/t		0.3 kg/h 0.011 kg/t	- -	-	-
Total acid emission	- -	- -	2.0 kg/h **0.083 kg/t**	-		9.2 kg/h **0.382 kg/t**	- -	-	0.8 kg/h **0.032 kg/t**

Note: Unit kg/t refers to kg H_2SO_4 emitted per tonne H_2SO_4 produced (as 100% H_2SO_4). *Source: NORAM*

SULPHURIC ACID TECHNOLOGY

This case study concentrates on the final absorption tower of a sulphur burning double absorption plant. The acid spray and mist load is up to 1,000 mg/m³, with an approximate distribution by weight of 30% <1 microns, 40% 1-3 microns and 30% >3 microns. The predicted results shown in Table 3 are for mist load of 700 mg/m³ and a FAT absorption efficiency of 99.99%.

Table 3 results show that a FAT equipped with high efficiency BD candles will have difficulty meeting the general US acid emission limit – indeed, emissions would be 11% too high. This is because the outlet gas, if saturated with acid and SO_3 vapour, will be very close to the limit, leaving very little room for upsets such as candle or SO_3 absorption performance excursions.

The acid emissions can be lowered by the use of a tail gas SO_2 scrubber. As the outlet gas from the final absorption tower is cooled further to 50°C and mixed with water vapour in the scrubber, the SO_3 and H_2SO_4 react readily with water and condense. Most of this condensation will likely take place homogeneously or on existing acid mist particles not removed in the upstream FAT. It is necessary to remove this newly-formed mist efficiently in the scrubber. The *TurboScrubber®* fluidised bed system can achieve this without the use of costly BD candles.

NORAM proposes replacing BD candles in the FAT with a low pressure drop mesh pad followed by a *TurboScrubber®* downstream. Removing the BD candles will free-up a 10 inch WC pressure drop with about 2 inch WC being used in the replacement mesh pad. The net 8 inch WC saved can be used in the scrubber for mist removal.

Removing the BD candles will result in more acid carry-over to the scrubber. As shown in Table 3, the total acid mist carry-over with a mesh pad in the FAT is about 7.5 kg/h versus 0.3 kg/h with BD candles. This additional acid mist carry-over only adds about 10% to alkaline chemicals consumption, as the SO_2 flow rate of 46 kg/h corresponds to 71 kg/h of H_2SO_4.

The gas leaving the final absorption tower mesh pad will have acid mist, acid vapour and SO_3 vapour from slippage. Table 3 shows that with *TurboScrubber®*, about 96.3% of the acid mist entering the fluidised bed scrubber is removed. Simultaneously, the SO_2 can be scrubbed from 310 to 2 ppmv (99.4% removal) with a scrubber pressure drop of only 8 inch WC. This 8 inch WC pressure drop of the scrubber system is also compensated for by replacing the BD candles in the FAT with a mesh pad. In this way, the *TurboScrubber®* system can be added to an existing plant without adding pressure drop to the acid plant.

In conclusion, by substituting the original FAT with a *TurboScrubber®* system, acid emissions are reduced from 0.083 to 0.032 kg H_2SO_4/t H_2SO_4, well below the regulatory limit. In addition, the SO_2 removal efficiency provides a large margin for SO_2 emissions requirements, which for some clients may be used for SO_2 credit trading.

Shell *Cansolv* SO_2 and Chemetics *BAYQIK®* technologies

Sulphuric acid production presents many challenges for smelter operators, including:

- Variable concentration of SO_2 in the off gases
- Fugitive emissions from multiple sources with weak SO_2 concentrations
- Off gases with high concentrations of SO_2 that must be diluted with ambient air
- Environmental regulations that impose SO_2 emissions reductions

The *BAYQIK®* process for the catalytic oxidation of SO_2 originally developed by Bayer AG can be easily integrated into an existing sulphuric acid plant. This innovative process is now offered by Chemetics following its purchase of all patents and know-how for *BAYQIK®* converter technology from Bayer in August 2016.

The Chemetics *BAYQIK®* converter enables sulphuric acid to be produced from constant or fluctuating gas streams with SO_2 concentration of up to 50%. The resulting acid plant has a smaller footprint, lower catalyst demand and a higher capacity for steam production when compared to single absorption (SA) and double absorption (DA) sulphuric acid plants.

The ability to cope with gases over a wide SO_2-concentration range, and its flexibility in terms of varying gas conditions, makes Chemetics *BAYQIK®* technology ideal for applications in challenging environments such as metallurgical plants. Since 2009, an industrial-scale plant incorporating the Chemetics *BAYQIK®* converter has been operating in a metallurgical application treating a process gas with fluctuating SO_2 concentrations peaking at up to 23 vol-%. Another industrial-scale plant was commissioned in Belgium in February this year. Several other plants are also at the design stage currently.

Shell's *Cansolv* SO_2 Scrubbing System enables sulphuric acid production from lean SO_2 gas streams by concentrating SO_2 into a pure gas stream. This has the added benefit of reducing emissions to levels lower than double absorption plants with a smaller pressure drop. The Shell *Cansolv* system, aside from its ability to meet SO_2 emissions targets as low as 10 ppmv, offers several specific benefits in metallurgical and acid plant applications (Table 4).

Combining Chemetics *BAYQIK®* and Shell *Cansolv* technologies creates synergies which amplify their individual benefits. The value added by bringing the two technologies together includes:

- The Shell *Cansolv* unit allows Chemetics *BAYQIK®* systems to be designed for optimum SO_2 conversion efficiency, in terms of capex, as it can cost-effectively manage the emissions resulting from limited conversion at higher SO_2 concentrations
- By acting as an SO_2 concentrator, the Shell *Cansolv* unit also helps maximise the SO_2 concentration at the Chemetics *BAYQIK®* system's inlet, so enabling the size and cost of the sulphuric acid production unit to be minimised
- Finally, the steam produced from the net energy output of the Chemetics *BAYQIK®* unit can be used in the regeneration step of the Shell *Cansolv* unit

Table 4: **Advantages of the Shell Cansolv SO_2 scrubbing system for metallurgical off-gas and acid plant tail gas applications**

Metallurgical off-gas applications

- Ability to handle inlet gases with variable SO_2 concentration (load levelling)
- Ability to handle gases at low SO_2 concentration below 1,000 ppmv
- Ability to handle multiple sources of gases
- All captured SO_2 is recycled to converted sulphuric acid

Acid plant tail gas applications

- Low pressure drop (typically less than 3 kPa)
- Ability to handle peaks in SO_2 concentration that usually occur during upsets and start-ups
- All captured SO_2 is recycled to the acid plant and converted to sulphuric acid

Source: Shell Cansolv

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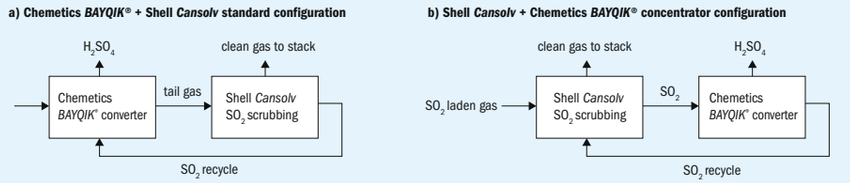
Fig 6: **Shell Cansolv + Chemetics BAYQIK configurations**



Source: Shell Cansolv

The Shell *Cansolv* unit can be positioned downstream of the Chemetics *BAYQIK*® unit in traditional tail gas treatment (standard configuration, Figure 6a). In other applications, the value of combining the two technologies requires placing the Shell *Cansolv* unit upstream of the Chemetics *BAYQIK*® unit, where it serves as an SO_2 concentrator while still treating the tail gas (concentrator configuration, Figure 6b).

The benefits of combining Shell *Cansolv* + Chemetics *BAYQIK*® are illustrated by the following two case studies.

Case study 1: Chemetics *BAYQIK*® + Shell *Cansolv* compared to conventional acid plant line-ups

Table 5 compares the standard Shell *Cansolv* + Chemetics *BAYQIK*® line-up (Figure 6a) with other traditional plant line-ups. These line-up options are for a 530 t/d sulphuric acid plant processing 11 vol-% SO_2 gas. Gas flow is 45,000 Nm^3/h and is assumed to be clean and dry. The four line-ups compared are:

- A single absorption (SA) acid plant
- A single absorption plant followed by a hydrogen peroxide tail gas scrubber
- A double absorption (DA) acid plant
- A Chemetics *BAYQIK*® acid plant followed by a Shell *Cansolv* SO_2 regenerative scrubbing system, where the Chemetics *BAYQIK*® system is designed to convert 95% of the incoming SO_2

Results show that SO_2 emissions and net acid production from the standard Shell *Cansolv* + Chemetics *BAYQIK*® line-up is comparable to that of a single absorption unit coupled with a hydrogen peroxide tail gas scrubber, and better than the double absorption acid plant. The pressure drop is slightly lower in a Shell *Cansolv* + Chemetics *BAYQIK*® line-up due to a lower number of heat exchangers in the gas path. It also consumes far less in terms of reagents with increasing SO_2 concentration in the inlet gas. Moreover, the Shell *Cansolv* + Chemetics *BAYQIK*® line-up generates the most additional steam.

Table 5: **Comparison of sulphuric acid production technologies with and without tail gas scrubbing**

	SA	SA + H_2O_2	DA	*BAYQIK* + *Cansolv*
SO_2 emissions, ppmv	< 3,000-6,000	< 50	< 150 - 400	< 50
Net steam production kg/t acid (t/h)	530 (12)	530 (12)	445 (10)	830 (15)
Pressure drop, mbar	290	330	350	240
Main blower energy consumption, kW	510	580	615	420
H_2O_2 consumption (50 wt-%), t/d	-	13	-	-
Catalyst filling, m^3	115	11	100	40

Source: Shell Cansolv

Table 6: **Gas flow rate and SO_2 concentration from multiple point sources**

	Acid plant	Slag furnace	Converter	
			Slag blow*	Blister blow*
Flow rate, Nm^3/h up to	15,000	10,000	40,000	50,000
SO_2 vol-% (dry)	≤ 1	1	up to 5	up to 6

Source: Shell Cansolv **Slag and blister blowing steps occurring intermittently during converter cycle.*

For applications where the SO_2 concentration is higher than 12 vol-% (in a copper flash furnace off-gas, for example), the Shell *Cansolv* + Chemetics *BAYQIK*® line-up offers even bigger cost advantages. This is because it will be designed to operate at higher concentration without dilution, whereas a traditional acid plant will require dilution of the inlet gas. The Chemetics *BAYQIK*® unit alone can result in a 40% capex reduction when compared to conventional acid plant technology.

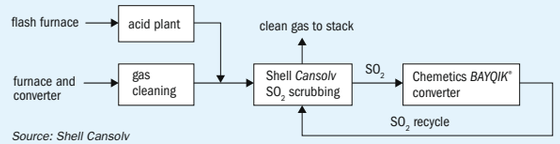
The Chemetics *BAYQIK*® line-up should also show a better environmental performance in terms of emissions intensity (kilogram of SO_2 per tonne of sulphuric acid produced), the metric commonly used to set acid plant emissions targets. Because it operates at higher concentration, this line-up processes less gas for the same acid production, resulting in a lower emissions intensity at a given tail gas SO_2 concentration.

Without the external input of energy, traditional acid plants cannot operate in a sustained way when the concentration of SO_2 falls below 5-6%. Whereas auto-thermal operation is possible using an in-line configuration of a Chemetics *BAYQIK*® unit followed by a Shell *Cansolv* unit, even when the inlet SO_2 concentration falls to less than 3 vol-%.

The standard Shell *Cansolv* + Chemetics *BAYQIK*® line-up (Figure 6a) therefore provides greater flexibility with respect to turndown ratio when compared to conventional sulphuric acid technology, as both units can operate at extremely low SO_2 concentrations without the use of additional fuel gas to maintain converter temperature.

Case study 2: Integrated multi-source management

Fig 7: **Proposed solution for multiple point source SO_2 management**



Source: Shell Cansolv

Sites often face more complex SO_2 management challenges, involving several gas sources of different concentrations, some of them highly variable or cyclical. In this metallurgical application case study, the aim was to reduce the emissions from a single absorption acid plant processing gas from a flash furnace, with a 5-9% inlet SO_2 concentration, that produces up to 150 t/d of acid. The proposed solution also needed to treat additional sources of gas from a converter and a slag furnace. The furnace gas has a low SO_2 concentration, while the converter gas fluctuates over an 8 hour converter cycle. Characteristics of the different gases are given in Table 6.

The proposed system addresses the different challenges of this application – multiple gas sources, variable SO_2 concentrations, and the need for additional conversion capacity – in a simple and cost effective way (Figure 7).

The gases from the furnace and converter go through a standard metallurgical gas cleaning system before both entering the Shell *Cansolv* absorber. The acid plant tail gas is also fed directly to the same absorber. The Shell *Cansolv* unit captures SO_2 from all gas streams and delivers it as a pure SO_2 stream to the Chemetics *BAYQIK*® unit for conversion to sulphuric acid. Finally, the Chemetics *BAYQIK*® unit tail gas is sent back to the Shell *Cansolv* absorber in a recycle loop.

Placing the Shell *Cansolv* unit upstream enables peak conditions to be managed by a smaller Chemetics *BAYQIK*® unit, since the SO_2 is first concentrated by the Shell *Cansolv* system and then sent to the Chemetics *BAYQIK*® unit at a steady flow rate.

The Chemetics *BAYQIK*® unit processes inlet gas at high concentration, while the conventional acid plant processes gases at between 6-9 vol-%. The incremental cost for this solution is therefore a fraction of the cost of a new acid plant. At the same time, the proposed solution de-risks the entire line-up due to its greater flexibility, availability and lower SO_2 emissions. Reduced catalyst consumption, a long operation cycle between maintenance shutdowns and full automation also contribute significant additional value. ■

Acknowledgement

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Unlocking the African market

Improving the supply, trade and distribution of fertilizers holds the key to unlocking Sub-Saharan Africa's massive agricultural potential. Increasing fertilizer availability and affordability in the region will require stronger supply and distribution channels, access to finance and trade policy reforms – coupled to improvements in agricultural extension services to help boost demand.

PHOTO: TRAVEL STOCK/SHUTTERSTOCK.COM

Tending crops in a pineapple field, Uganda.

It is hard to overstate the importance of agriculture to Africa. The sector holds the key to the continent's economic prosperity, the livelihoods of its people and its food security. Agriculture currently accounts for about 20% of Africa's GDP, 60% of the continent's jobs and 20% of its exports in goods. The sector is also main source of income for 90% of Africa's rural population. In Sub-Saharan Africa, agriculture covering a 215 million hectare area contributes roughly $400 billion to regional GDP.

Africa is one of just a few regions of the world where large unexploited tracts of land remain available for agricultural development. Only 29 percent of the continent's arable land is currently farmed and over half of global unused fertile cropland is believed to be located in Africa. Yet the continent's huge agricultural potential remains largely undeveloped. A number of barriers, including inefficient distribution and high costs, have also prevented farmers from applying fertilizers in the quantities required to maintain soil nutrient levels.

Closing the yield gap

Poor soil fertility, by depressing crop yields, has acted as a major limit on agricultural productivity in Sub-Saharan Africa. Average yields for cereals grown in the region (<1.5 t/ha) have stagnated at 25 percent of attainable yields (>5 t/ha).

Fertilizers have a vital role to play in closing such yield gaps having, for example, contributed more than 30 percent to the yield improvements achieved during Asia's 'Green Revolution'[1]. As well as increasing land productivity, greater fertilizer use also helps raise labour productivity, total farm output and smallholder incomes.

Africa's leaders have long recognised that the continent's goals of agricultural expansion and improved food security cannot be achieved without increasing fertilizer use. They therefore pledged to boost the production and availability of fertilizers at the landmark 2006 African Fertilizer Summit held in Abuja, Nigeria. The resulting Abuja Declaration included a bold ambition to increase African fertilizer application rates at least six-fold, from an annual average application rate of 8 kg/ha to at least 50 kg/ha by 2015.

Progress in meeting this pledge has been slow and patchy. The International Fertilizer Association (IFA) estimates that the average fertilizer application rate in Sub-Saharan Africa was close to 15 kg/ha in 2013, although it expects this to rise further to 17 kg/ha by 2019[2].

The International Fertilizer Development Center (IFDC) separately reports that average nutrient application rates in Sub-Saharan Africa (11 kg/ha) remain "the lowest in the world", being equivalent to "three percent of Asia's and nine percent of North America's application rates." Only South Africa's application rate (55 kg/ha) exceeds the Abuja Declaration threshold. Africa's overall application rate (24 kg/ha) is also helped by North African fertilizer consumption (120 kg/ha), the highest on the continent[1].

However, applying generalisations to Sub-Saharan Africa, a region of over forty nations, can be misleading and unhelpful. Indeed, the region's diversity is reflected in a wide variation in application rates between countries (Figure 1).

Progress has undoubtedly been made in Sub-Saharan African fertilizer consumption during the 11 years following the Abuja Declaration[1].

"There have been positive developments in policy and regulations, private sector provision and distribution of fertilizers, and government interventions to improve access to fertilizers," reports the IFDC, while cautioning that: "Nevertheless, current fertilizer policies are still not adequately conducive to… [establishing] competitive, private sector-led… systems to deliver to farmers the fertilizer quantities needed at the right time and place and at an affordable price."

African fertilizer demand

Although Africa is the world's second-largest and second-most-populous continent, its share of global fertilizer demand amounts to just several percent. The continent's nutrient demand last year was an estimated 5.45 million tonnes versus a global demand total of 183.8 million tonnes.

In Sub-Saharan Africa, fertilizer demand is even lower at around 3.5 million tonnes nutrients, according to recent estimates[2], some 1.9 percent of world demand. The region currently represents a comparatively small, fragmented market with the majority of countries consuming fertilizers in the hundred thousand tonne range annually[3]. South Africa, Ethiopia, Nigeria, Kenya, Zambia, Malawi, Ghana, Zimbabwe and Tanzania are the major fertilizer consuming countries within Sub-Saharan Africa.

Fig 1: **Fertilizer application rates, 2014, selected Sub-Saharan African countries**

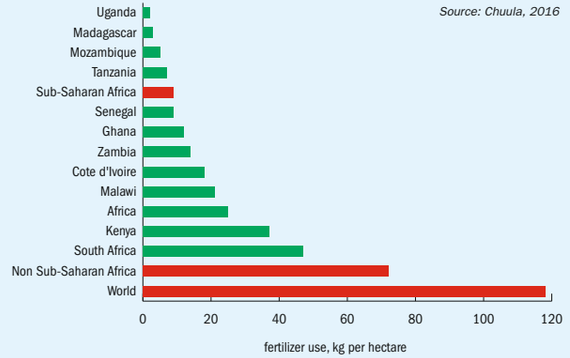
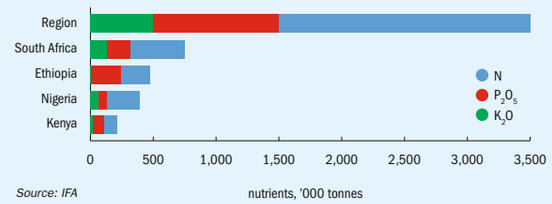
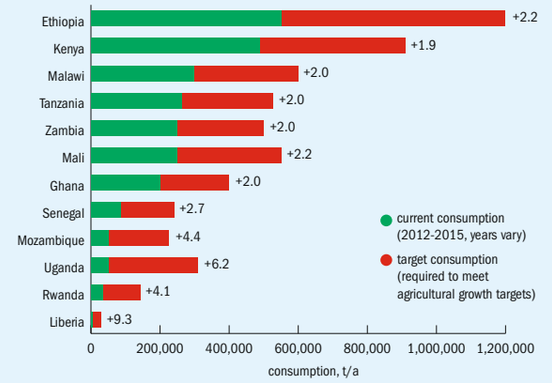


Fig 2: **Fertilizer demand in Sub-Saharan Africa, 2014 estimates**



Source: IFA

Fig 3: **Current fertilizer consumption versus target consumption in Sub-Saharan Africa**



Source: IFDC Market Assessments

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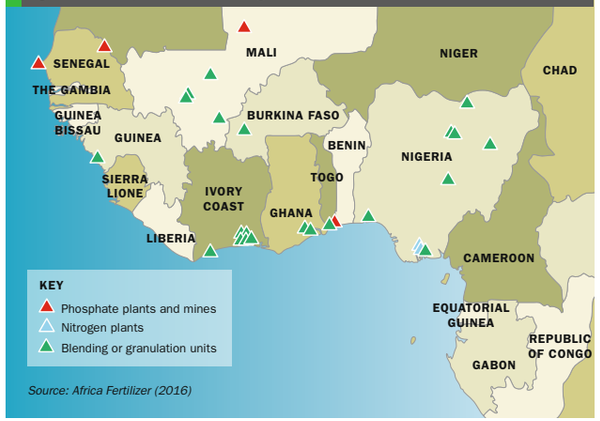
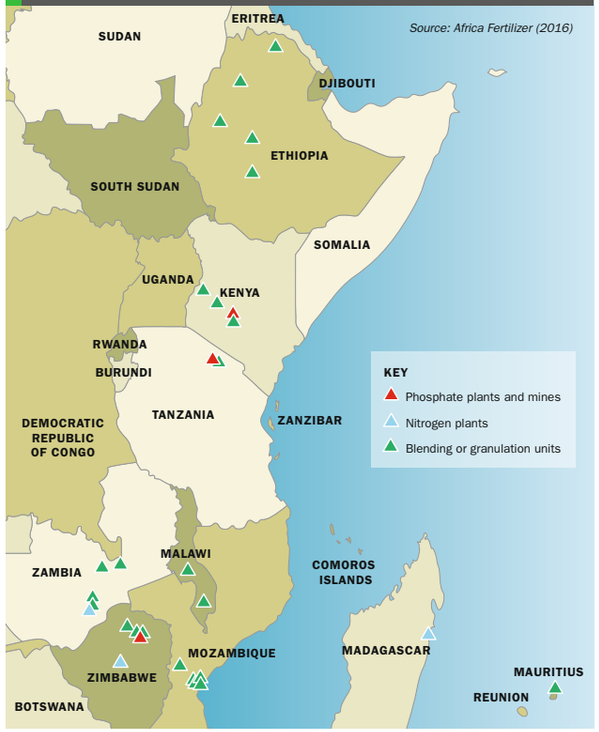
Fig 4: **Fertilizer plants and blending units, West Africa**



Source: Africa Fertilizer (2016)

Fig 5: **Fertilizer plants and blending units, East and Southern Africa**



The first four of these countries account for over half of regional demand (Figure 2), a reflection of their relatively strong commercial farming sectors.

Market opportunity

Growth in the economies of Sub-Saharan Africa has slowed in recent times after a period of sustained expansion. Côte d'Ivoire, Democratic Republic of Congo, Ethiopia, Tanzania, and Rwanda were among the world's fastest-growing countries in 2015, with GDP growth of seven percent or higher. However, overall regional growth slipped to 1.5 percent last year, the weakest performance in over two decades. Growth should, however, quicken to 2.9 percent this year, according to the World Bank.

Sub-Saharan Africa's impressive economic performance has helped create a strong demand environment for fertilizers. Consumption has grown robustly since 2008, boosted by GDP growth, policy support and private investment. Looking ahead, African fertilizer demand is expected to grow by some 70 percent between 2008 and 2019, and exceed seven million tonnes nutrients before the end of the decade[2]. Encouragingly, fertilizer demand is expected to more than double (+130%) in Sub-Saharan Africa (excluding South Africa) over this period.

The size of the market opportunity for additional fertilizer consumption in Sub-Saharan Africa is around five million tonnes, according to some estimates[3], based on the difference between current fertilizer consumption and crop requirements. The IFDC calculates that countries in the region will need to more than double their current consumption levels to meet national agricultural production targets (Figure 3).

In the short-term, African fertilizer demand is forecast to rebound (+4.7%) in 2016/17, due to increased agriculture investment, after contracting (-0.4%) year-on-year in 2015/16[4].

Fertilizer production and supply

Fertilizer production in Sub-Saharan Africa is restricted to the manufacture of phosphates and nitrogen products – as potash is not mined in the region at present. According to the most recent survey[5], fertilizer production in the region is concentrated in around a dozen plants located in nine countries, excluding South Africa (Figures 4 and 5). Many of these plants

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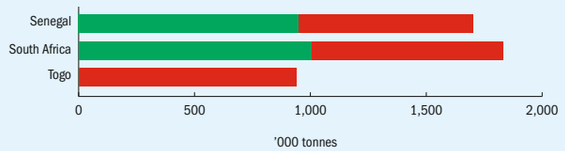
Fig 6: **Sub-Saharan Africa: phosphate rock production, home deliveries and exports, 2015**



Total production: 4.7 million tonnes
Total home deliveries: 2.0 million tonnes
Total exports: 2.5 million tonnes

Source: IFA

Table 1: **Foskor's production output, 2014-2016**

	Production ('000 tonnes)				
	2014	**2015**	**2016**	**2017***	**2018***
Phosphate rock	2,164	1,983	1,876	1,960	2,300
Phosphoric acid	510	393	307	550	700
Granular fertilizers	307	297	198	400	450

**Company target* *Source: Foskor*

are said to be operating at less than 20% capacity[5].

In the past, Sub-Saharan African production has relied heavily on the supply of imported raw materials and, due to low African agricultural demand, the fertilizers manufactured in the region have been mainly destined for export.

Phosphates mining and production

There are six main phosphate mine operators in Sub-Saharan Africa:

- Foskor in South Africa
- Industries Chimiques du Senegal (ICS) in Senegal
- Société Nouvelle des Phosphates du Togo (SNPT) in Togo
- Sable Chemicals Limited in Zimbabwe
- Minjingu Mines and Fertilizer Limited in Tanzania
- Toguna Agro Industries in Mali

Two other plants in the region, Kel Chemicals in Kenya and Phosphate Industries Limited in Zimbabwe, manufacture phosphate fertilizers using externally purchased phosphate rock

South Africa and Senegal and Togo in West Africa are major phosphate rock producing countries. They collectively extracted more than 4.5 million tonnes of phosphate rock in 2015, exporting almost two million tonnes of this amount (Figure 6). However, the most recent International Fertilizer Association (IFA) statistics suggest that neither Mali nor Tanzania produced any phosphate rock in 2015. Zimbabwe's 2015 production was also minor.

Senegal's phosphate reserves of 50 million tonnes are the largest in West Africa. The country produced 1.8 million tonnes of phosphate rock in 2015, two-fifths of which (752,400 tonnes) went for export. The country's phosphate rock and phosphoric acid production is largely targeted at the Indian market. Phosphate rock exports fell 37 percent to 472,609 tonnes in 2016, whereas phosphoric acid shipments were up 54 percent year-on-year to 336,624 tonnes (P_2O_5), all of which was delivered to India.

Indorama Group bought a majority stake in **Industries Chimiques du Senegal (ICS)** in August 2014, with a promise to invest $226 million in the Senegalese phosphates producer. The group currently owns 78% of ICS, while Indian co-operative IFFCO retains a 7% share. ICS has the capacity to produce 300,000 t/a of fertilizers and a planned second plant at Mbao could eventually see its fertilizer production capability rise to one million t/a.

Togo possesses world-class phosphate reserves of 30 million tonnes. Phosphate mining is of strategic importance to Togo's economy with overseas shipments generating a significant slice of the country's export earnings. Togo's phosphate mines were privatised in 2001 only to be renationalised as the **Société Nouvelle des Phosphates du Togo (SNPT)** six years later. SNPT's mining and production operations, located in Hahotoe, 35 kilometres east of the capital, Lome, employ around 5,000 workers. The state-owned firm launched a $150m investment programme in 2010.

Togo's phosphate rock production, which totalled 1.2 million tonnes in 2015 (Figure 6), declined by a quarter in 2016. Togo's phosphate rock exports also declined 10% last year to 845,900 tonnes. Looking ahead, the strikes which have affected SNPT's output in recent years should now cease following a four-year strike moratorium agreed with workers last September in exchange for higher wages.

South Africa has 1.5 billion tonnes of phosphate reserves, the fifth largest in the world. The country extracted 1.7 million tonnes of phosphate rock in 2015, exporting almost half this amount. South African producer Foskor mines phosphate rock at Phalaborwa, transferring it by rail to the company's Richards Bay site to produce phosphoric acid, monoammonium phosphate (MAP) and diammonium phosphate (DAP). The company also has the ability to produce NPK bulk blends. The company supplies domestic and international markets, particularly India.

Foskor produced 1.876 million tonnes of phosphate rock, 307,000 tonnes of phosphoric acid and 198,000 tonnes of granular fertilizers in 2016. Around 307,000 tonnes of phosphate rock was exported through Maputo. The company's output has fallen for two years in a row, with 2016 phosphate rock, phosphoric acid, and fertilizer production down 5%, 22% and 33%, respectively, on 2015 levels. Rock production was adversely affected by community unrest last year. Acid production was also hit by unscheduled stoppages due to a reactor failure and water and power shortages. Foskor has, however, set ambitious production targets for 2017 and 2018 (Table 1).

Customs data show that South Africa's phosphoric acid exports rose 66% year-on-year in the first nine months of 2016. Exports between January and September last year reached 184,768 tonnes up from 111,483 tonnes during the same period in 2015, although this was still 30% down on 2014 levels.

New phosphate miners

In March, Australian developer **Avenira Ltd**, formerly Minemakers Ltd, made the maiden shipment from its Baboab phosphate project in Senegal. The company shipped 21,400 tonnes of phosphate rock to India from the Port of Dakar. The project's processing plant is currently undergoing commissioning and debottlenecking. Production from the Baobab mine, located 145 km east of the port of Dakar, will eventually ramp-up to 500,000 t/a.

The new $120 million Elandsfontein phosphate mine in South Africa began production in March. South African mining company **Kropz** is developing what is said to be South Africa's largest sedimentary phosphate deposit at a 5,000 hectare site located on the country's west coast. The project's first phase involves producing 1.2-1.5 million t/a of high-grade (32% P_2O_5) rock concentrate from a total resource of 250 million tonnes.

Nitrogen fertilizers

Nigeria's **Notore Chemicals Industries Limited** and **Indorama Eleme Fertilizer & Chemicals Limited** operate Sub-Saharan Africa's two urea plants. Indorama's new 1.4 million t/a granular urea Port Harcourt plant was commissioned last year, making the company the largest urea producer in the region. Under offtake agreements, Indorama supplied Trammo and Helm with up to 450,000 tonnes of urea each in 2016, marketing the remaining 400,000 tonnes of plant output itself. Dubai-based Abraaj Group acquired a minority stake in Indorama at the end of 2016. Abraaj says it will use its expertise and networks to support Indorama's market penetration and future expansion plans.

Other plants in the region manufacture ammonium sulphate (AS) and ammonium nitrate (AN) using imported ammonia. These include International Raw Materials' AS plant in Madagascar and Sable Chemicals Industries Limited's AN plant in Zimbabwe.

Plentiful gas resources

New nitrogen fertilizer capacity is being added in Sub-Saharan African countries with access to plentiful gas resources. Saipem is currently constructing Africa's biggest fertilizer plant in Edo state in southern Nigeria for **Dangote Group**. The plant will include two trains with a granular urea production capacity of 3,850 t/d each, using technology provided by Uhde Fertilizer Technology.

Also in Nigeria, the **Brass Fertilizer and Petrochemical Company Limited** (BFPCL) is developing the $4 billion Brass Fertilizer project at Brass Island in Bayelsa State. The proposed nitrogen complex, which has yet to reach financial close, will be built in two phases and eventually produce 1.3 million t/a of urea and 1.66 million t/a of methanol. Phase one of the project, which is expected to come on-stream in 2020, includes a dedicated export jetty and a gas processing plant. The project has secured a 25-year 300 mmscf/d gas supply from the Shell Petroleum Development Company of Nigeria Ltd. BFPCL also signed a $6 billion methanol offtake deal with BP last December.

Riaba Fertilizers Limited is developing a world-class petrochemicals complex at Riaba in Equatorial Guinea. The company's REPEGE project includes a 1.5 million t/a ammonia and urea plant and an export terminal. An EPC contract for the project was awarded to a Chinese consortium led by East China Engineering Science and Technology Co. Ltd in February 2016. Front-end engineering and design work was also carried out last year. The project has a gas supply agreement with Noble Energy, the operator of the Alen offshore field. The project is due to enter operation in December 2019, although analysts Nexant rank the likelihood of completion as low due to potential gas issues (*Nitrogen+Syngas* 346, p40).

> **"The mismatch between fertilizers and the nutrient needs of soils and crops is the most important constraint on productivity.**

Tanzania has also unveiled plans to build a $3 billion nitrogen fertilizer plant in partnership with an international consortium of German, Danish and Pakistani partners. State-owned **Tanzania Petroleum Development Corporation (TPDC)** signed a joint venture agreement for the 3,800 t/d urea plant last year with EPC contractor Ferrostaal, technology-provider Haldor Topsoe and plant operator Fauji Fertilizer Co. The plant's output will be aimed at both the domestic and export markets.

Construction was due to start last December in the south of the country and will access large offshore gas finds located nearby. Tanzania announced the discovery of another 2.2 trillion cubic feet of offshore gas in February 2016, raising its reserves to more than 57 trillion cubic feet.

However, analysts CRU remain cautious. "On paper this project has favourable fundamentals, benefiting from natural gas supply, its ability to serve the domestic market, as well as India and Europe, and political stability," commented CRU. "Despite this, no clear information is provided regarding how the $3 billion plant will be financed – or what is included in the $3 billion cost estimate."

OCP makes a difference

Morocco's **OCP Group** has agreed to build a large-scale fertilizer complex in Ethiopia under a $2.4 billion partnership deal signed with the Ethiopian ministry of public enterprise. The proposed Dire Dawa Fertilizer Complex will produce potash and nitrogen fertilizers using local mineral and natural gas resources. It will also consume OCP-supplied phosphoric acid.

An initial investment of $2.4 billion could see 2.5 million t/a of fertilizers produced by 2022, according to OCP. This would make Ethiopia self-sufficient in fertilizers and create additional volumes for export. Construction is expected to begin this year and last for three years, according to analysts CRU, with banks funding 60% of the project and the two partners financing the remainder. A subsequent investment of $1.3 billion will increase total production to 3.8 million t/a by 2025. Tonnage capacities for specific products have not been provided at this stage.

OCP also plans to jointly develop an NPK fertilizer plant and a fertilizer distribution network in Nigeria with Dangote Group under an agreement signed last December. Morocco will also supply fertilizer blending plants in Nigeria with imported phosphate under a separate agreement between OCP and the Fertilizer Producers and Suppliers Association of Nigeria (FEPSAN). This should enable Nigeria to produce one million tonnes of fertilizers for the wet season and half a million tonnes for the dry season during 2017, potentially saving the Nigerian government up to NGN 60 billion ($196 million) in fertilizer subsidies.

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Blending and distribution

A total of 47 plants in 18 countries provides Sub-Saharan Africa with approximately 5.4 million tonnes of blending and steam granulation capacity, according to the most recent industry register[5], although this excludes South Africa (Figures 4 and 5). Almost 60 percent of installed capacity (3.2 million tonnes) is located in West Africa, with the remaining 40 percent (2.2 million tonnes) found in East and Southern Africa. More than 90 percent of blended fertilizers are imported pre-blended in East Africa, compared to 34-39 percent in South and West Africa.

Over two-fifths of West African fertilizer blending capacity is centred in Nigeria. Eight blending plants located across the country collectively provide 515 t/h of capacity. Cote d'Ivoire is also relatively well served with six blending plants providing around 370 t/h of capacity. Five of these plants are located in Abidjan, including two units operated by **Louis Dreyfus Commodities** and **Yara Cote d'Ivoire**. In Ghana, Louis Dreyfus Commodities and Yara Ghana also run blending units at Kpong and Tema, respectively. On the other side of the continent, Ethiopia has access to five blending plants which combined provide around 250 t/h of capacity.

South African based **Omnia Fertilizer** is a major fertilizer distributor and retailer in Sub-Saharan Africa, with regional offices in Mauritius, Mozambique, Zambia and Zimbabwe. The company also services Botswana, the Democratic Republic of the Congo (DRC), Kenya, Lesotho, Malawi, Namibia and Swaziland directly from South Africa.

Omnia Fertilizer, together with its sister company Omnia Specialities, produces and sells granular, liquid and speciality fertilizers to wholesalers, commercial farms and small-scale farmers. The company distributes fertilizers throughout Africa using sales depots, warehouses and blending plants. These include a 30 t/h blending units in Banket, Zimbabwe, and another 40 t/h unit in Beira, Mozambique.

OCP Group subsidiary **OCP Africa** recently unveiled plans to set up 10 new distribution centres in African towns by 2020. The new centres, called 'houses of the farmer', should eventually provide agricultural products and services for a total of one million farming families across the continent. The first two centres will be opened in Morocco and Nigeria in the near future and then rolled-out to other West and East African countries.

Unlocking the fertilizer market

In tandem with improvements to manufacturing and blending capacity, unlocking the fertilizer market in Sub-Saharan Africa will require demand-side reforms and the removal of regulatory barriers and logistical constraints. Reforms will need to address[3, 4]:

- High logistics costs (30-70% of total costs)
- Small market size leading to higher unit costs
- Import restrictions
- Price support and subsidy levels
- Tariffs (taxes, import duties)
- Non-tariff barriers (permits, border delays and bribes at road blocks and weighbridges)

Many of these issues are long-standing, having been recognised in the 2006 Abuja Declaration. Around one-third of Sub-Saharan countries impose import duties and half levy a tax on fertilizers. Different national blend specifications also make it difficult to move fertilizers between countries and increase production costs[4].

"Barriers to market entry… [include] restrictions on fertilizer imports, restrictions on who can sell fertilizers… and state involvement in import and distribution," reports the IFDC. "Trade policies discourage investment by raising the costs of business through tax and non-tariff regimes. These include… restrictions on prices through price controls or support."

Inefficient and weak supply and distribution channels also restrict access to fertilizers and contribute to higher fertilizer prices, as does a lack of port, road, rail and storage infrastructure. Improving transportation and logistics across the continent will, however, be a long-term, capital-intensive process.

The small size of fertilizer markets in many African countries prevents economies of scale being exploited in fertilizer production and blending. Regional markets in fertilizers have largely failed to emerge because individual countries typically specify their own fertilizer blend compositions[3, 4]. Organisations such as the Alliance for Commodity Trade in East and Southern Africa (ACTESA) are, however, working to harmonise fertilizer standards and fertilizer quality across the region as part of efforts to remove barriers to intra-regional trade and reduce transaction costs.

Fertilizer affordability remains a key issue. Fertilizer prices in landlocked Sub-Saharan countries can be more than ten times higher than in other agricultural nations. In 2010, farmers in Burundi paid $2,700/t for nitrogen-based fertilizers, while farmers in Malawi, Zambia, and Uganda paid $1,500/t, $1,400/t and $1,100/t, respectively. That compared unfavourably with equivalent price levels of around $600/t in South Africa and $500/t in Kenya, and the $250-500 price range of fertilizers in Pakistan, Argentina and Brazil.

Access to finance is a common obstacle for companies in the fertilizer distribution chain, according to the African Fertilizer and Agribusiness Partnership (AFAP). One way of addressing this is for fertilizer manufacturers and importers to agree to provide trade credit to downstream distributors and/or retail outlets in return for a guarantee from AFAP to share the risk. AFAP has trialled this type of credit risk guarantee in a two-year pilot in Tanzania, Mozambique, Ghana and Cote d'Ivoire. The Partnership is also helping overcome supply and distribution obstacles by financing 'Hub & Spoke' agro-dealers in five Sub-Saharan African countries. These help cut distribution and transaction costs by acting as intermediaries between suppliers/importers and rural agro-dealers.

The importance of agronomic research and agricultural extension services is highlighted by the IFDC[1]: "The single most important constraint to increased agricultural productivity in Africa is the mismatch between the fertilizers that are being used by the majority of farmers and the nutrient needs of the soils and crops."

The IFDC recommends addressing this mismatch by taking action to:

- Produce national soil maps
- Develop fertilizer recommendations by location, soil type and crop type
- Establish at least one national soil testing facility
- Establish more fertilizer blending facilities in the region
- Train more agro-dealers and extension officers
- Increase the number of fertilizer demonstrations and trials

Prioritising soil fertility in this way, by improving the response of crops to fertilizer use and raising farm productivity and profitability, should help stimulate fertilizer demand in Sub-Saharan Africa at a smallholder farm-level.

Some countries such as Ethiopia have already moved to more balanced fertilizer applications by using soil fertility maps as a support tool for nutrient management and improving fertilizer recommendations. The Africa Programme of the International Plant Nutrition Institute (IPNI) has also been championing integrated soil fertility management (ISFM) as a long term sustainable approach to crop nutrition.

Summary outlook

Rates of fertilizer consumption in many parts of Africa remain low by global standards, leading to soil mining, large yield gaps and food insecurity. This situation is, however, changing rapidly in leading African nations where food production is rising sharply, spurred by economic and population growth. Sub-Saharan Africa is a fast growing fertilizer market, although, with application rates still below 20 kg/ha, both supply- and demand-side reforms are needed if the region is to fulfil its huge agricultural potential.

The African market for NPKs, in excess of two million t/a currently, is becoming increasingly important and shows significant growth potential. Much of this demand is met through tenders, amounting to more than 1.5 million t/a, the largest of which take place in Ethiopia.

South Africa, and Senegal and Togo in West Africa, are major phosphate rock and phosphoric acid producing countries. However, their industries remain export-oriented with output targeted at India in particular. Emerging urea capacity in Nigeria and Equatorial Guinea offers potential for import substitution as well as production for export. OCP Group's strategy for Africa involves the construction of production and blending units as close as possible to major farming areas. It wants to capture and realise the value of fertilizer raw materials, such as ammonia, phosphate rock and phosphoric acid, within Africa.

Achieving the 50 kg/ha application rate target in the Abuja Declaration would require Sub-Saharan consumption to rise from the current 3.5 million tonne level to 11.5 million tonnes nutrients. The optimum nutrient consumption level in the region could be as high as 33.8 million tonnes, based on the intensification of current area under cultivation. But creating a fertilizer market in Sub-Saharan Africa at large-scale will only occur if consumption by smallholder farmers increases .

OCP Group's newly-established subsidiary OCP Africa is committed to supplying the continent's farmers with affordable fertilizers. Operations will encompass agronomics, production, logistics, marketing and sales. Its ultimate aim is to guarantee that Africa's farmers have access to sufficient quantities of the right fertilizers at the right time and at the right price. ■

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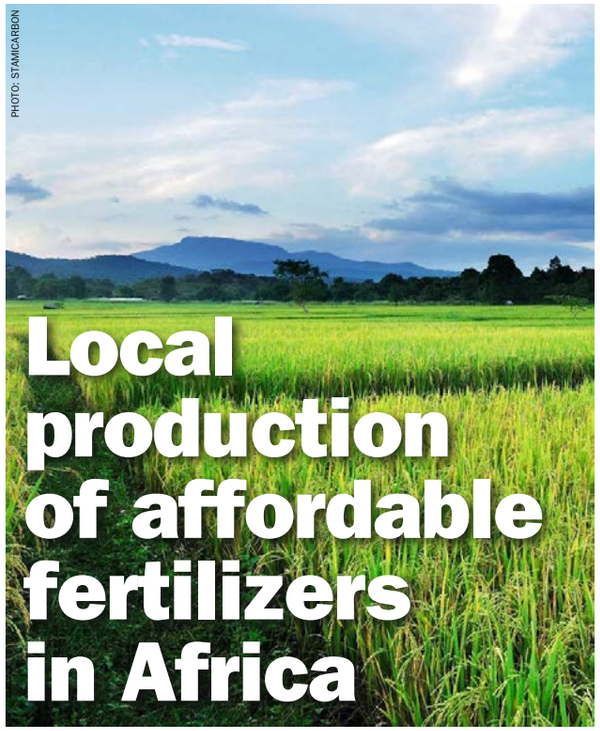


PHOTO: STAMICARBON

Local production of affordable fertilizers in Africa

Left: African cropland.

Current fertilizer applications rates in Africa, around 15 kg/ha, fall short of the 50 kg/ha goal set in the 2006 Abuja Declaration. Improving the supply of nitrogen fertilizers to Africa's heartland offers one way of getting within reach of this goal. Stamicarbon's **Joey Dobrée** and **Tom Tiethof** describe two viable production solutions for Africa: large-scale coastal urea plants and smaller-scale local production units.

This article discusses how the affordability and accessibility of fertilizers in the heartland of Africa can be improved, with a focus on Sub-Saharan Africa.

Organisations such as the African Fertilizer and Agribusiness Partnership (AFAP) are helping develop the African fertilizer market, and are opening up the region to international investment in supply chain and storage infrastructure. This has sparked the interest of the major fertilizer companies – as demonstrated by the number of new sales offices that have opened over the continent in the last twelve months. This is evidence of a rapidly intensifying battle for market share in Africa.

These developments are welcome as they will improve access to fertilizers. But fertilizer affordability in Africa will not be solved while fertilizers continue to be imported and transported over long distances into the continent's heartland. Tackling affordability will require simpler logistics, shorter supply routes and more localised production.

Market potential

Despite current marginal application rates, Africa's long term agricultural potential is highly promising, given the availability of water and arable land. The potential for developing nitrogen fertilizer demand in landlocked areas with favourable agronomic dynamics is also substantial.

Varying soil and climate conditions in Africa, and the corresponding diversity in crop varieties, mean there is an additional need for nitrogen-based speciality fertilizers. Urea, the main nitrogen commodity fertilizer, when combined with ammonium sulphate, can unlock the potential for urea ammonium sulphate (UAS) fertilizers, for example.

High prices and limited availability in Africa currently makes the efficient use of fertilizers a necessity. Fortunately, the amount of fertilizer supplied by local blenders has been growing substantially. This has helped manage growing demand for speciality products from African farmers and also optimised crop output per tonne of imported fertilizer.

Cumulative annual growth rates for African fertilizer demand (6.5%) are strong and well above global rates (2.0%). Despite this strong growth, absolute fertilizer demand in Africa remains relatively minor on a tonnage basis, and is insufficient to boost application rates, according to the International Fertilizer Association (IFA).

Feedstock availability

The key natural resource requirement for nitrogen fertilizer production is gas availability. Africa is fortunate enough to be rich in both natural gas and associated gas from oil production. Forecasts of future gas production in Africa are highly promising (Figure 1), to the extent that the continent could eventually become self-sustaining in nitrogen fertilizer production.

Since production is forecast to increase rapidly, gas producers are looking for suitable consumers and end markets. However, one of the most attractive options, liquid natural gas (LNG), is not the obvious choice it once was, due to low prices and high investment costs. The secondary choice, power generation, also suffers from limitations such as the lack of grid availability, gas infrastructure and hurdles in bringing offshore gas to land. Converting available natural gas resources into nitrogen fertilizer has therefore become the obvious choice for African governments, especially as this will help develop the main agricultural sector of national economies.

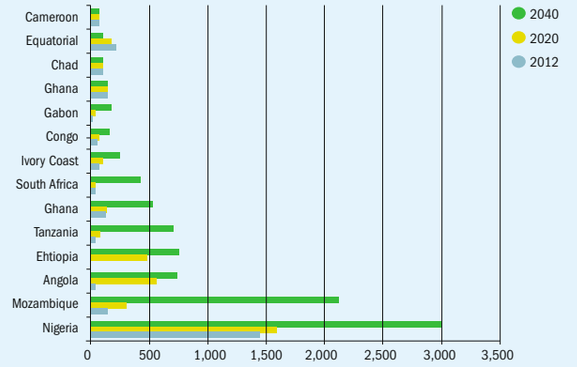
The viability of local fertilizer production as a proposition has been further improved by policies supporting the allocation of natural gas to nitrogen plants, and the strong desire of African nations, gathered in the African Green Revolution Forum, to strengthen their local agricultural industries. Government initiatives in Ethiopia, Mozambique and Tanzania have generated substantial support for nitrogen fertilizer production and have attracted industry interest.

Affordability

After availability, fertilizer affordability is the second main concern in Africa. In 2017, fertilizer prices in local markets surged far beyond $500/t. The cost of importing fertilizers limits their affordability and is also one of the main reasons why fertilizers are inaccessible in the heartland of Africa.

Figure 2 provides the cost breakdown for importing and transporting one tonne of urea fertilizer to Uganda over a distance of around 1,000 kilometres from the nearest port. The figure compares urea costs for farmers in Uganda with farm costs for gas-based production in the US and coal-based production in China. US farmers benefit from easy access to regionally-produced fertilizers via an efficient distribution network, while those in Uganda rely on imported urea transported over long distances to isolated rural areas. Figure 2 shows the high port, distribution and logistical costs in African supply chains, and how this is responsible for an unnecessary cost burden of at least 40 percent. The result is that local farmers in the heartland of Africa need to spend twice as much on fertilizer inputs compared to farmers in the United States.

Fig 1: **Natural gas production forecast / BCF per annum**



Source: IEA World Energy Outlook, Africa

Fig 2: **Comparison of fertilizer cost structures**

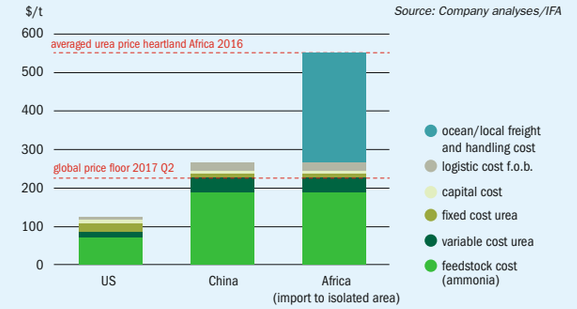
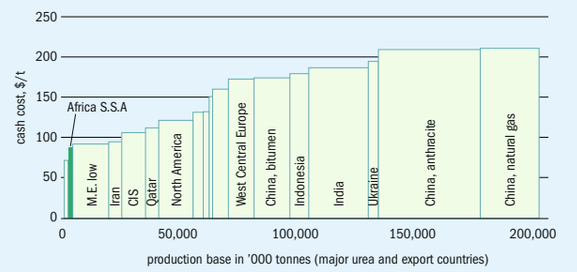


Fig 3: **Urea fertilizer cash cost curve 2017 (excluding depreciation)**



Source: Company analyses

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African fertilizer production

Local production is one solution that could potentially half the cost of nitrogen fertilizer for African farmers. This solution is a double-edged sword, though, as imported fertilizers are often subsidised by governments. Imported fertilizers are also subject to price fluctuations on the world market, and the subsidies paid are a heavy burden on agricultural budgets. Subsidies also preserve the status quo by masking the very high costs of inefficient distribution and allowing this to continue.

Encouragingly from an investment point of view, the cost curve for an African fertilizer plant shows that production can be competitive on the world market (Figure 3). This healthy and competitive cost position is primary based on low feedstock cost. Cash costs are estimated at $80-100/t, excluding depreciation of around $40/t. That makes the competitive position of African producers comparable to producers in North Africa and the Middle East.

The export market can be used to bridge the gap between local fertilizer demand and the output of African fertilizer plants. Supplying both the export and domestic markets makes it possible to build large, efficient plants that benefit from the economies of scale. Such plants can provide the fertilizer supply necessary for the development of local agricultural markets and tap into their future growth potential.

Improving affordability and accessibility

Nowadays, to benefit from economies of scale, urea is mainly produced at facilities with a production capacity greater than one million tonnes per annum, usually located at petrochemical hub sites close to natural gas infrastructure, e.g. in the Middle East, North Africa and the FSU.

The poor affordability of fertilizers in Africa is largely attributable to high logistical costs and distribution inefficiencies, while the lack of access to fertilizers is mainly due to the absence of local production. Both issues are, however, inter-connected, as improving accessibility can also improve affordability by reducing dependency on imported fertilizers.

Access to fertilizers can be improved by taking advantage of legislation that allocates available natural gas for fertilizer production, and by utilising small-scale gas reserves and associated gas or flare gas. Stamicarbon has identified two main urea production routes for Africa:

1. Large-scale coastal urea production

One option involves capturing coastal gas reserves, offshore gas reserves and associated gas for large-scale ammonia and urea production, which mainly targets the export market but also meets local demand for nitrogen fertilizers. This production route has two main benefits. Firstly, exports provide a stable basis for plant finance. Secondly, abundant local availability should stimulate rapid increases in fertilizers application rates in coastal areas. Examples of this production route are taking place across Sub-Saharan Africa with various projects in progress.

The main disadvantage of large-scale coastal urea plants is their high capital investment requirement, typically in the range of two billion dollars, and the country risk. Large investments can be difficult to justify, especially in times of low commodity prices. Another disadvantage is that large coastal facilities do not solve the affordability issue in the African heartland, as logistical inefficiencies remain in place.

2. Small-scale domestic production

Small-scale fertilizer production, using small gas reserves, associated gas and flare gas from oil production, or bio-based feedstocks, is another option for Africa. These type of plants can focus on supplying nitrogen fertilizers for local consumption and can offer dedicated production of speciality fertilizers to match local soil and crop requirements.

Stamicarbon's *LAUNCH MELT™ Compact* design is ideally suited to this type of production. The design consists of a state-of-the-art, small-scale urea unit. This has the capability to produce urea, urea ammonium sulphate (UAS) and urea combined with secondary nutrients and micronutrients. Advantageously, it can also be combined with standard NPK(S) blending units. The product mix from this type of plant can be adjusted to meet specific local requirements, thereby maximising the value of the plant's output.

The lower investment cost required, in the range $100-500 million depending on capacity, allows investors to spread the country risk by making project financing and risk investment easier to mitigate.

Developments in new technology are also helping to off-set the loss of economy of scale. A modular construction approach also reduces project lead-in times, enabling a quicker return on investment. Technological innovation also allows plant operators to mitigate the risk of a less-skilled workforce by providing remote monitoring and support tools. Training and investment in the local workforce should ensure the availability of skilled maintenance support. Having access to spare parts and qualified welders on reasonable notice is also important.

However, this type of small-scale plant will only be able to compete with imports under certain conditions. A transport/logistical advantage of around 500-1,000 kilometres is usually necessary, as is the ability to directly supply speciality fertilizers matching local requirements. By avoiding high transport costs over large distances, small-scale local production can achieve a price reduction of around 40 percent.

Reducing dependency, becoming self-sufficient

Generally, both large-scale and small-scale production routes will support the much needed agricultural development of Sub Saharan Africa by supplying farmers with necessary fertilizers. Dedicated efforts to reduce the region's dependency on imported fertilizers and develop local agriculture should ultimately result in nutrient self-sufficiency. However, progress on agricultural development will be gradual, and a diverse strategy is clearly required to break with the current status quo and boost fertilizer applications rates throughout the Sub-Saharan region.

Stamicarbon in Africa

Stamicarbon is the world's leading urea licensor and well-known for its plants in Algeria, Egypt and Libya. For many years, it had the only urea plant reference in Sub-Saharan Africa in Port Harcourt, Nigeria. With decades of experience and a long track record on the African continent, Stamicarbon strives to contribute to the development of the African fertilizer market by providing project development services and state-of-the-art technology, customised to unlock Africa's fertilizer potential. ■

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IFA's Michel Prud'homme (left) chairing the regional plenary.

PHOTO: CRU

Phosphates 2017

More than 400 delegates from 36 countries gathered at the Marriott Tampa Waterside Hotel, Tampa, Florida, 13-15 March, for CRU's Phosphates 2017 conference.

We report on the keynote, regional market, trade dynamics and other plenary presentations at CRU's 10th Phosphates International Conference and Exhibition held in Tampa in March.

The 2017 price rally

The recent sharp recovery in finished phosphates prices – and whether this would be sustained – was a major talking point throughout the three-day conference. Spot prices increased from around $325/t at the end of last year to $375-400/t by mid-March, based on NOLA diammonium phosphate (DAP) and Brazil monoammonium phosphate (MAP) benchmarks.

Walter Precourt, senior vice president, phosphates, at The Mosaic Company turned the spotlight on the 2017 price rally during his opening keynote on the global outlook. He described it as a "buying rush in a rising market" and linked this to:

- Low channel inventories worldwide
- Uncovered commitments for the current application season
- Declines in Chinese export availability
- Jumps in raw materials costs
- Ship loading delays at Jorf Lasfar, Morocco

Precourt expected the momentum behind the rally to continue during the first half of 2017, with more upside than downside risk. Agricultural demand drivers such as nutrient affordability and soybean, palm oil and cotton prices all continue to look positive. Mosaic is currently predicting global phosphate deliveries of 67-68 million tonnes this year. Chinese exports, which are projected to drop to around eight million tonnes in 2017, should also help keep the supply/demand balance tight.

Beyond 2017, demand prospects continue to look strong over the next five years, with forecast annual growth of around two percent. On the supply side, no new large-scale projects are expected after 2018. Following completion of OCP's Jorf Lasfar expansions and Ma'aden's Wa'ad Al-Shamal project, the next wave of new capacity from Morocco and Saudi Arabia is not expected until after 2021. A restructuring of the Chinese phosphates industry is also expected to see China's exports and production stabilise at a lower level.

"In the next five years we expect to see a rebound in Indian use and strong gains in Brazil and we think other regions such as Africa and Asia [ex China] will also post solid gains," commented Precourt. "We think there's a closeness between the additional capacity that's coming on the market and overall demand, such that the balance is pretty reasonable."

Shares also rally

Ben Isaacson, equity analyst, global fertilizers, at Scotia Capital gave the view from the capital markets. The majority view among investors is that DAP prices and phosphate producer margins will remain either flat or move slightly lower this year. Isaacson highlighted the rally in fertilizer stocks over the last 12 months. Mosaic and PhosAgro outperformed their peers with year-on-year stock price increases of

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30 percent and 27 percent, respectively.

Equity investors tend to view nitrogen as the best performing industry segment and potash as the worst – with phosphates occupying the middle ground. Nearly two-thirds of institutional investors, for example, believe nitrogen has the best outlook over the next five years, whereas just over half believe potash has the worst outlook. Looking ahead, while investors are confident phosphates will not be the best performing segment over the medium-term, suggests Isaacson, they are equally confident it will not be the worst performing nutrient either.

Isaacson summed up by asking delegates: "Are you a bull or a bear? I'll leave that up to you."

On the bearish side, he pointed out: "It's not clear that fertilizer prices have bottomed. Balance sheet leverage has risen as earnings have declined. While peak capex is behind us, there'll be another $11-12 billion of capex spend by the majors over the next few years. There's a wave of extra potash capacity over the next 18 months, new phosphates supply will also hit the market, and it's not clear if demand growth will soak all that up. There's significant nitrogen capacity with respect to urea – we have [supply at] 2-3 times demand growth hitting the market in 2017 alone."

On the bullish side, he added: "Fertilizer prices have been rising. Fertilizer demand growth remains strong despite weaker farm economics. Chinese nitrogen and phosphate closures have been tightening the market. Many potash producers are sold out. Debt is mostly long dated. Phosphate and potash industries are being concentrated with opportunities for further consolidation. And stocks are trading at deep discounts to replacement costs."

Closing the chasm

The question of whether China can close the chasm between capacity and demand was the main theme of the phosphates market outlook from **Chris Lawson**, CRU's head of phosphates. He also asked how much longer the current "price rally in a perfect storm" can be sustained.

The rally has seen DAP prices invert after sustained declines stretching back two years. The fall in Chinese DAP to below $300/t at the end of 2016 – for the first time in four years – helped spark the current rally, suggested Lawson. Some 8-10 producers in China reacted by announcing production curtailments. The Chinese industry also agreed to reduce operating rates to 65-70 percent during 2017. Consequently, DAP prices (f.o.b. Tampa), which had languished at close to $310/t in December 2016, rose steadily during January-March, as impressive global demand and ship loading issues tightened availability. Rumours of a DAP subsidy increase in India also helped fuel the rise.

CRU believes the rally is unlikely to last as 2017 progresses, due to downward pressure from a number of supply-side factors. These include:

- The start-up of unit III at OCP's Jorf Lasfar Hub
- The return of China to the market with no export tax
- The recovery of Tunisian phosphate rock production
- The start of testing at Ma'aden's Wa'ad Al Shamal project toward the middle of this year and its ramp-up in 2018

CRU expects to see a wave of new phosphoric acid production capacity in the Middle East and North Africa between now and 2021. This will see global capacity grow by 2.4 percent annually over the next five years. This will add to the growing chasm between global phosphoric acid capacity and demand that dates back to 2013. However, a rationalisation in Chinese capacity could help close this chasm, suggested Lawson.

Chinese DAP producers occupying the third quartile of the cost curve have been operating at a loss. Some of the country's DAP production, concentrated in Hubei, Yunnan and Guizhou regions, is therefore being idled – but could return in response to rising prices.

Looking ahead, CRU estimates that 3.5 million tonnes (P_2O_5) of Chinese phosphoric acid capacity is at a medium-to-high risk of permanent closure over the next five year. The loss of this capacity, if it were to occur, could spur a much-needed tightening of the global market. Chinese DAP and MAP utilisation rates are also expected to fall to 65 percent and 50 percent, respectively, over this period.

On the demand side, lower prices have helped boost demand. But significantly higher demand growth is likely to be necessary over the next five years to close the chasm with supply. CRU estimates that, to balance the market by 2021, demand needs to grow by close to one million tonnes P_2O_5 every year– equivalent to a 2.1 million tonne increase in DAP consumption annually.

Chinese diversification

The Chinese phosphate market is facing the twin challenges of long-term oversupply and declining domestic demand, says **Isaac Zhao**, senior CRU consultant.

China's production capacity for finished phosphate fertilizers amounts to around 21-22 million tonnes P_2O_5 currently. The country's total capacity increases to around 24 million tonnes P_2O_5, once 2.5 million tonnes of additional feed phosphate and purified wet acid (PWA) capacity is factored in. This leaves China with roughly 10 million tonnes P_2O_5 of excess capacity above its domestic consumption needs.

Redirecting this excess capacity away from DAP, MAP and triple superphosphate (TSP) production will require a strategy of diversification, argues Zhao. Indeed, China's producers are already looking to diversify, prompted by the downward pressure on DAP and MAP margins. Tightening of environmental regulations have significantly increased production costs, and even forced some smaller Chinese phosphate plants to close.

A shift to NPK production is currently the primary choice for diversification. Other options for producers include a move into feed phosphates, PWA or value-added fertilizer markets. Overseas investment offers another way of diversifying.

Shifting to products with reasonable margins, and ensuring production methods are not environmentally damaging, will be key in putting China's phosphate industry on a more sustainable footing, concludes Zhao.

Beyond China and India

The era of large countries driving phosphate demand growth appears to be over, reported **Andy Jung**, Mosaic's director for market and strategic analysis. Instead, a more broad-based rise in phosphate demand is likely in 2017 in his view.

Although China and India once fuelled phosphate demand growth almost single-handedly, they have mainly acted as a drag on global phosphate deliveries in recent years. Fortunately, this has been offset by increased consumption elsewhere.

India and China combined were responsible for 90 percent of the growth in deliveries (5% p.a.) between 2005 and 2010. Deliveries to India subsequently fell back between 2010 and 2015 (-4.6% p.a.) and deliveries to China declined sharply last year (-6.8% year-on-year).

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Mosaic is not expecting much of a demand stimulus from either country this year. While India and China did clear out their distribution pipelines last year, their demand for phosphate has tended to disappoint, said Jung.

Phosphate deliveries to Brazil, in contrast, are expected to reach record levels in 2017. This is being driven by the high prices of agricultural commodities in local currency. Deliveries of DAP, MAP, NPS and TSP to Brazil are expected to reach 8.5 million tonnes this year, a 10% rise on 2016 deliveries (7.9 million tonnes).

> **Profitable farm economics in Brazil will drive record setting phosphate shipments in 2017.**

"We expect profitable farm economics [in Brazil] will drive a second consecutive year of record setting high-analysis phosphate shipments in 2017," commented Jung.

Argentinian phosphate demand, which surged in 2016, is also poised for a very strong 2017, according to Jung. Pakistan's healthy and profitable agricultural sector has become another important demand centre. Phosphate deliveries in Pakistan reached a record 2.225 million tonnes in 2016, some 23 percent up on 2015, driven by DAP subsidy support. CRU and Mosaic expect Pakistan phosphate demand to reach a healthy 2.25 million tonnes this year.

African phosphate demand has also been "quietly growing" since 2015 and should exceed two million tonnes in 2017. Finished phosphates imports, excluding South Africa, were in excess of one million tonnes last year. Elsewhere, Vietnam, Thailand, Turkey and Russia – where nutrient demand is booming – are also emerging as growing phosphate markets.

The overall global demand picture also remains positive, concluded Jung, thanks to record agricultural production. World grain and oilseed output reached new highs in 2016. The removal of primary nutrients from the global harvest last year, likely to be in excess of 10 million tonnes for main crops, will need to be replenished. At the same time, phosphates and other nutrients remain affordable by historical standards.

Favourable fundamentals in Eurasia

Eurasia is vast. It consists of 93 countries, contains three-quarters of the world's population and possesses 60 percent of global arable land. **Irina Evstigneeva**, PhosAgro's marketing and development director, therefore made the practical choice of focussing on the markets of the Commonwealth of Independent States (CIS) in her presentation. This cluster of states includes Armenia, Belarus, Kazakhstan, Kyrgyzstan, Moldova, Russia, Tajikistan, Turkmenistan, Ukraine, and Uzbekistan.

CIS phosphates production (DAP/MAP, NP/NPS) reached 4.6 million tonnes in 2016. Regional phosphate demand also accelerated to 1.7 million tonnes P_2O_5 last year.

The growth in fertilizer consumption in Russia in 2016 helped push up crop yields. Russian cereal (+24%) and oilseed yields (+16%) last year, for example, were well above the 10-year average, as were those of sugarbeet (+47%) and feed corn (+21%).

CIS production remains globally competitive and is set to grow in the short term, advised Evstigneeva. The region's producers, PhosAgro, Acron and EuroChem, have access to high-quality phosphate rock and are investing in on-site integration with ammonia. They are also able to combine production flexibility with a diverse product offering.

CIS producers have sought to capitalise on their favourable fundamentals in three main ways: by making upstream and downstream investments; integrating into wholesale and retail operations internationally; and by continuing to develop improved and more effective fertilizer products.

Home markets have also become increasingly important to Eurasian producers. The strong growth in CIS agriculture in recent years has helped domestic market sales. Russia harvested 260 million tonnes of cereals, sugarbeet, oilseeds, potato, vegetables and feed corn last year, a 27 million tonne rise on 2011. Russian fertilizer demand has been supported by state subsidies for agriculture (worth one billion roubles in 2016), restrictions on food imports and the positive impact of the rouble's devaluation on farm economics.

Rising application rates and farming land expansions in CIS countries should support domestic fertilizer demand going forward. The region is expected to consume two million tonnes more phosphate fertilizers by 2021, Evstigneeva concluded.

African distribution

The African Fertilizer and Agribusiness Partnership (AFAP) is currently working in five 'gateway' countries in Sub-Saharan Africa, namely Kenya, Tanzania, Mozambique, Ghana and Cote d'Ivoire. The Partnership is funding, training and advising fertilizer distributors in these countries, explained **Jason Scarpone**, AFAP's president and CEO. It is also piloting a two-year fertilizer trade finance programme.

AFAP is helping to set up a network of 'hub' agro-dealers in Africa to improve fertilizer distribution. These hubs will act as supply chain intermediaries between large-scale fertilizer suppliers/importers and small, rural agro-dealers. The overall aim is to increase fertilizer storage capacity in Africa and stimulate demand. Intermediate scale hubs help lower costs for importers by reducing the number of points of sale. Also, being more local, hubs are better placed to supply and support rural agro-dealers further down the supply chain.

Agribusiness outlook

Some unusual new realities were highlighted by Terry Barr, senior director at CoBank: "The unusual thing, at this point in time, is the epicentre of uncertainty is now the US, and that's kind of an anomaly. If you look back over the last two or three years, we've spent most of our time talking about the Middle East, about China. But a lot of that uncertainty now is really centred on the US."

Agriculture in the US is highly export dependent with China and Mexico being the top two markets for many US grain, oilseed and meat products. That makes the state of trade relations with both countries a cause for concern. The debate on the 2018 Farm Bill, and the level of funding available, has also begun in the US.

Although President Trump has issued 22 far-reaching executive orders to date, Barr highlighted the constitutional restraints: "The President proposes and Congress disposes with the Supreme Court checking both."

It is not just the direction of US domestic and foreign policy that is adding volatility to global growth expectations. Agribusiness is facing a broad range of global uncertainties, suggested Barr. The growth path of China's economy, for example, remains an enigma in his view. The future of the EU and the Euro are also linked to the uncertain outcome of both Brexit negotiations and national elections in Europe.

Despite this, there is optimism that global economic growth will be solid in 2017-18, although downside risks remain. In the agricultural commodities market, global coarse grains, wheat, soybean and cotton volumes were at record highs last year, although the strong dollar has affected US competitiveness.

A shift in land acreage is taking place in the US with more soybean being grown and less corn. The decline in the wheat growing area is also continuing. This has seen the wheat industry downsize aggressively. Looking ahead, US farm incomes are likely to recover slowly and return to 2010 levels, advised Barr, unless supply side changes were to intervene.

Prevailing trends could, however, drastically alter the agribusiness sector over the next three years. Mega mergers, new technology, farm consolidation, global economic conditions and tax and regulatory reforms could all reshape supply chains by 2020, concluded Barr.

Feed phosphates market

The global demand for feed phosphates has remained flat over the last decade, despite a growing requirement from livestock feed production, explained CRU's **Chris Lawson**. While feed market fundamentals have been supportive of growth, this has failed to translate into greater phosphate demand.

The picture is more mixed regionally, however, with Russia showing feed phosphate demand growth and China experiencing a demand slowdown since 2012.

Global feed phosphates production is in excess of three million t/a P_2O_5 and is broadly divided between three product groups:

- Dicalcium phosphate (DCP)
- Monocalcium phosphate/monodicalcium phosphate(MCP)/MDCP)
- Defluorinated feed phosphate/tricalcium phosphate (DFP/TCP)

About a third of global production (one million tonnes P_2O_5) is traded internationally every year. CRU expects growth in traded products to be modest over the medium term. Nonetheless, MCP exports have been increasing at the expense of DCP, and now account for around three-quarters of exports volumes.

China has been responsible for most of the growth in world feed phosphates production over the last 15 years. Chinese production increased from 0.5 million tonnes P_2O_5 in 2000 to more than one million tonnes by 2010. Lomo is China's largest producer, followed by SinoChem and Chanhen.

The global production share for MCP/MDCP (47%) has increased by seven percentage points since 2012, edging out DCP's production share (45%), which has fallen by 10 percentage points over the same period. DFP/TCP has a global market share of under 10 percent currently.

DCP consumption has sharply declined in the US market, a trend that is likely to be followed by other major consuming countries. China's production is also steadily shifting towards MCP/MDCP, although DCP manufacture still predominates.

New capacity on the horizon includes three projects from EcoPhos in France (220,000 t/a DCP capacity), India (220,000 t/a DCP capacity) and Egypt (60,000 t/a DCP capacity). In China, Yunnan Phosphate Chem (150,000 t/a MDCP capacity) and Chuanjinnuo (50,000 t/a MCP capacity) are also proceeding with projects. Ma'aden has, however, decided against developing 500,000 t/a of feed phosphates capacity as part of its Wa'ad Al-Shamal project in Saudi Arabia, at least for the time being.

The extra feed phosphates capacity coming on-stream over the next few years, against a backdrop of stagnant demand, should make the market increasingly competitive. The declines already seen in feed phosphate prices, from $700/t to $500/t (DCP f.o.b. US) between 2012 and 2015, have cut the premiums enjoyed over fertilizers such as DAP. Looking ahead, market conditions will cap prices and maintain the current squeeze on premiums, in Lawson's view.

Industrial markets

Willem Schipper of Willem Schipper Consulting helped unravel the complexities of non-agricultural markets for phosphorus. Non-ag uses account for around 10% of the global phosphates market and include:

- Feed phosphates
- Food phosphates
- Technical phosphates and detergents
- Markets for derivatives of elemental phosphorus (P_4)

Global P_4 capacity is concentrated in China (600,000-800,000 t/a) with other centres of production in the US and Kazakhstan (both 80,000-90,000 t/a) and Vietnam (80,000 t/a).

A range of derivatives are manufactured from P_4 via the thermal phosphoric acid (TPA) production route using arc furnaces. Major uses for these derivatives include glyphosate, lithium-ion batteries, flame retardants, anti-wear engine oil additive (ZDDP), electroless nickel plating, detergents and industrial water treatment. Overall demand for these applications is flat to slightly growing. The largest markets for P_4 and its derivatives are China, Japan, the US and the EU.

Purified wet acid (PWA), sourced from conventional merchant grade acid (MGA), is the starting point for feed phosphate production. PWA also directly competes with TPA in the food phosphates and technical phosphate segments of the market, and has the advantage of being 10-20% less expensive to manufacture.

The price of Chinese P_4 exports was as low as $2,700/t last September, but has risen subsequently by about $100-200/t due to a hike in coke prices. Strong competition means PWA has been trading at around $1,130-1,160/t P_2O_5 in the EU. PWA prices generally track around $400-600/t above MGA prices.

Merchant ammonia outlook

Doug Hoadley of Hoadley Consulting stressed the importance of phosphates production as a key driver of the merchant ammonia market. Almost half (45%) of the 18.4 million tonnes of ammonia traded globally in 2015 – around 10 percent of world ammonia production (181.8 million) – was sold to phosphates and NPK producers.

The merchant ammonia market tends to be localised due to high freight costs. Around four-fifths of ammonia trade is intra-regional because of this, explained Hoadley. North African, FSU and European producers mainly sell into the European and North African markets, for example, whereas trade from Canada and Trinidad targets the US market.

Ammonia trade dynamics are changing. US ammonia imports are set to decline by 2-2.5 million short tons over the next couple of years, as new domestic capacity starts to displace imports from Trinidad. Russia is also expanding its merchant ammonia supply over the next three years, and will target the EU market.

Ammonia prices declined to a seven year low of $200/t late last year. The merchant market will remain highly competitive through to 2018, in Hoadley's view, keeping up the pressure on prices. ■

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Phosphogypsum: co-product not waste?

As it expands globally, phosphate fertilizer manufacturing is generating ever larger volumes of phosphogypsum waste. Billions of tonnes of this material is currently being managed at great cost within giant waste stacks. Yet, outside of North America, phosphogypsum is finding increasing use as a co-product in agricultural, building and construction applications. We examine whether the unwanted solid waste generated by the phosphates industry is on the verge of becoming a valued resource.

Paradoxically, the manufacture of phosphate fertilizers is both highly efficient and wasteful. Modern process technology is very effective at capturing the phosphorus locked within mined ore. Yet production also generates large volumes of waste material.

The conventional manufacturing route for phosphate fertilizers involves treating phosphate rock with sulphuric acid to make phosphoric acid. This intermediate is then used to produce a range of finished fertilizers such as diammonium phosphate (DAP), monoammonium phosphate (MAP) and triple superphosphate (TSP). But reacting rock with sulphuric acid also generates a gypsum-rich waste known as phosphogypsum.

Although commercial fertilizer production is the primary objective, phosphogypsum is the most abundant material obtained by this wet process route. Almost five tonnes is generated for every tonne of fertilizer obtained (P_2O_5 basis). Put simply, phosphoric acid plants mostly make gypsum. This raises two fundamental questions: how is phosphogypsum best managed and to what extent can it be transformed from waste into a valuable resource?

Costly-to-manage waste

Phosphogypsum, in the form of a wet slurry, is often stored indefinitely above ground in engineered containments known as 'stacks'. Stockpiling in wet stacks is common industry practice, although Ma'aden in Saudi Arabia and JPMC in Jordan also store phosphogypsum in dry stacks. More than one billion tonnes of phosphogypsum is stacked in Florida, the main centre of US phosphate production. Large phosphate fertilizer operations may need to open one or more extra phosphogypsum stacks during their lifetime.

Phosphogypsum in China is either stacked in open yards, occupying large areas of land, or dumped into the sea[1]. Other countries, notably Morocco and South Africa, also discharge phosphogypsum into the sea as a dilute slurry. Coastal discharges of phosphogypsum globally amount to 31 million t/a, almost one-fifth of the total amount of phosphogypsum produced annually[2].

Storing phosphogypsum safely in stacks is a carefully managed and highly regulated process (see box). It is also worse than doing nothing, consultant John Wing, an expert on the phosphoric acid process, told delegates at last year's AIChE Clearwater conference[3].

"What do we do with our biggest product? In the US, it's usually nothing – worse than nothing, actually," said Wing. "Most phosphogypsum in North America is simply stacked and left to sit.

He added: "After stacking phosphogypsum at great cost, we wish we could leave it forever. Sadly, 'forever' comes too soon as – even when a phosphoric acid plant shuts down permanently – complex procedures need to be properly performed to close the stack and keep it environmentally-safe."

> **"Most phosphogypsum in North America is simply stacked and left to sit.**

Increasing use

How phosphogypsum is classified and regulated varies from country to country. In the US, stringent radiological protection criteria, introduced more than 25 years ago, place major restrictions on use. The International Atomic Energy Agency (IAEA) and the US Environmental Protection Agency (EPA) currently have very different stances on the potential risks associated with phosphogypsum use (see box).

Although phosphogypsum with a low radium content continues to be used as a soil amendment in peanut farming in Florida, it represents a tiny fraction (0.03%) of the state's total production[2]. This has not always been the case. Before US regulatory restrictions were introduced in 1989, for example, an entire phosphogypsum stack in California was used for agricultural purposes.

Elsewhere, phosphogypsum is finding increasing use as a co-product in many countries. It is used in agriculture throughout the world – in Australia, Bangladesh, Brazil, Egypt, India, Kazakhstan, Pakistan and Spain, for example. Spanish phosphogypsum has been applied in agriculture since the 1950s, and two-fifths of Bra-

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zil's annual phosphogypsum production is consumed in agricultural applications. Phosphogypsum is also permitted for use as a calcium sulphate soil amendment in the EU.

China is making great efforts to use more phosphogypsum, although overall utilisation rates are still low, partly due to high transportation costs. Around 19 million tonnes of phosphogypsum was used in China in 2013, just under one-quarter of the total produced that year[1]. Encouragingly, two-thirds of the phosphogypsum generated by major Chinese producer Wengfu is consumed by the agricultural and construction sector. Civil engineering projects, including the Three Gorges Dam, have consumed 80 percent of the phosphogypsum output from China's largest phosphoric acid plant[2].

Indonesia uses all of its phosphogypsum, either directly as a cement retardant or reacted to make ammonium sulphate and lime using the Merseburg process. India's reclassification of its phosphogypsum as a co-product, rather than as hazardous waste, has provided a springboard for increasing adoption and use in the subcontinent[3].

Some phosphate producers are reportedly reaping large profits by selling phosphogypsum as a co-product[3].

"It beats limestone for road beds – especially with a smidgen of sand and cement," comments John Wing. "Farmers use phosphogypsum as a combination of soil conditioner plus sulphate fertilizer, and they receive added benefits from its phosphate and minor nutrient content."

He adds: "A surprisingly large portion of soil in the US and Europe has become sulphur-deficient in recent years. Phosphogypsum can solve that need – either as direct application or, when processed, with other fertilizer. Relatively pure gypsum is often utilized in cement or processed to make various products – ammonium sulphate, calcium carbonate, wallboard, sulphuric acid, even hydrogen and glass."

The phosphate industry, which currently spends billions annually discharging phosphogypsum to waste stacks or the ocean, could instead reap tens of billions in profits if more phosphogypsum was utilised as a co-product, in Wing's view[3].

Phosphogypsum Stacks

Disposing of phosphogypsum in stacks has become increasingly managed, tightly regulated and expensive in recent decades[3]. Preventing environmentally-damaging discharges and protecting ground and surface waters is generally an overriding priority during disposal and storage.

Waste accumulating on a massive scale

Phosphogypsum is currently accumulating in China on a massive scale. The country generated 315 million tonnes of phosphogypsum between 2006 and 2011. Phosphogypsum is being generated by 538 phosphate fertilizer plants across the country – some 234 of these being large-scale operations – based on a 2012 industry snapshot. The rate of generation in China has also accelerated from 80 million t/a in 2012 to 110 million t/a in 2015[1].

In Florida, nearly one billion tonnes of phosphogypsum is contained within 25 stacks, 22 of these being located in central Florida. The amount of phosphogypsum generated in the US between 1910 and 1981 is thought to be around 7.7 billion tonnes. US phosphogypsum waste has subsequently been added to at a rate of 40-47 million t/a, according to some estimates. The industry in Central Florida was generating about 32 million tonnes of phosphogypsum annually, prior to 2004.

Stack management

Phosphogypsum discharged from phosphoric acid plants is mixed with water as it leaves the filtration system, pumped to ponds at the top of stacks and allowed to settle. Water drains from the top of stacks to cooling ponds at ground level before being recycled and returned to the plant. The water is generally managed either as a closed circuit (recirculating) system or an open circuit (once through) system.

Water handling and management requires the installation of a complex system of ponds, trenches, pumps and pipework. Environmental standards have improved over time. New stacks in the US have an underlying impervious liner to prevent the downward seepage of water into the ground and aquifers. They also have more protective ditches and ponds. Tight management of the water balance ensures less water enters the stack and also avoids the outflow of effluent.

Closure and regulation

Stacks are eventually taken out of service when they reach their maximum height. The Tampa Bay stack in Florida was growing in height by six metres annually when it was operative. By the time of its closure in 1992, it was 66-69 metres tall and covered 138 hectares.

Stack closure has become increasingly common in Florida, as the scale of North American production has declined. The closure process in the state is subject to a formal procedure, being carried out according to a detailed specification in a published plan, and is usually sub-divided into phases. This makes closure an expensive and relatively complicated process. Acidic water within the stack requires neutralisation, and the treated water obtained must be disposed of in an environmentally safe manner. Closed stacks are capped with an impervious barrier and covered with soil and revegetated. The cost of closing an individual stack can exceed $100 million. Surety bonds help guarantee the financing of stack closure.

The closure of a stack is designed to ensure that potential pollutants, such as acidic water, heavy metals and radionuclides, are effectively contained, and that long-term environmental and health impacts remain negligible. Extensive monitoring carried out over many years at over twenty sites in Florida has confirmed that radionuclide discharges from stacks and migration to groundwater are insignificant[2].

Cost of stacking phosphogypsum

The total life cycle cost of stacking phosphogypsum is in the region of $25 per short ton, according to Phosphogypsum Working Group (PGWG) estimates. As five tonnes of phosphogypsum are generated for each tonne of P_2O_5 obtained, this is equivalent to a production cost burden of $125 per short ton of P_2O_5. The main cost components associated with phosphogypsum stacks include[3]: The value of land; earth moving; the underlying impervious seal; the expense of transferring solid waste and the return of water; surety bonds, typically $150 million; equipment to shape and maintain the stack; operational, maintenance and monitoring costs; managing environmental impacts, both routine and accidental; the cost of closure; and land remediation after closure ■

Use as a building material

Phosphogypsum can be used as cement and plasterboard raw material. Other construction applications include brick, block, tile and artificial stone production. Glass and glass ceramics can also be readily manufactured from phosphogypsum and tailings sand.

Quality is an important consideration in this market. Phosphogypsum used in building products generally requires washing to remove acidic residual water. Additional processing to remove residual phosphate may also be necessary[2].

The cement and plaster market could potentially consume phosphogypsum on a large scale. The use of phosphogypsum in such products was once commonplace in two former producing countries, Belgium and France, from the 1960s onwards. There continues to be a market for phosphogypsum for building products in Belgium, Brazil and India, subject to certain restrictions. It also has potential to be exploited as a building material in South Africa, a country where low-cost housing is a priority.

> **"Farmers use phosphogypsum as a combination of soil conditioner plus sulphate fertilizer."**

Phosphogypsum is a naturally occurring radioactive material (see box). Consequently, its use in building materials has been widely evaluated by Spain, Australia, Brazil, India and others. While most studies have shown that radiation exposure is unlikely to be a serious concern[2], the agriculture use of phosphogypsum largely predominates. This is because phosphogypsum can struggle to compete with natural gypsum in the building materials market – on both technical and cost grounds. Unfortunately, market mechanisms do not take account of the wider financial and environmental liabilities associated with indefinite storage in stacks[2].

Road construction

Road building is a widely studied and tested use for phosphogypsum. Initial work on road construction applications in Belgium and France in the 1970s and 1980s focused on its use in embankments and for road stabilisation. More recent work suggests that use in building road beds is the most attractive construction application. For this end-use, phosphogypsum is generally mixed with 5-7% cement, and sometimes with fly ash.

Pilot roads have been successfully built with phosphogypsum in the US, South Africa and Finland. A two-lane 100-metre road base test section, made of a stabilised phosphogypsum-cement mixture, was constructed in Texas in 1991. Two experimental roads were also built in Florida in 1986-1987 using phosphogypsum. The cement-stabilised phosphogypsum and sand mixtures used in these roads had a greater load-bearing capacity than locally-mined limestone[2].

Such pilots have helped demonstrate that phosphogypsum, if sourced within 150-200 kilometres of the construction site, is no more expensive than more traditional road building materials. The routine use of phosphogypsum in road beds could consume 25,000 tonnes per kilometre, equivalent to a potential annual consumption of 140 million tonnes in the US alone, according to some calculations.

Other applications

The use of phosphogypsum in marine engineering is economically attractive, as many phosphogypsum stacks are located near coastal areas. Applications include the protection of coastal wetlands against the risk of flooding, the construction of artificial reefs and making oyster bed materials. Mixtures made from phosphogypsum, cement and fly ash have shown little degradation in sea water during marine trials over a two-year period.

Phosphogypsum also has potential for landfill containment. Its use as a landfill liner has been piloted in Italy. Test results suggest that sulphur present in phosphogypsum increases landfill degradation rates, potentially allowing 30-45% more refuse to be buried.

The use of phosphogypsum as a sulphur source has been extensively studied using both chemical and biological processes. However, sourcing sulphur in this way is unlikely to be competitive with low-cost sulphur recovery from oil and gas.

From waste to resource?

Turning phosphogypsum from a waste material into a valuable co-product is likely to be limited by three main factors:

Agriculture

Phosphogypsum can improve the productivity of agricultural land in four main ways[2]:

- Land reclamation – in estuarine marsh areas for example
- Remediation of saline and sodic soils
- A soil amendment to prevent crusting and improve water retention
- As a fertilizer to provide crops with nutrients

Spain has pioneered the use of phosphogypsum in land reclamation. A large area of land near Huelva, Spain, has been successfully returned to productive agricultural use via the application of phosphogypsum.

The use of phosphogypsum as a sulphur fertilizer, typically at application rates of 100-600 kg/ha, has been shown to significantly increase the yields of a wide range of crops. It can be directly applied to the surface of soils using a conventional spreader. However, it may be necessary to saturate phosphogypsum with rainwater for around a year prior to field application to displace acidic process water.

Phosphogypsum also improves the condition of saline and sodic soils by[2]:

- Reducing sodium and aluminium toxicity
- Increasing calcium and sulphur content
- Increasing ammonia retention and water retention
- Improving water efficiency

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Regulation: barrier or opportunity?

Quality and impurities

In a phosphoric acid plant, phosphate rock reacts with sulphuric acid to form phosphoric acid and gypsum as follows:

$$Ca_5(PO_4)_3X + 5H_2SO_4 + 10H_2OL \rightarrow 3H_3PO_4 + 5CaSO_4{\cdot}2H_2O + HX$$

Where X = OH, F, Cl, and Br

Although gypsum is the main constituent of phosphogypsum – the waste product formed by this process – a range of impurities may also be present, including acidic water, residual phosphate, acid insoluble material, calcium fluoride, organic matter, iron and aluminium. Although quality does vary according to the production process (Table 1), phosphogypsum is not usually suitable for direct use in plasterboard or cement and generally requires pre-treatment to remove some of the impurities present.

The quality of phosphogypsum, and the nature and levels of any impurities present, can affect how it is regulated and used. The Chinese Ministry of Environmental Protection, for example, classifies phosphogypsum as a hazardous industrial by-product currently[1]. Quality considerations are important, given that phosphogypsum competes in some markets with higher purity natural gypsum and gypsum from flue gas desulphurisation.

Regulating radioactivity

Radioactivity has also been a regulatory stumbling block and a major barrier to use, particularly in the US. Phosphate rock contains the naturally occurring radionuclides uranium-238, thorium-232 and their decay products. Some of these radionuclides, particularly radium, become concentrated in phosphogypsum during the production process.

In the United States, the stacking of phosphogypsum became a legal necessity in 1989 after the US Environmental Protection Agency (EPA) prohibited its use on radiological grounds. This blanket ban was later modified to allow phosphogypsum with a low radium content (< 10 pCi/g) to be used as an agricultural amendment. Central Florida phosphogypsum generally ranges above this threshold (20-35 pCi/g radium). The lower radioactivity of north Florida phosphogypsum (5-10 pCi/g radium), in contrast, does, allow it to be sold as a soil amendment to peanut farmers as a source of calcium for peanut shells.

In marked difference to the US EPA, the International Atomic Energy Agency (IAEA) does not consider phosphogypsum to be radiologically hazardous[2]. In 2013, it concluded that: "All evidence suggests that the doses received as a result of the use of phosphogypsum in agriculture, road construction, marine applications and in landfill are sufficiently low that no restrictions on such uses are necessary."

This makes radiological regulation of phosphogypsum un necessary, in the IAEA's view. It suggests that regulation should focus on promoting safe use instead: "There is no necessity for additional regulation for purely radiological purposes. Future liabilities associated with… large phosphogypsum stacks place a considerable burden on future generations. This… provides a very compelling reason for creating a regulatory environment that is conducive to identifying and promoting… ways of safely using phosphogypsum as a co-product… rather than having to manage it as waste."

Table 1: **Phosphogypsum chemistry and yield versus production process**

	Process		
Chemistry	**Dihydrate (DH)**	**Hemihydrate (HH)**	**Hemidihydrate (HDH)**
CaO (%)	32.50	36.90	32.20
SO_3 (%)	44.00	50.30	46.50
P_2O_5 (%)	0.65	1.50	0.25
F (%)	1.20	0.80	0.50
SiO_2 (%)	0.50	0.70	0.40
Fe_2O_3 (%)	0.10	0.10	0.05
Al_2O_3 (%)	0.10	0.30	0.30
Cryst. H_2O (%)	19.00	9.00	20.00
Dry yield (t/t P_2O_5)	4.90	4.30	4.90
Comment:	Dirtiest gypsum	Higher gypsum content	Cleanest gypsum

Source: *FIPR*

Policy stimulus

The IAEA's stance on radioactivity, because of the organisation's international standing and authority, should provide a strong stimulus to phosphogypsum use globally.

China's policy framework is also targeting greater phosphogypsum use. The country aimed to increase phosphogypsum use to 40% by the end of 2015, as part of guidelines issued by the industry and information technology ministry in 2011. The country's 12th Five-Year Plan (2011-2015) also prioritised waste reduction, reuse and recycling. This included a specific implementation plan for the safe disposal and comprehensive use of phosphogypsum[1]. China also has policies promoting investment in the circular economy.

The EU is also seeking to introduce a circular economy policy package. The aim is to 'design out waste', encourage product reuse and make Europe's economy less wasteful. Disposal is already the option of last resort in the EU's existing waste hierarchy.

- **Quality:** a purification and/or neutralisation step is necessary in the building product market and some other end-uses
- **Cost:** high-purity natural gypsum is relatively inexpensive to mine and abundant. Gypsum generated by flue gas desulphurisation also increases competition in some markets
- **Location:** the cost of transporting phosphogypsum to end markets from its source in stacks and phosphoric acid plants may be prohibitive

Quality and cost considerations are two of the factors limiting phosphogypsum use in China, according to a recent International Fertilizer Association (IFA) report[1]. This noted that: "Compared to natural gypsum, performance is inferior… [with] no price advantage. Impurities affect its colour and appearance and limit its use. Low strength and poor water resistance also adversely affect utilisation." High transportation costs in China have also hampered utilisation[1].

More positively, help is on hand for any producer looking to find end-uses for phosphogypsum and wishing to market it as a saleable product. The Florida Industrial and Phosphate Research Institute (FIPR) has been providing knowledge and expertise on phosphogypsum use for decades. For a number of years now, the international Phosphogypsum Working Group (PGWG) has also been advising producers on how best to turn phosphogypsum from a waste into a resource.

Phosphate producers also have access to a growing body of information. Earlier this year, IFA published a report on the agricultural potential of Chinese phosphogypsum, for example[1]. This followed a comprehensive report on the sustainable management and use of phosphogypsum issued by IFA at the beginning of 2016[4].

Finally, not all phosphogypsum is the same. The hemidihydrate (HDH) process, although not widely used in phosphoric acid manufacture, produces relatively pure gypsum (see box) containing around 0.3% P_2O_5. This allows all the phosphogypsum produced by the two HDH plants at Gresik, Indonesia, to be used as a cement retardant and to manufacture ammonium sulphate by the Merseburg process[3]. Phosphogypsum obtained by the hemihydrate (HH) process is also purer than that yielded by the dihydrate (DH) route.

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Phosphate rock quality and granulation

Phosphate rock quality has a significant influence on fertilizer granulation. **Curtis Griffin** of PegasusTSI explains how variations in the quality of phosphate ore from the US, Morocco, Saudi Arabia and Peru affect the granulation process.

Phosphate rock quality

Most of the world's mined phosphate rock is beneficiated and reacted with sulphuric acid to produce wet-process phosphoric acid. The phosphoric acid generated is largely consumed in the manufacture of granular fertilizers. The quality of phosphate rock has a significant impact on the granulation process. Quality is determined by both the ore grade (% P_2O_5) and the levels and types of impurities present in phosphate rock.

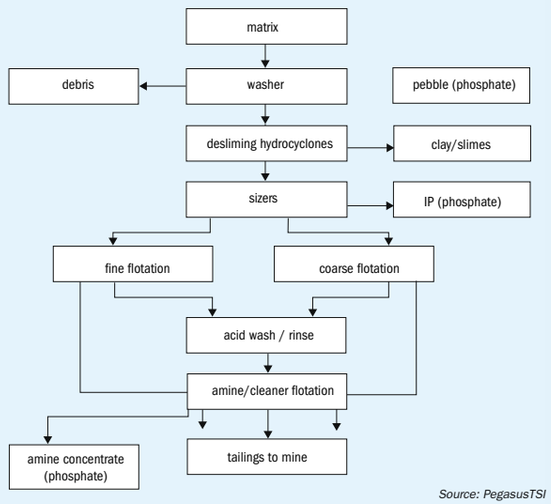
Phosphate rock deposits are widely-distributed across the world. The chemistry and quality of each of these deposits is distinctly different (see Table 1). Beneficiation can successfully remove silica, dolomite, calcite and clay impurities (see flowsheet in Figure 1). But other impurities such as iron (Fe_2O_3), aluminium (Al_2O_3) and magnesium (MgO) can remain after beneficiation as they are generally more difficult to remove.

Table 1: **Phosphate Rock Qualities from Various Ore Deposits**

	Idaho	North Carolina	Central Florida	Morocco	Saudi	Peru
% P_2O_5	32.30	30.00	31.20	31.50	27.75	30.05
% CaO	46.80	49.00	46.60	51.20	53.30	47.10
% Fe_2O_3	0.44	0.72	1.50	0.24	0.16	0.70
% Al_2O_3	1.10	0.43	1.20	0.35	0.19	0.63
% MgO	0.37	0.53	0.60	0.47	0.23	0.69
% F	3.20	3.80	3.70	3.86	2.80	3.02

Source: PegasusTSI

Fig 1: **Typical phosphate plant beneficiation flow sheet**



Source: PegasusTSI

Effects of impurities on granulation

The successful production of high-quality granular fertilizers requires a phosphate rock feedstock with an optimum level of impurities. Either too many impurities or too few impurities can cause operational and product quality issues during the manufacture of granulated fertilizers.

The main impurities that affect the granulation, product grade and chemistry of diammonium phosphate (DAP), and many other fertilizers, are Fe_2O_3, Al_2O_3 and MgO. Levels of these impurities are usually expressed as a ratio to P_2O_5, known as the minor element ratio (MER):

Table 2: **Phosphate rock impurity ratios from various ore deposits**

	Idaho	North Carolina	Central Florida	Morocco	Saudi	Peru
CaO/P_2O_5, rock quality	1.45	1.63	1.49	1.63	1.92	1.57
F/P_2O_5, reactivity	0.099	0.127	0.119	0.123	0.101	0.100
Fe_2O_3/P_2O_5, drying	0.010	0.020	0.050	0.010	0.010	0.020
(Fe_2O_3 + Al_2O_3)/ P_2O_5, grade	0.048	0.038	0.087	0.019	0.013	0.044
(Fe_2O_3 + Al_2O_3 + MgO)/ P_2O_5, MER grade	0.059	0.056	0.106	0.034	0.021	0.067

Source: PegasusTSI

$$MER = (Fe_2O_3 + Al_2O_3 + MgO) / (P_2O_5)$$

MER, together with other impurity ratios, can be used to predict the quality of granular fertilizer products. For example, it is generally difficult to meet product grade in DAP manufacture once the MER increases above 0.080. Conversely, DAP grade is likely be over-formulated once the MER falls below 0.060.

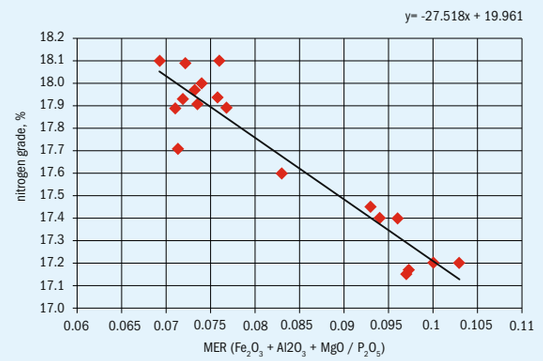
A number of other element ratios are also valuable and can be used to complement the MER:

- The CaO/P_2O_5 ratio is a good indicator of overall rock quality
- The F/P_2O_5 ratio indicates reactivity
- The Fe_2O_3/P_2O_5 ratio is an indicator of how well the product will dry
- The (Fe_2O_3 + Al_2O_3)/P_2O_5 ratio is used to predict the product sizing or granulation of the plant

The latter ratio is important as good granulation generally requires a minimum amount of Fe_2O_3 and Al_2O_3. Percentage MgO in the rock is also very important, as granulation plants start to have operational problems if MgO content exceeds 0.60%. These become significant once MgO reaches 1% as high MgO levels cause a number of granulation problems. Final products are soft and are easily broken into fines, for example, plus a significant amount of dust will be generated in the plant.

Impurity ratios for various phosphate rock deposits around the world are shown in Table 2. The impurity ratios in this table are a great way of predicting granular fertilizer quality. For example, the MER ratios indicate that Central Florida rock will have a difficult time making product grade, while Saudi rock will be over-formulated on product grade. The (Fe_2O_3 + Al_2O_3)/P_2O_5 ratios also signal that Saudi and Morocco rock will have granulation difficulties due to low levels of Fe_2O_3 + Al_2O_3.

Fig 2: **MER ratio versus nitrogen grade of DAP**



Source: PegasusTSI

Impacts of impurities on DAP Grade

The ideal product grade for DAP is 17.9% N and 45.9% P_2O_5. This grade optimises the use of raw materials and should also ensure that there are no quality complaints from customers. The minimum acceptable product grade is 17.6% N and 45.6% P_2O_5 – although producing DAP with a grade this low is not recommended. Products are considered to be over-formulated if the grade is above 18% N and 46% P_2O_5. Product grades above these threshold values results in N and P_2O_5 being given away for free.

The ideal MER range to make DAP of the optimum grade is between 0.060 and 0.080. Granulation at MER values below 0.060 will result in over formulation, while MER values above 0.080 will produce off-specification grades. Percentage nitrogen can be plotted against MER for specific rock types to predict the desired nitrogen grade (N%) in DAP, as is shown by the example in Figure 2.

Operational improvements to increase DAP grade

If the MER is too high (>0.080), causing product N and P_2O_5 grade to be too low, the following can be done to improve grade:

- Phosphate rock can be blended prior to entering the phosphoric acid plant to limit the MER.
- The sulphate levels in the 30% phosphoric acid can be checked: sulphate levels above 2.5% could impact P_2O_5 grade by converting to ammonium sulphate which acts as a diluent with respect to P_2O_5.
- The solids levels in the phosphoric acid can be checked: if solids levels are too high they can impact on overall N grade, and operational changes should be made to reduce these.
- The calcium sulphate levels in the phosphoric acid can be checked: too much calcium sulphate can impact on overall N grade, and operational changes should be made to reduce these.
- The product moisture can also impact on grade: decreasing moisture from 2% to 1.5% can increase N grade by 0.1% and increase P_2O_5 grade by 0.2%.

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- A clarification step can be added to remove solids from phosphoric acid: cleaning-up phosphoric acid to reduce solids will increase grade.

Clarification to remove solids from phosphoric acid can be done at different concentrations. Clarification at the 30-40% stage will remove calcium sulphate, for example. Clarification at the 54% stage will remove Fe_2O_3 and small amounts of Al_2O_3. The removal of these solids will improve grade.

Clarification can be further improved by cooling the phosphoric acid and adding flocculants. P_2O_5 can also be recovered from stored clarification sludges to produce lower-grade (10% N and 50% P_2O_5) nitrogen products such as monoammonium phosphate (MAP).

If all the operational changes suggested above have been made – and the N grade still remains low – liquid nitrogen products can be added to the process such as urea ammonium nitrate (UAN) and ammonium nitrate (AN).

Operational improvements to decrease DAP grade

If the MER is too low (<0.060), causing product grade to be over-formulated, the following measures can be used either separately or in combination to reduce DAP grade:

- Fillers can be added to reduce both P_2O_5 and N grade
- Reactor and granulator mole ratios should be evaluated and optimised to decrease N grade
- Sulphuric acid can be added to the reactor to reduce P_2O_5 as this slightly increases N grade by forming ammonium sulphate

Economic impact of over-formulation

Over-formulation of DAP grade has adverse economic impacts and optimising DAP grades can therefore deliver significant cost savings, as the following example shows:

DAP production of 500,000 t/a results in an over-formulated grade of 18.4% N and 46.8% P_2O_5. A filler is therefore added to reduce the grade to 18.08% N and 46.0% P_2O_5. This enables the production of an additional 8,650 t/a of DAP. This will generate an additional $1.7 million dollars profit per year, assuming a DAP profit margin of $200/t. Lower ammonia consumption will also deliver a further $380,000 in annual savings, raising the total extra profit to $2 million per year. This assumes a filler such as gypsum is used to minimise costs.

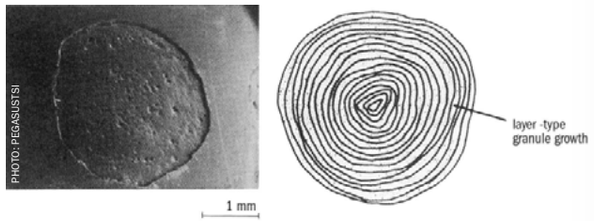

Photo of actual fertilizer granule (accretion)

Granule formed by accretion

Fig. 3: Granulation by accretion/layering.

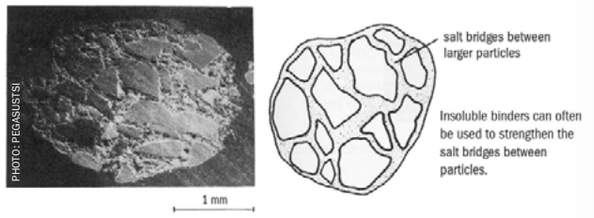

Photo of actual fertilizer granule (agglomeration)

Granule formed by agglomeration

Fig. 4: Granulation by agglomeration.

Granulator

Impacts of impurities on granulation

The industry quality standard for granulation is typically 2-4 mm granules between 93-95%, with a size guide number (SGN) of 225-300 and uniformity index (UI) of 50-60. The SGN is the median granule diameter multiplied by one hundred, i.e. the size at which 50% of the product is retained, expressed in millimetres, multiplied by one hundred.

$$SGN = d_{50} \times 100$$

The UI is the ratio of small granules (particles retained at 95%) to large granules (particles retained at 10%) multiplied by one hundred. A UI of 100 means that all the granules are the same size.

$$UI = [95\% \text{ retained}] / [10\% \text{ retained}] \times 100$$

Layering is the preferred mechanism for making granular fertilizers. The layering mechanism occurs when ammonium phosphate slurry is sprayed onto the surface of the recycle or 'seed' particles to form an additional layer. Each time a seed particle is recycled, an additional layer is added and granule size increases. This mechanism is typical of 'high recycle' processes where a granule makes many passes through the granulator before being removed as product. Products formed by layering have good hardness and are spherical (see Figure 3).

Granulation by an agglomeration mechanism is not desirable and occurs when the process is not optimised. Agglomeration occurs when recycled particles become cemented together due to salt bridges forming between particles. This mechanism is typical of 'low recycle' processes and also occurs when undesirable impurities are present. Products formed by agglomeration are much less spherical, are difficult to dry, as moisture is held deep within granules, and more prone to breakage as particle bonds are weak (see Figure 4).

Impurities in phosphate rock have a significant impact on the granulation mechanism. Process issues occur when MER is above 0.080 and MgO above 0.6%. The DAP particles generated at these MgO levels are typically dry, dusty and weak. The particles also agglomerate to form irregular shapes and generate fines. Finally, the product obtained will not meet the SGN and the 2-4 mm size requirements. Additionally, if the Fe_2O_3 is too high, drying becomes difficult and the granular fertilizer leaving the plant will have a high moisture content.

Conversely, If MER is too low (<0.050) there may not be enough seed particles present to allow layering to take place during granulation. Small-size products are generated and there is less ability to control product size during the process. Impurities may need to be added to overcome these issues and improve granulation.

Conclusion

The impurities present in phosphate rock have a significant impact on the quality of granular fertilizer products. Minor element ratio (MER) must be maintained within a range of between 0.060-0.080 to ensure optimum grade DAP products are obtained.

The $(Fe_2O_3 + Al_2O_3)/P_2O_5$ ratio is a good predictor of granulation and plants will have process issues if this ratio is too low. MgO content is also important and will generate dry, dusty and weak DAP particles if present above 0.6%.

MER has a critical influence on the overall performance of granulation plants. Fortunately, operational changes can be used to optimise this ratio and ensure that the granular fertilizers produced are of optimum quality. ■

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SOP project prospects

PHOTO: VERDANT MINERALS

Verdant Minerals brine trench, Lake Karinga, Northern Territory, Australia.

An increase in the supply of primary SOP could potentially transform the market for this premium potash fertilizer. We provide a round-up of the most promising greenfield SOP mining projects worldwide.

Sulphate of potash (SOP, K_2SO_4) commands a premium price due to its value as a chloride-free source of potassium for lucrative cash crops such as tobacco, tree nuts and citrus fruits.

The market for SOP, around 6.1 million tonnes in 2015, is forecast to grow by more than one-fifth to 7.5 million tonnes by 2020 (*Fertilizer International* 475, p49). SOP prices have appreciated by around 10% in recent years, while prices for muriate of potash (MOP, KCl) declined by over two-fifths between mid-2014 and mid-2016.

SOP supply is currently very concentrated. Just three countries, China, Germany and Belgium, account for more than three-quarters of global capacity. Some 44 percent of world SOP capacity comes from primary production, largely from the solar evaporation of natural brines. The remaining 56 percent of SOP capacity is attributable to secondary production, mostly by treating MOP with sulphuric acid in the Mannheim process (*Fertilizer International* 475, p49).

Market signals the need for extra capacity

SOP production has been a profitable business in recent years due to the large margins between the price of SOP and its production costs. In 2015, for example, the SOP price averaged $533/t, over one hundred dollars higher than production costs at the top end of the cost curve ($420/t). According to analysts CRU, this is clear signal from the market that extra SOP production capacity is needed.

The question is: where will extra SOP capacity come from to fulfil market expectations and meet growing demand? CRU believes an increase in primary SOP outside China has the potential to transform the market. At the beginning of last year, it identified 15 primary SOP projects that could potentially add almost five million tonnes (4.88 million t/a) of extra primary capacity to global SOP supply, if they were all successfully commissioned (Figure 1).

Twelve of these projects were classed as either probable or possible and a further three as speculative. Eleven of these prospects are located in just four locations, East Africa, Western Australia, North America and Brazil.

"They're not yet in our base case forecast because, by and large, they haven't achieved financing," commented CRU last year. "East Africa is particularly interesting as there are four large SOP projects planned in Eritrea and Ethiopia. There are also other projects, largely speculative, in South Asia and Australia."

We review the status of all 15 of these projects below. How many of these will eventually enter production remains an open question. Whether likely or not, any rise in primary SOP supply outside of China remains an important market issue to watch – as it could herald a decline in SOP prices and ratchet-up the cost pressures on vulnerable secondary SOP producers (*Fertilizer International* 475, p49).

Danakali sets the pace

Australian mining junior Danakali Limited (formerly South Boulder Mines) was recently granted a mining licence for its Colluli SOP project in Eritrea. The ASX-listed developer announced it had secured the licence from the Eritrean energy and mines ministry in February, following the signing of a mining agreement.

The mining licence extends over an area of more than 60 km² and covers some 60 years of the expected 200-year mine life set out in Colluli's definitive feasibility study. It allows potassium, calcium, sodium and magnesium salts and bromine to be mined from the Colluli deposit.

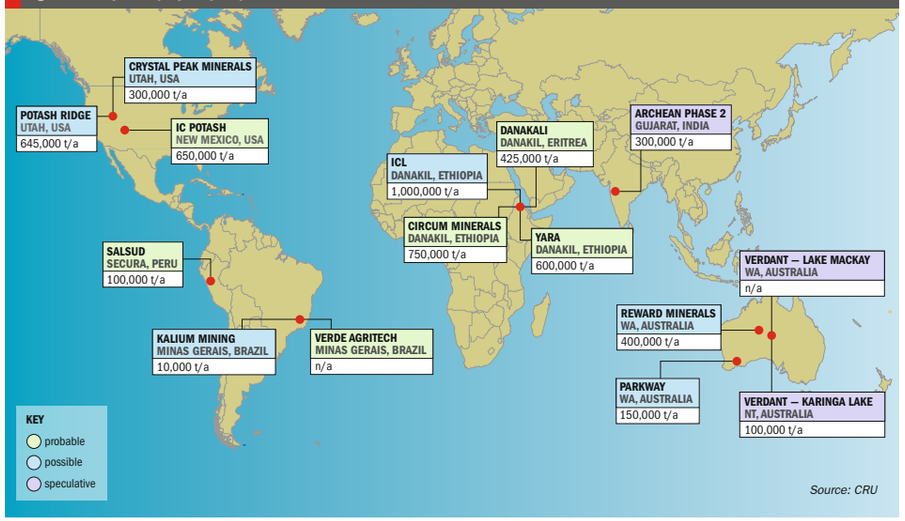
In a further sign of progress, Danakali recently appointed construction firm Fluor to lead the front end engineering design (FEED) and optimisation process for the Colluli project. Global Potash Solutions have also joined the project's FEED & optimisation team.

JPMorgan Chase & Co became a shareholder of Danakali last August. The US investment bank took a 9.12% stake in Danakali, via a AUD 6.7 million ($5.1 million) private placement, the sum raised going towards Colluli's development. JP Morgan already has a successful track record in Eritrea through its investment in Nevsun Resources, the operator of the country's Bisha copper mine.

Danakali unveiled plans to construct an open pit SOP mine and 425,000 t/a processing plant in its February 2015 prefeasibility study (PFS) (*Fertilizer International* 463, p39). A project definitive feasibility study (DFS) published in November that year revealed:

- Ore reserves of 1.1 billion tonnes with an expected mine life of 200+ years
- Phase I SOP production of 425,000 t/a
- A reduction of more than 30% in Phase I capex to $298 million
- Phase I opex of $235.05/t
- Commissioning in the fourth quarter of 2018
- 3.5 years capital payback period
- Post-tax Net Present Value (NPV) of $860 million
- Post-tax Internal rate of Return (IRR) of 29%
- Phase II expansion to increase total SOP production to 850,000 t/a commencing in year six of operations
- Additional capex of $175 million needed for Phase II
- Opex falls to $207.25/t in Phase II

Fig 1: **Primary SOP project prospects**



Circum gains a mining license

In a milestone development, the Ethiopian government granted **Circum Minerals** a mining license for its Danakil Potash project in March. This provides Circum with exclusive potash mining rights over an area of 365 square kilometres for an initial period of 20 years. The license is renewable indefinitely for further 10 year periods, subject to financial viability.

The Danakil Potash project has made rapid progress since Circum purchased Ethiopian Potash Corp (now AgriMinco Corp). The company has plans to mine both MOP and SOP as part of the project (*Fertilizer International* 478, p58).

The project's 2015 DFS confirmed proven and probable KCl reserves of 107.8 million tonnes, and measured, indicated and inferred resources of 4.9 billion tonnes (18.1% KCl). In the project's first phase, production from solution mining is scheduled to commence in mid-2018 and ramp-up to two million t/a of MOP and 0.75 million t/a of SOP over the next three years. A mine life of 26 years is expected for production on this scale.

Circum is aiming to be a competitive producer with operating costs in the lower quartile and capital costs around half those of existing Russian and Canadian producers. An optimised DFS commissioned from Senet and K-UTEC AG Salt Technologies was released in March 2016. This reduced project capex by $276 million and opex by around $3/t. Highlights included:

- Capex of $2.3 billion
- Opex (f.o.b. Djibouti) of $81/t for MOP and $156/t for SOP
- Pre-tax NPV of $2.8 billion
- Pre-tax IRR of 29%

Circum also appointed Morgan Stanley to carry out a strategic review of the project in March last year. The investment bank was asked to look at the potential for introducing strategic investors and joint-venture partners. The review is also looking at the potential for corporate or project-level debt and/or equity investments.

Circum is managed by London-based private investment group Plinian Capital Ltd. Another London-based private equity firm, African Minerals Exploration and Development (AMED), acquired a 37% stake in Circum in 2014.

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Yara reduces its project stake

Fertilizer giant **Yara International** has invested tens of millions of dollars in Yara Dallol BV, its Ethiopian potash mining project (*Fertilizer International* 478, p58). Although Yara reduced its holding in the project two years ago, it still holds a majority stake.

The Norwegian producer became involved in the venture after acquiring a $50 million majority stake in mining junior Ethiopotash in 2012. One quarter of the shares in Yara Dallol were subsequently sold to Boston-based Liberty Metals & Mining (LMM) for $51.25 million in 2015, netting Yara a $35.4 million share of the proceeds. Yara now holds 51.8% of Yara Dallol shares, LMM 25% and XLR Capital Limited 23.2%.

Yara awarded an engineering, procurement and construction management (EPCM) contract to experienced potash project developer SNC-Lavalin at the end of 2015. The contract covers front-end engineering design, construction and commissioning of the Yara Dallol project.

Yara Dallol holds exploration licenses for two concessions, North Musley (18.7 km^2) and Crescent (35.3 km^2), located around 605 km northeast of the capital Addis Ababa. A DFS for the project, put together by Canada's NovoPro Projects Inc, was released in February 2015. This provided costings for a 600,000 t/a SOP solution mine and solar evaporation operation, and demonstrated sufficient reserves for 23 years of production.

The plan, as set out in the DFS, involves solution mining the western part of the North Musley area with 28 caverns a year to ultimately recover over 14 million tonnes of SOP. The SOP produced will be trucked to a purpose built storage and handling terminal on the coast at Tadjoura, a new port being constructed by the Djibouti Port Authority. Overall, the project will require capex of $740 million and produce SOP for an opex of $167/t (f.o.b. Djibouti).

Some final hurdles remain, though, and construction cannot commence until the Ethiopian Ministry of Mines grants a mining licence and approves an environmental and social impact assessment (ESIA). Construction should take around two years to complete, once the necessary approvals are granted and the finance is in place.

A final investment decision for the Dallol project is also still pending, according to Yara's 2016 annual report. This also noted that: "There are multiple uncertainties related to the project's profitability, mineability of the reserves, financing, required infrastructure and necessary governmental permits. Any negative development to these uncertainties could trigger a decision to stop the project and a resulting impairment loss."

Yara's total carrying value in the project is NOK 1.7 billion ($200 million).

IC Potash moves away from SOP

Intercontinental Potash Corp (ICP) is developing the Ochoa polyhalite mine project in Eddy and Lea counties, New Mexico. The company received mining authorisation from the US Bureau of Land Management for the project in 2014. This covered the construction and operation of Ochoa's mine, mill and processing facilities.

A project feasibility study was also published in 2014. The study, compiled by Agapito Associates and SNC-Lavalin, proposed producing 650,000 t/a of SOP from polyhalite using a five-stage process: crushing/washing, calcination, leaching, crystallisation/evaporation and granulation.

However, IC Potash subsequently commissioned a preliminary economic assessment (PEA) from Golder Associates to look at the feasibility of mining and marketing two million t/a of polyhalite as a direct application fertilizer. On publication of the PEA last November, the company signalled it no longer planned to produce SOP via a chemical processing route, and announced that the Ochoa project would now focus on the mining of direct application polyhalite instead.

"IC Potash has revised the project to consider direct application of polyhalite as a crop nutrient product rather than producing SOP through a chemical processing plant," the company said in a statement. "The resulting project has a reduced capital cost, a shorter ramp-up time and improved financial metrics."

Ochoa's polyhalite resources, estimated at 330 million short tons, should be sufficient for 38 years of production. Mining is scheduled to begin in 2019. Yara International has invested $40 million in the project in return for 30% off-take.

SalSud at basic engineering stage

Salmueras Sudamericanas (SalSud), a company founded in 2011 and owned by Pacasmayo (74.9%) and Quimpac (25.1%), is developing an SOP brine project in Peru's Sechura desert. The project is located at kilometre 882 of the Panamericana Norte, between the districts of Sechura (Piura), Olmos and Mórrope (Lambayeque). The project's three concessions, Cañacmac, El Tablazo and Ñamuc, collectively cover an area of more than 136,000 hectares.

SalSud is proposing to manufacture SOP fertilizer, feed phosphate and industrial chemicals by extracting and processing a potassium-, magnesium- and bromine-rich underground brine. The project plans to produce:

- 100,000 t/a of SOP
- 110,000 t/a of dicalcium phosphate (DCP)
- 120,000 t/a of magnesium sulphate
- 60,000 t/a magnesium oxide and hydroxide,
- 10,000 t/a of liquid bromine

2014 was a landmark year for the SalSud project. Its Environmental Impact Assessment (EIA) was approved by the government and a water permit was also granted by Peru's national water authority, the Autoridad Nacional del Agua (ANA). Progress since then has been limited. A basic engineering study by Germany's K-Utec AG Salt Technologies, completed over a year ago, is still being assessed by Pascamayo and Quimpac. "This [study] is currently being evaluated by both partners in order to determine how to move forward according to their investment priorities," Pacasmayo said in February this year in its latest company results.

Verde Agritech champions innovation

An innovative thermal production process is being attempted by the Cerrado Verde project in the western Alto Paranaiba region of Minas Gerais state, Brazil. Developer **Verde AgriTech** (previously Verde Potash) plans to manufacture a range of fertilizers and soil conditioners from potassium silicate rock. These include:

- The chloride-free potash fertilizer *TK47*
- The fertilizer and soil conditioner *Super Greensand*
- *Alpha*, a source of plant available silicon

Verde's innovative thermal process for manufacturing 'ThermoPotash' (*TK47*) involves strip mining a potassium silicate

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surface deposit (a glauconitic meta-argillite) and then mixing and calcining it with limestone. This transforms potassium present in the rock into a more soluble plant-available form that is slowly released when added to soil. *TK47* contains 7% K_2O, is chloride-free and, because it is not easily leached from soil, has a residual effect from one harvest to the next.

A 2014 PFS on production via the ThermoPotash process by AMEC, Andes Mining Services (AMS) and Ingeniería y Construcción (NCL) indicated:

- Proven reserve of 5.38 million tonnes (10.8% K_2O) and probable reserve of 1.64 million tonnes (10.7% K_2O), enough for a mine life of 31 years
- Production of 330,000 t/a tonnes
- Capex of $113.6 million
- Opex cost of $55.29/t
- NPV of $145.7 million at 10% discount rate
- IRR of 23.5%
- Five year payback on capex
- Sustaining capital of $31.5 million for life of mine

This followed the earlier publication of a PEA study by SRK Consulting in 2012.

Verde AgriTech was granted an Environmental License in February. Several steps are now needed before the Cerrado Verde project enters production: securing a mining permit, concluding an agreement with a mining contractor, and the signing of an agreement with contractors for the production of its *Super Greensand* and *Alpha* products.

Verde AgriTech says all these steps are being executed and are at an advanced stage. The company is still targeting the start of production in the first half of this year, and expects to produce 19,500 tonnes of *Super Greensand* and 500 tonnes of *Alpha* initially. *Super Greensand* production represents a quicker and less costly route to market for Verde AgriTech. It is an intermediate product obtained by mixing and grinding the ore with limestone and, unlike *TK47*, does not require thermal treatment.

Spotlight on Utah

Utah has become a North American SOP hotspot thanks to project developers Potash Ridge Corp and Crystal Peak Minerals Inc.

Potash Ridge is developing the 255,000 t/a Blawn Mountain SOP project located in a hilly region of Utah 31 miles northeast of the town of Milford. The company is proposing to surface mine an alunite ore deposit found within 11,550 acres of state-owned land.

An updated prefeasibility report for Blawn Mountain was released in January. This set out Potash Ridge's ambition to be North America's lowest cost SOP producer. Key highlights include:

- A surface mine based on conventional crushing, roasting, leaching and crystallisation
- A flexible production process capable of producing SOP in soluble crystalline and granular forms
- SOP production ramping up to 255,000 short tons per annum
- Proven and probable reserves of 153 million short tons supporting a 46-year mine life
- Capex of $458 million
- Opex of $172 per short ton, including transportation costs of around $40 per short ton
- After-tax IRR of 20.1%
- After-tax NPV of $482 million at a 10% discount rate

> **Utah has become a North American SOP hotspot thanks to project developers Potash Ridge Corp and Crystal Peak Minerals Inc.**

Rival junior miner **Crystal Peak Minerals** is developing the 300,000 t/a Sevier Playa potash project in southwestern Utah. The company is aiming to produce SOP from brine using solar evaporation. Crystal Peak's mineral leases cover more than 124,000 acres at its Sevier Playa property in Millard County, Utah. The brine resource within its lease contains economically-valuable potassium, magnesium, sulphate and lithium.

The company commissioned a project feasibility study from CH2M, Norwest and Novopro in June last year. This will build on the results of the project's 2013 PFS.

Western Australian projects

Western Australia has become another area of intense interest for SOP project developers, notably Reward Minerals and Parkway Minerals NL.

ASX-listed **Reward Minerals** describes its 400,000 t/a Lake Disappointment (LD) brine project as potentially the world's largest high grade, in-situ surface SOP resource. New independent estimates released in February increased the size of the SOP resource present within LD sediments to 596 million tonnes. Drainable SOP resources were calculated to be 153 million tonnes (11.35 kg SOP/m^3 of brine).

Reward plans to use solar evaporation and well-established processes (milling, kainite conversion and SOP crystallisation) to produce SOP fertilizer. The company has successfully piloted a 10,000 litre brine evaporation trial. The project's dry hot climate supports annual evaporation of 4,000 millimetres, making it well-suited to brine production. A 2015 scoping study estimated:

- Project capex of $256 million (AUD 320 million) for a 400,000 t/a operation
- Opex of $263/t f.o.b. (AUD 328/t)
- Pre-tax NPV of $427 million (AUD 534 million)
- Pre-tax IRR of 37%

These figures were based on a previous resource estimate of 24.4 million tonnes and a 13-year mine life. Lake Disappointment formally entered the environmental approval process with Australian authorities in June last year.

Greensands and glauconite

Another ASX-listed company, **Parkway Minerals NL** (formerly Potash West) is developing the Dandaragan Trough project, 175 km north of Perth. The company is seeking to exploit the Dinner Hill phosphate and potash deposit, a very large, shallow greensand body in the Perth Basin. This greensand contains both phosphate nodules and the potassium-rich mineral glauconite.

Parkway acquired the option to purchase land covering more than 90% of the Dinner Hill deposit at the end of last year. Dinner Hill has total indicated and inferred potash resources of 195 million tonnes (3.8% K_2O), according to a revised 2015 estimate, together with indicated phosphate resources of 250 million tonnes (2.0% P_2O_5).

Parkway is ultimately seeking to develop both potash and phosphate fertilizers as part of the Dandaragan Trough project, namely:

- Manufacturing single superphosphate from the phosphate present
- Producing SOP, alum and other products from the greensand's glauconite content using its proprietary *K-Max* process

However, stage one of the project is focussed solely on the commercial development of phosphate at Dinner Hill. Under the current timetable, 'blue sky' potash production using the *K-Max* process is not scheduled to begin until after 2023.

Brazil's **Kalium Mineração** is also developing an innovative process to produce SOP from glauconite. The company's Glauconita project is attempting to exploit a 144.4 million tonne (10.56% K_2O) glauconite deposit in Minas Gerais state. The basic design for the project was completed at the end of 2015.

Kalium Mineração plans to mine 60,000 t/a of glauconite at Serra da Saudade and transport this 40 km to a chemical plant at Dores do Indaiá. This plant will use an innovative treatment process to produce:

- 9,870 tonnes of potassium sulphate
- 7,490 tonnes of iron sulphate
- 7,921 tonnes of alumina
- 4,830 tonnes of magnesium sulphate
- 44,880 tonnes of high purity silica

The company was granted a mining concession in 2014 and has also received environmental permits for its mine and plant. The current status of the project is unclear.

ICL terminates Danakhil Potash project

ICL announced it was terminating its Danakhil Potash project in Ethiopia last October, citing the failure of the country's government "to provide the necessary infrastructures and regulatory framework for the project". The decision came after ICL's appeal against what it called an "unjustified and illegal" project tax assessment was rejected by Ethiopian authorities. ICL said the termination of the project had cost the company $198 million.

ICL purchased Allana Potash Corp for $110 million in June 2015 strengthening the credentials of the Danakhil Potash project as one of Africa's front-running greenfield ventures (*Fertilizer International*, 468 p58). ICL had previously invested $23 million in Allana in February 2014 and then cemented the partnership with a further $14.4 million of financing in April that year.

Allana's permit covers a 312 km^2 area of the Danakil Depression. Plans to produce MOP from this concession were already well-advanced prior to ICL's acquisition. The project also began exploring the options for SOP production in 2015 after commissioning a preliminary economic assessment of the kainite resources within its concession.

Other prospects

India's **Archean Chemical Industries Limited** (ACIL) has been producing SOP from a fertilizer chemical complex at Greater Ran of Kutch, north of Hajipir, Gujarat, since 2014. The complex produces 100,000 t/a SOP from the processing of sea brine. The process was designed by Germany's K-UTEC AG Salt Technologies, who also carried out basic engineering and helped commission the operation.

A pre-feasibility report into a SOP capacity expansion project at the complex was released in February 2015. The project would increase SOP production at the complex by 300,000 t/a. Bromine production would be raised from 12,500 t/a to 80,000 t/a as part of the expansion. The capacity of the co-generation power plant (CPP) at the site would also be increased from 10 MW to 45 MW. The expansion is conditional on environmental clearance from India's ministry of environment & forests.

ASX-listed **Verdant Minerals** (formerly Rum Jungle) has a portfolio of five SOP brine projects distributed across Australia's interior:

- The Karinga Lakes and Lake Amadeus prospects, Northern Territory
- Lake MacDonald prospect on the Western Australia/Northern Territory border
- Lack Mackay prospect, Western Australia
- The Lake Frome prospect, South Australia

The majority of these projects are close to existing road and/or rail infrastructure and gas pipelines, according to Verdant. Karinga Lakes has a brine resource (measured, indicated and inferred) of 8.3 million tonnes SOP (av. potassium concentration 4.76 kg/m^3). A project scoping study was completed at the end of 2014. The potash brine resource at Lake Mackay is even larger, at 13 million tonnes SOP (av. potassium concentration of 3.76 kg/m^3).

At the end of 2015, Verdant said it was prioritising the near-term development of the Karinga Lakes SOP project to help generate cash flow for its Ammaroo Phosphate project. It was for aiming for 40,000 t/a of SOP production for less than $80 million capex at an opex below $300/t. The work programme to achieve this involved the preparation of a PFS followed by a bankable feasibility study and a final investment decision by the end of 2016. The start of production was scheduled for early 2017, subject to finance and the necessary approvals.

However, in a change to this strategy, Verdant is currently making the development of the Ammaroo Phosphate project its main priority, while still seeking interest from industry players and technology providers to help develop its SOP portfolio, particularly the Karinga Lakes, Lake Amadeus and Lake Frome projects.

Conclusions

Out of the six 'probable' primary SOP projects highlighted by CRU in March last year:

- One leading contender, IC Potash Corp's Ochoa project, has changed production from SOP to direct application polyhalite
- Yara has reduced its stake in the Ethiopian Yara Dallol BV project and cited risks to the project from multiple uncertainties
- Brazil's Verde AgriTech is pursuing an innovative production route using glauconite-rich ore and has yet to secure a mining license

That leaves three 'probable' projects as leading SOP project contenders: the Pascamayo/Quimpac SalSud project in Peru, Danakali's Colluli project in Eritrea and Circum Minerals' Danakil project in Ethiopia.

Of the six 'possible' SOP projects identified by CRU:

- ICL has terminated the Danakhil project, a leading Ethiopian greenfield project
- Brazil's Kalium Mineracao and Australia's Parkway Minerals, similar to Verde AgriTech, both rely on innovative production processes and an unconventional glauconite-rich ore
- Two Utah-based projects currently at the prefeasibility stage, Potash Ridge's Blawn Mountain and Crystal Peak's Sevier Playa project, are based on more conventional brine and ore processing technology
- Reward Minerals' Lake Disappointment brine project has access to a very large-scale SOP resource, has completed scoping study and has formally entered the environmental approval process ■

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