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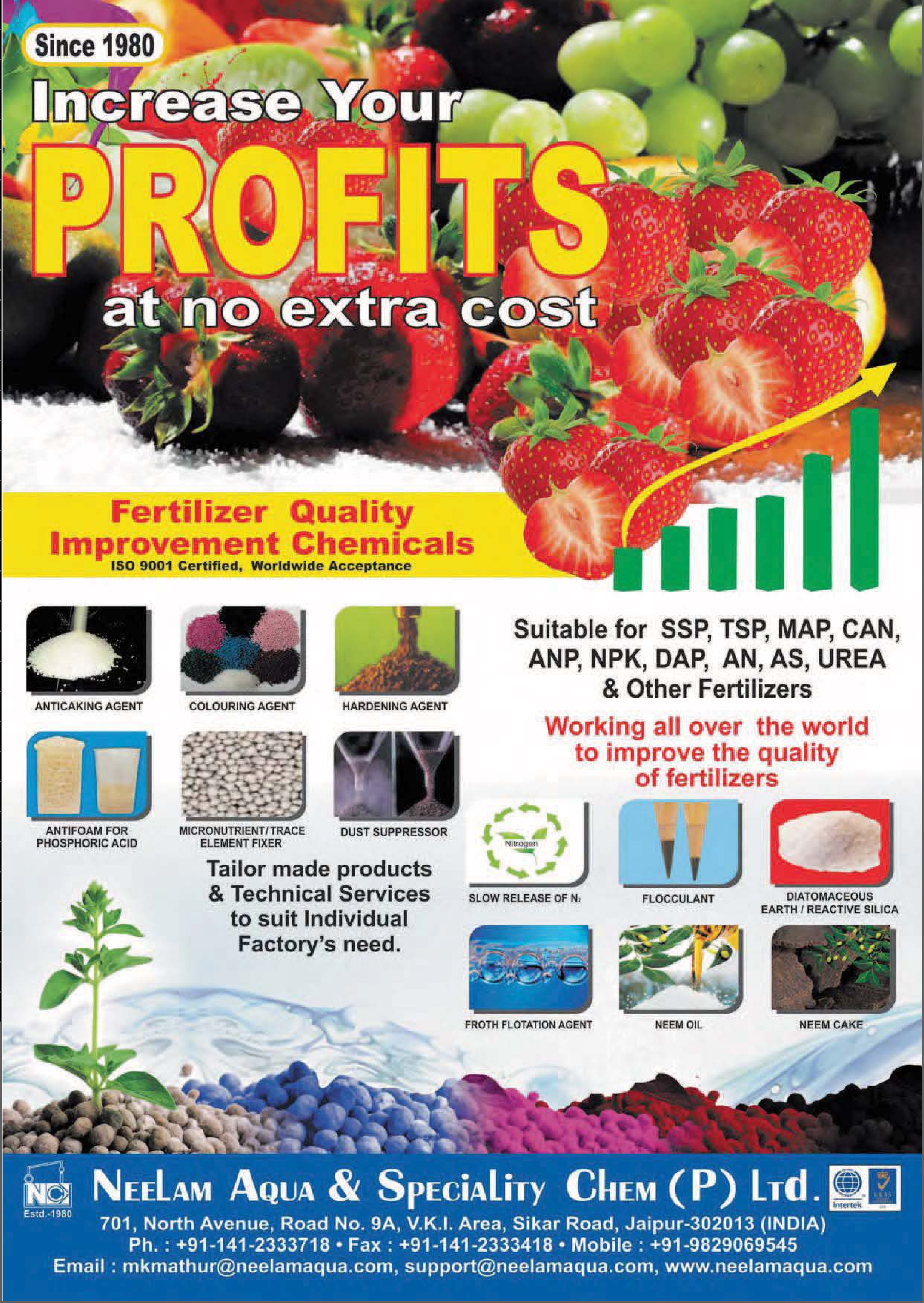
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Foliar fertilisation

Potash solution mining

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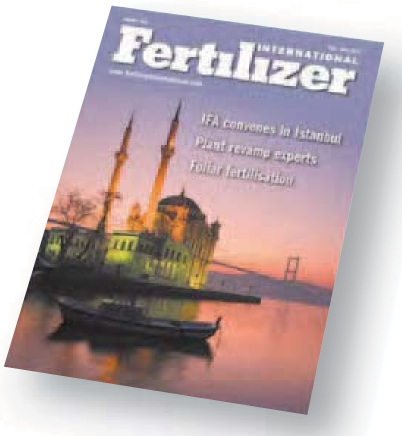
REGULARS

Editorial



Sustainability matters

1987's landmark Brundtland Report gave the world a new phrase: sustainable development. It's a phrase that has stubbornly refused to go away over the intervening three decades. The demand for governments, businesses and individuals to behave more sustainably has grown ever more insistent. However, sustainability, as a slippery abstract noun, has been open to a wide variety of interpretations. But is this about to change?

In March, the United Nations published draft Sustainable Development Goals to replace soon-to-expire Millennium Development Goals. One goal promises to "end hunger, achieve food security and improved nutrition and promote sustainable agriculture". Another goal aims to "build resilient infrastructure, promote inclusive and sustainable industrialisation and foster innovation".

Interesting, then, that both sustainable agriculture and innovation are firmly on the fertilizer industry's agenda at the moment. Indeed, Sustainable Development Goals are specifically mentioned in a new guide to managing water and fertilizer use for sustainable intensification published in March by IFA in collaboration with IMWI, IPNI and IPI. This advises that innovation in the way plant nutrients are applied, managed, reused and recycled will be a critical part of moving to sustainable production systems.

Innovation was also very much on the mind of Mosaic's senior vice president, Rick McLellan, in his keynote address to this year's Phosphates 2015 conference in Tampa in March (p56). He made it clear that sustainable intensification was now very much part of Mosaic's DNA. Innovation in how businesses report on sustainability was also behind Mosaic's decision to sign up to Global Reporting Initiative (GRI). McLellan was candid enough to admit that the fertilizer industry doesn't "own the truth" and needs to have a dialogue with those "who think differently" on the environment.

And Mosaic is not alone in prioritising corporate social responsibility (CSR). EuroChem's commitment to CSR has also been recognised as among the best in Russia. The firm won an award for the high quality of its sustainability reporting from the Russian Union of Industrialists and Entrepreneurs this spring.

Agriculture sustainability is clearly not the sole responsibility of the fertilizer industry, as it requires a concerted, collaborative effort across the whole supply chain. Last autumn, a bold new initiative on commodity grain crops from the Environmental Defence Fund (EDF) set itself the highly ambitious goal of eliminating fertilizer pollution as a major environmental concern in the US. Fortunately, it has the backing of Walmart, the largest grocer in the US. The retail giant already requires many of its major suppliers to submit fertilizer optimisation plans. EDF will build on this by developing and implementing fertilizer efficiency programmes with Walmart suppliers such as General Mills, Smithfield and the Coca-Cola Company. Iowa-based United Suppliers, a wholesaler that provides agricultural products and services to around 700 growing co-operatives and retailers, is another participant. Impressively, it is promising to optimise fertilizer use on 10 million acres of US farmland.

The management, use and recycling of nutrients has also featured strongly this year. News emerged this spring that North America is looking at the example of the European Sustainable Phosphorus Platform (ESPP). This is to be the model for the newly-launched North American Partnership for Phosphorus Sustainability (NAPPS). The partnership is holding its inaugural meeting in Washington DC this May and is actively recruiting from the industry. It is canvassing widely and consulting the US EPA, US Department of Agriculture and the Ontario Ministry of the Environment, for example.

ESPP, meanwhile, goes from strength-to-strength and held the Second European Sustainable Phosphorus Conference in Berlin this spring, sponsored by the European Commission and the German and Netherlands governments. The commission's Luisa Prista urged delegates to develop a 'circular economy' for phosphorus. Britain also launched its own national UK Nutrient Platform in London at the end of April. Looking ahead, a project proposal for an International Nitrogen Management System is likely to be submitted to the United Nations over the summer and, if approved, will run between 2016 and 2019

If an imperative is needed, more reminders of why sustainability matters also emerged recently. In March, the influence of climate on long-term European crop yields was revealed by Frances Moore and David Lobell of the Lawrence Livermore Laboratory in the *Proceedings of the National Academy of Sciences*. They conclude that climate trends can explain 10% of the slowdown in Europe's wheat and barley yields since the early 1990s. A team lead by Kansas State University's professor Vara Prasad also published a significant new paper in *Nature Climate Change* in February. This warned that one-quarter of the world's wheat production will be lost to extreme weather in the coming decades if no adaptive measures are taken.

Climate science is always provisional and subject to uncertainty. But what is heartening is the fact that the fertilizer industry is on the front foot and acting on sustainability concerns of its own volition. That it is seeking partners across the whole agricultural supply chain to join together on sustainability is also to the industry's credit.

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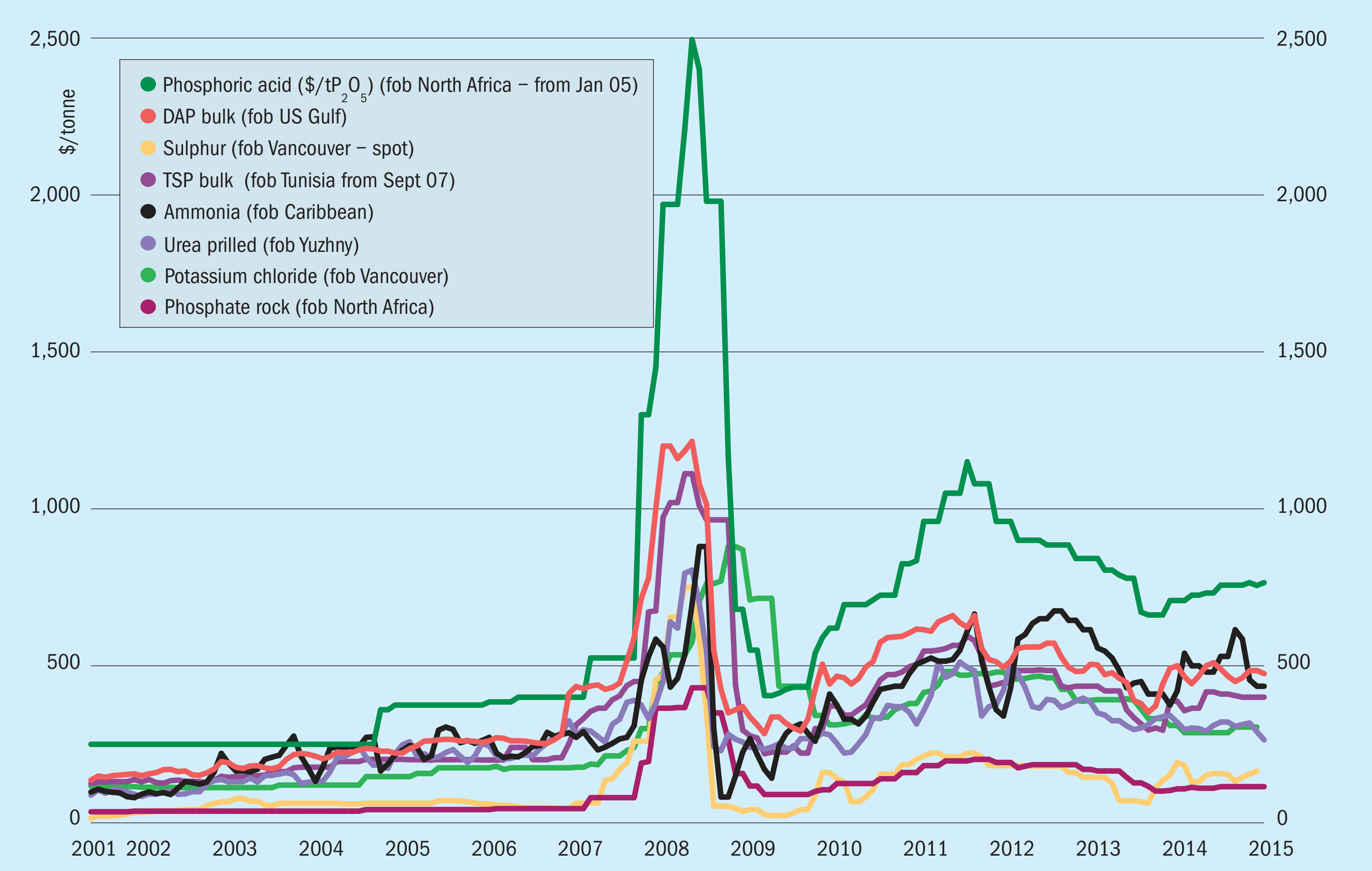
Market outlook

Historical price trends $/tonne



Source: BCInsight

Market insight courtesy of Integer Research

AMMONIA

Concerns about the impact of oil prices, and general price levels, applied to global markets for both ammonia and urea over the past few months. Ammonia prices decoupled from urea in the second half of 2014, due to an unusually tight supply situation in key export regions. Prices dropped in early 2015 when producers in Ukraine, Egypt, Algeria and Trinidad, which had all previously been suffering from lower than expected availability, returned to higher utilisation rates.

UREA

The central question for the global urea market currently revolves around what is to blame for tumbling prices in early 2015. Urea prices declined consistently throughout the first quarter of 2015, falling below the $260/t f.o.b. mark in March. Falling oil prices, traditionally linked to nitrogen prices through energy market dynamics, have so far shown little impact. As the market is currently in a supply driven phase, prices are determined by costs of the marginal producers rather than global oil prices.

PHOSPHATES

Average ammoniated phosphates prices rose year-on-year in January 2015 with US Gulf DAP prices 2% higher at $485/t, while the Black Sea MAP benchmark rose 4% to $495/t over the same period. The market has slowed down as the quarter progressed. Adverse weather in North America delayed crop inputs purchases, while the majority of Latin American buyers had negotiated contracts for Q1 2015 deliveries in Q4 2014 and January 2015. At $483/t f.o.b., the average Q1 2015 Black Sea MAP price was $3/t lower year-on-year, while the DAP benchmark was $10/t lower at $480/t f.o.b.

During Q1 2015, DAP market players awaited the results of phosphoric acid contract negotiations between Indian importers and Morocco's OCP. Buyers were holding out for a decrease from the $780/t contract of Q4 2014, whilst OCP was seeking a 5% increase. As the negotiations played out, little DAP business was done, as Indian buyers waited to see whether it would be more cost effective to import finished DAP or produce DAP locally on imported raw materials.

POTASH

The international potash market was focused on the negotiations for volumes/pricing in the key contract market of China in early 2015. Significantly, Belarusian Potash Company (BPC) led proceedings, agreeing to deliver about 1.7 million tonnes to this market through to December 2015. The marketer is also challenging the status quo, stepping in before either Canada's Canpotex or Russian producer Uralkali, and underscoring the increasingly competitive nature of today's market. BPC also agreed a price in China – $315/t on a cfr basis – that was only $10 higher year-over year, dashing the hopes of its rivals for a bigger increase. Aggregate firm seaborne tonnage for China from all major suppliers now stands at approximately 6 million tonnes.

1 47 2 48 3 49 4 50 5 51 6 52 7 53 8 54 9 55 10 56 11 57 12 58 13 59 14 60 15 61 16 62 17 63 18 64 19 65 20 66 21 67 22 68 23 69 24 70 25 71 26 72 27 73 28 74 29 75 30 76 31 77 32 78 33 79 34 80 35 36 37 38 39 40 41 42 43 44 45 46

Attention is turning now to India, where a contract price for the new fertilizer year (April 2015-March 2016) is awaited in May, with buyers pushing for last year's $322/t cfr to be rolled over. Higher prices are not being reflected in the spot potash markets either, with prices for granular grade MOP under pressure in Brazil and most other markets remaining flat. Scope for further price increases is limited given inventory levels and relatively poor price discipline amongst suppliers.

SULPHUR

Global sulphur prices and sentiment weakened in Q1 2015, following the sharp increase in prices in the latter part of 2014 as tightening supply and increased trade activity spurred the market. The downturn is seen as a downward correction and had been anticipated by the market. The lack of buying interest in China has been a key issue driving prices down, with sulphur stocks at major ports dwindling in 2015. While historical levels of over 2 million tonnes of sulphur are no longer the norm, average stocks in 2014 were closer to 1.5 million tonnes. The new normal appears to be 1 million tonnes – leading to a disconnect in the relationship between sulphur stocks and pricing. Middle East producers Adnoc, Tasweeq and Aramco Trading all reduced monthly price postings for March. Availability issues eased significantly, however, with Saudi Arabia in particular thought to hold spot cargoes for the open market, putting further downward pressure on the market.

Market price summary $/tonne – Early-May 2015

Nitrogen	Ammonia	Urea	Ammonium Sulphate	Phosphates	DAP	TSP	Phosphoric Acid
f.o.b. Caribbean	425	n.m.	f.o.b. E. Europe 127-132	f.o.b. US Gulf	460-464	n.m	n.m
f.o.b. Yuzhny	395-405	263-293	-	f.o.b. N. Africa	480-510	380	715-840
f.o.b. Middle East	375-405	295-315**	-	cfr India	483-490	-	805*
Potash	KCl Standard	K_2SO_4	**Sulphuric Acid**		**Sulphur**		
f.o.b. Vancouver	293-320	-	cfr US Gulf	70-80	f.o.b. Vancouver	135-140	
f.o.b. Middle East	290-310	-			f.o.b. Arab Gulf	140-145	
f.o.b. Western Europe	-	€440-480			cfr North Africa	160-165	
f.o.b. FSU	276-300				cfr India	160-170+	

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 outlook:** The ammonia market is determined by similar dynamics as the urea market with sustained oversupply in conjunction with low demand currently depressing prices. However, this situation is less pronounced for ammonia and prices have declined less strongly, remaining relatively stable into the second quarter of 2015. New demand is expected to emerge shortly from West of Suez and is likely to stabilise prices.
- **Urea outlook:** While weak demand is having a moderate effect on prices, and oil prices remain out of the equation for now, it is global oversupply that is driving urea market dynamics at present.
- Chinese urea flooded international urea markets as exports reached a record high in January following the introduction of flat tax rate in 2015 to replace the previous seasonal rates. However, there are signs that this might be about to change.
- Significant efforts by the Chinese government to shift away from energy intensive industries have included severe supply side restrictions for Chinese coal and prices seem to have reached their floor. Higher energy costs for Chinese producers will help to keep vast Chinese supply at bay and are likely to provide good news for global urea prices.
- **Phosphates outlook:** In late March, phosphoric acid contracts were agreed between buyers and sellers at $805/t cfr India. Global ammonia prices, meanwhile, held firm after a four-month bear-run and are expected to rebound in Q2 2015. As such, quarter-on-quarter margin growth for non-integrated DAP producers in Q2 2015 could be attainable, if DAP prices improve significantly enough over the period.
- Historically, Q2 phosphates prices tend to be comparatively weak. We expect pent-up DAP demand from India to be met with adequate supply from China, North America and the Middle East in Q2 2015, although the competition between suppliers may weigh on DAP prices. However, we anticipate Indian DAP imports in Q2 2015 – and therefore global DAP trade – to be firming year-on-year.
- **Potash outlook:** The outlook for potash near-term demand is mixed. Activity is scant in the USA, with fears that farmers will skip spring potash application given lower corn and soybean prices. India's potash demand could recover further in 2015, but estimates seem to vary from 4.1 million up to 5 million tonnes. After record purchasing in 2014, Brazil's imports are likely to be slightly lower in the coming months.
- Uralkali may in due course review its earlier annual production target of 10.2 million tonnes MOP. Production ceased at its Solikamsk 2 mine last November after water incursion and could be closed permanently.
- In Israel, a labour strike at ICL's Dead Sea Works site has seen production halted since February. However, there appears to be sufficient supply globally to bridge the gap, and greater operational capability in North America in 2015 – with PotashCorp's operational capacity increasing 21% year-over-year – should counterbalance any tightness in supply.
- **Sulphur outlook:** The outlook for sulphur is stable-to-weak, with the uncertainty around Chinese purchasing behaviour expected to add some short-term hesitancy from traders and end-users in other markets.
- Prices are expected to decline later in the year, based on the assumption that there will be a significant rise in sulphur exports out of the UAE from the large-scale Al Hosn Shah gas project. However, fundamentals point to prices holding at healthy levels, as global supply and demand is expected to remain balanced for 2015.

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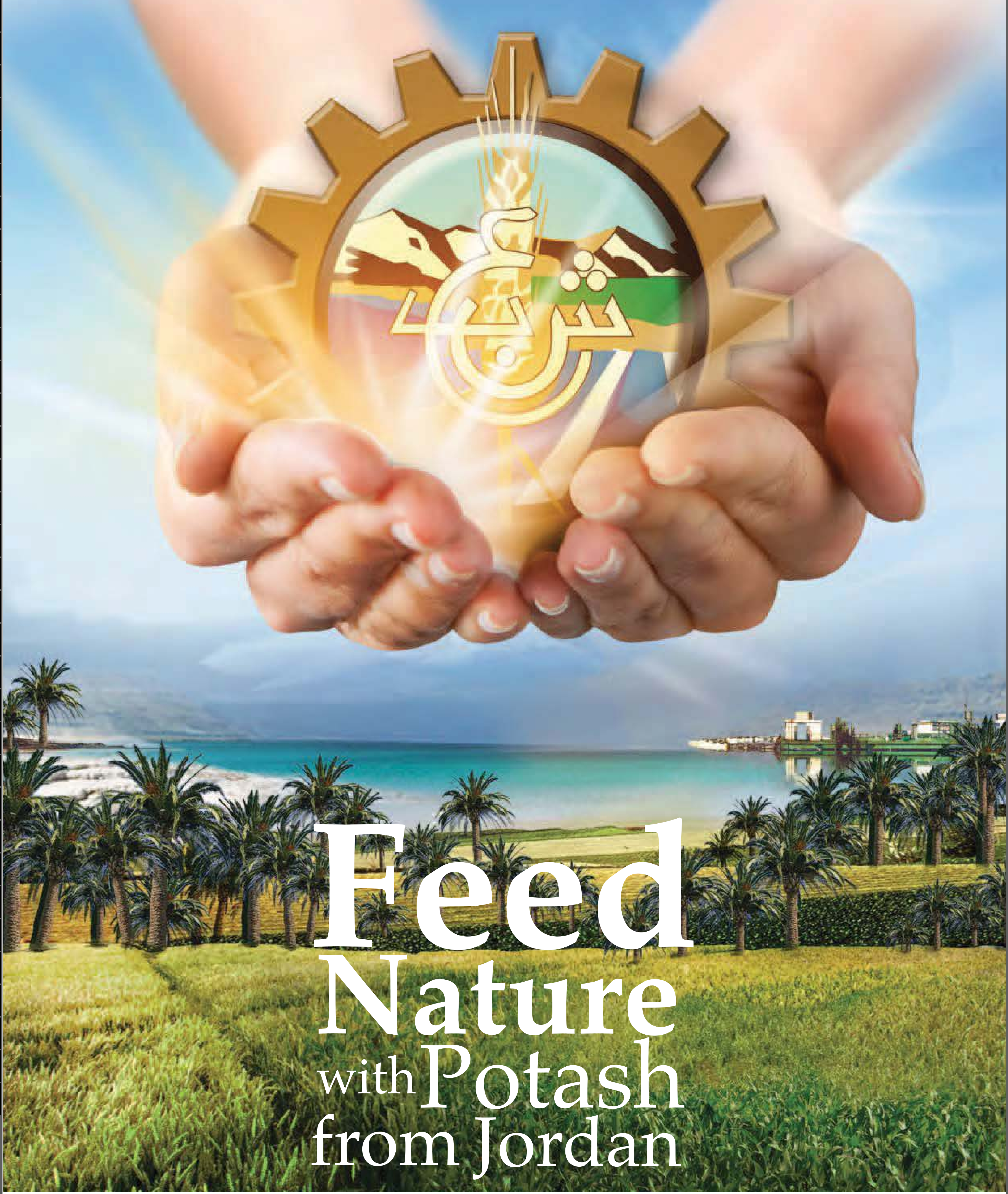

Fertilizer Industry News

ETHIOPIA

ICL buy-out boosts Allana Potash prospects

Israel Chemicals Ltd (ICL) has bought out Canadian mining junior Allana Potash Corp for CAD137 million ($109.50 million). The takeover looks set to fast track the development of Allana's potash project in Danakil, northeast Ethiopia. ICL won out over Yara who had been in talks with Allana over the project earlier this spring.

Allana chief executive, Farhad Abasov, said the deal "provides the best liquidity opportunity for shareholders and firmly validates the efforts of the last six years of development by the Allana team". Steve Hansen, an analyst at Raymond James, agreed: "We're inclined to believe this deal represents the best practical outcome for investors given the challenged market environment for junior potash companies. We don't view going it alone as a viable option and we don't expect another strategic party to surface – given ICL's existing ownership position and previously secured offtake agreement."

Allana released a positive preliminary economic assessment for the Danakil project prior to the sale. This revealed that the project will require capital expenditure of $787 million for mining, processing, port and logistics infrastructure. The market welcomed ICL's buy-out with Allana's stock trading 44% higher at one point in reaction to the news. ICL, which already owns a 16.4% stake in Allana, expects to finalise the deal by 17 August.

CHILE

SQM board ousts chief executive to restore confidence

Chilean fertilizer producer SQM dismissed its chief executive officer, Patricio Contesse Gonzalez in a surprise move linked to corruption investigations by Chile's inland revenue service. The board announced the replacement of Contesse by his deputy, Patricio de Solminihac Tampier, on 16 March. Turmoil at SQM deepened when three more board members representing PotashCorp also resigned without explanation a day later. Trading in SQM shares on the Santiago stock exchange was suspended on 18 March after heavy falls, adding to the sense of crisis at the company.

The flurry of high-level resignations occurs at a time when SQM is being investigated over alleged illegal payments to politicians, including former Chilean deputy mining minister Pablo Wagner. SQM says it will now comply with a request from Chile's internal revenue service to hand over tax records stretching back six years – a request Contesse had previously resisted. The request is part of a larger investigation by Chilean authorities into alleged illegal financing of electoral campaigns by UDI, Chile's leading conservative grouping and the former party of General Pinochet. Top level individuals at UDI and Chile's Banco Penta have already been charged with bribery and tax evasion. On 26 March, SQM admitted to investigators that it had identified $11 million worth of questionable invoices issued between 2009 and 2014. The company has, however, set up an *ad hoc* committee to investigate these irregularities.

The resignations at SQM also come in the middle of a PotashCorp review of its equity investments in other companies led by CEO Jochen Tilk. PotashCorp's stake in SQM is around a third, currently, although there are no plans to either increase or sell this stake as part of the review, according to PotashCorp.

LIBYA

Yara writes down Libyan investment as security worsens

Yara has written down investment in its Libyan Lifeco joint venture by $112 million, leaving a value of $18 million for the project on its books. Yara owns 50% of the Marsa El Brega ammonia-urea complex, located on the Mediterranean coast, 700 km east of Tripoli, under a 2009 agreement with the National Oil Corporation of Libya (NOC) and the Libyan Investment Authority (LIA).

The Norwegian producer blamed the write-down on the "worsening security outlook" in the country and the "high likelihood of further deterioration in 2015". These security problems have compounded existing financial and feedstock difficulties faced by the joint venture. Yara said it was monitoring operations at Marsa El Brega to protect both its employees and assets. The firm will also continue to be involved in Lifeco's governance in the hope that full production can be resumed "once real improvements are seen in the security and political situation in Libya".

CANADA

Mosaic makes Saskatchewan potash investment

The Mosaic Company is to channel CAD1.7 billion of extra investment into its K3 potash mine project at Esterhazy, Saskatchewan. This will be invested over the next eight years and enable Mosaic to accelerate the production ramp-up at the mine.

"Mosaic is committed to the growth, efficiency and sustainability of our potash operations here in Saskatchewan," said Walt Precourt, Mosaic's senior vice-


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president of potash. Saskatchewan's premier, Brad Wall added: "This is a great announcement and further evidence that Saskatchewan's diversified economy remains strong. Despite the downturn in oil prices, other sectors continue to show strong growth."

K3 is expected to start mining potash ore towards the end of 2017 and will function as a satellite mine supplying milling and storage facilities upgraded as part of Mosaic's Esterhazy Stage 1 expansion. The new investment is extra to the original CAD1.5 billion earmarked for K3 by Mosaic in 2009 as part of a long-term strategy to expand its potash business.

RUSSIA

Uralkali's 2014 earnings rise 9% but profits slide

Russian potash producer Uralkali's 2014 earnings before interest, tax, depreciation and amortisation (EBITDA) have risen 9% year-on-year to $1.784 billion. Revenues also rose by 7% in 2014 to $3.559 billion. However, Uralkali ended 2014 with a net loss of $631 million after its profits were wiped out by foreign exchange and derivatives losses of $2.0 billion. EuroChem also posted a 2014 net loss of $578 million for similar reasons (*Fertilizer International 465, p11*), as did PhosAgro (see below). The flooding of the 2 million t/a Solikamsk-2 in November came too late to significantly dent last year's production figures. Uralkali's production of potassium chloride (KCl) was up 21% in 2014 to 12.1 million tonnes. Annual sales volumes also increased by 24% to 12.3 million tonnes KCl.

Uralkali has also unveiled a new five-year, $4.5 billion investment strategy to counter the loss of Solikamsk-2 and maintain its position as the world's largest potash producer. It plans to increase annual production capacity to 14.4 million tonnes by 2020 by constructing a new mine at Ust-Yavyinsky, a new shaft at Solikamsk-3 and two new shafts at Solikamsk-2. Expansion projects should provide Uralkali with an extra 800,000 tonnes of potash capacity from 2016.

Urakali has found little difficulty in raising finance. Last year, the company agreed a $450 million 5-year unsecured loan facility with five international banks and a 10-year $250 million unsecured line of credit with Russia's Promsvyazbank. This finance is extra to its unsecured $2 billion credit line with Sberbank. Urakali also moved to strengthen access to the Brazilian market in 2014 by purchasing a 25% stake in Equiplan Participacoes, the owners of the Antonina port terminal.

EuroChem agrees five ammonia plant construction deal

EuroChem, Maire Tecnimont and SACE are to collaborate on the construction of five new ammonia plants in Russia, the US and Kazakhstan over the next 10 years. Under a memorandum of understanding signed by the three firms in April, Maire Tecnimont will submit engineering, procurement and construction (EPCM) proposals to Eurochem and SACE will evaluate project credit insurance.

EuroChem and Maire Tecnimont will collaborate on three Russian projects: an ammonia-urea plant at Nevinnomyssk, just north of the Black Sea, an ammonia plant at Kingisepp near St Petersburg and a further project to integrate urea production at Kingisepp. Maire Tecnimont has already completed the front-end engineering design (FEED) for these.

The two companies will also cooperate on Eurochem's Louisiana ammonia-urea project and another ammonia-urea project near Zhanatas, Kazakhstan. Collectively, the five projects will provide EuroChem with an additional 5 million t/a of ammonia capacity and 7.5 million t/a of urea capacity, if and when they are completed.

In a change of heart, EuroChem recently named a site in St John the Baptist Parish as the preferred location for its Louisiana nitrogen complex and distribution centre. The firm had previously earmarked land purchased in Iberville Parish for the $1.5 billion project. Go ahead for the North American venture is still not guaranteed, however, as EuroChem has yet to make its final investment decision.

Higher sales but weak rouble hits PhosAgro

The rouble's depreciation meant PhosAgro's recorded a net loss of RUB13,395 million ($349 million) in 2014, sliding into the red from the RUB8,576 million ($269 million) net profit reported the year before. This was despite an 18% year-on-year increase in revenues to RUB123,124 million ($3.2 billion) and a 57% rise in earnings (EBITDA) to RUB 37,609 million ($979m) for 2014.

Revenues for its phosphates business grew by 16% to RUB105,832 million ($2,754 million) last year. The production of phosphates grew 3.2% during 2014 and sales volumes increased by 0.8% over the year. Nitrogen revenues performed even more strongly, increasing by 30% to RUB16,626 million ($433 million) last year, driven by a 14% increase in sales volumes and a 16% increase in revenues per tonne.

Foreign exchange and financial derivative losses were the main factors behind the 2014 net loss. This drew comment from PhosAgro's CEO Andrey Guryev: "The rouble devaluation also resulted in a significant unrealised FX loss in Q4 2014 due to the revaluation of our USD-denominated debt, creating a net loss for the full year despite very strong performance at all other levels." Guryev also saw advantages in the currency situation: "The weak rouble, combined with our cost-cutting initiatives, has substantially improved PhosAgro's global cost position, and I am very optimistic about the results we will report for 1Q 2015."

UZBEKISTAN

Mitsubishi win ammonia plant contract

Japan's Mitsubishi Heavy Industries have secured the contract to build a new $962 million ammonia and urea complex in Uzbekistan for chemicals company Navoiazot. Both parties are still discussing terms although construction is expected to begin later this year. The 660,000 t/a ammonia capacity and 577,500 t/a urea capacity complex will be partly financed through a $320 million loan from the Fund for Reconstruction and Development of Uzbekistan. Local and foreign banks, as well as Navoiazot itself, are expected to provide the remaining finance.

GERMANY

Haldor Topsoe and Ferrostaal form joint venture

Haldor Topsoe and Ferrostaal are to work together to develop and finance major petrochemicals, refining and environmental projects and bring these to fruition. Both firms will have equal ownership of Ferrostaal Topsoe Projects, a new joint venture between the two companies based in Essen. Germany. The venture will combine Ferrostaal's global capabilities as an industrial project developer with Haldor Topsoe's expertise in catalysis and process technologies. Fast-growing emerging economies will be targeted, as will the North American market. The new partnership formalises existing collaboration between Haldor Topsoe and Ferrostaal, including the development of two major ammonia projects in Tanzania and Cameroon. The development of a $1 billion large-scale ammonia complex in Tanzania is currently the largest investment project in the east African country. The project is being developed with the state-owned Tanzania Petroleum Development Corporation and was discussed during the German president Joachim Gauck's state visit to Tanzania in February.

BRAZIL

PotashCorp buys into Fertilizantes Heringer

PotashCorp has bought a 9.5% stake in leading Brazilian fertilizer distributor Fertilizantes Heringer for $55.7 million as part of its global growth strategy. The deal will improve PotashCorp's foothold in Brazil and should be finalised during the second half of the year, subject to regulatory approval. The announcement paves the way for a long-term potash supply agreement between the two firms, according to Jochen Tilk, PotashCorp's president and CEO. The Canadian potash producer wants to eventually become Heringer's principal supplier. Heringer earned net revenues of $2.5 billion in 2013 from distributing five million tonnes of fertilizers – including around one million tonnes of potash. The 46-year old company operates a network of 21 production, marketing and distribution units in Brazil's main consuming regions.

UNITED KINGDOM

York Potash project gains key approvals

UK authorities have granted two key planning approvals needed by Sirius Minerals for its York Potash mining project. Redcar and Cleveland Borough Council (RCBC) approved the firm's application for a materials handling facility (MHF) at Wilton, Teesside, on the North Sea coast at the end of April. The facility will receive, handle, granulate and store polyhalite produced from the proposed mine. RCBC also gave approval for the project's mine and mineral transport system (MTS) application earlier in April. The MTS is an underground conveyor needed to transport minerals from the proposed mine to the MHF on Teesside.

These planning approvals are important milestones for Sirius Minerals but are not decisive under the UK's complex planning rules. This is because the mine and MTS application still needs the additional approval of North York Moors National Park Authority. This approval, which is critical to the future of the 5 million t/a potash project, is expected imminently. The UK Planning Inspectorate is also deliberating on an application for harbour facilities at Teesside. York Potash could begin production in 2018 and eventually expand to 12-13 million t/a in the 2020s, if it overcomes UK planning hurdles. Sirius Minerals raised a further £15 million to develop the project in March.

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People

SQM shakes up its board

Chilean fertilizer company SQM has reshuffled its board following the dismissal of its CEO, **Patricio Contesse** and his replacement by his deputy, **Patricio de Solminihac Tampier** (see p12). Existing SQM board member **Juan Antonio Guzman** becomes chairman replacing **Julio Ponce**, former son-in-law of General Pinochet, who has chaired SQM since 1987. The new board includes three directors, **Robert Kirkpatrick**, **Joanne Boyes** and **Arnfinn Prugger**, nominated by stakeholder PotashCorp. The new board also includes members nominated by Ponce, notably **Hans Dieter Linneberg**, a corporate governance specialist. SQM has moved to strengthen corporate practices by setting up a new corporate governance and nominating committee as well as an *ad hoc* committee to handle the Chilean government's investigation into alleged illegal payments by the firm.

Changes at the top for Yara

Svein Tore Holsether is to succeed **Torgeir Kvidal** as CEO of Yara in October, in a move that will lead to other senior level changes at the company. Acting CEO Kvidal will resume his previous position as chief financial officer (CFO) from October. This in turn will require **Thor Giæver**, the current acting CFO, to return to his position as head of investor relations. Holsether was born in Norway in 1972 and holds a BSc in Finance from the University of Utah. He has been president and CEO of Sapa Group since 2011 and held a number of management positions in Elkem, Orkla and Sapa prior to this. **Terje Knutsen** also becomes head of Yara's downstream business from the start of May and will oversee the company's global fertilizer sales, marketing and distribution. He replaces senior vice president **Egil Hogna** who has resigned. Knutsen currently manages Yara's downstream activities in northern and eastern Europe and was head of the company's Asian business unit prior to this.

A new role for Morgane

Morgane Danielou has been appointed vice president of operations at Emerging Ag Inc. In her new role, Morgane will continue to be based in the Paris area. For the past seven years, Morgane has enjoyed a high industry profile as Director of Communications & Public Affairs, International Fertilizer Industry Association (IFA). In addition to managing IFA's communications and public affairs services, including relations with stakeholders, Morgane was responsible for institutional and external relations with international organisations and was the fertilizer industry's spokesperson at the UN Committee on World Food Security (CFS) and the OECD Business and Industry Advisory Committee. Her CFS role was on behalf of the International Agri-Food Network (IAFN), an informal coalition of international trade associations involved in the global agri-food sector.

Morgane Danielou

Morgane has also served as Co-chair of Farming First, the coalition of 150 multi-stakeholder organisations representing the world's farmers, scientists, engineers and industry, as well as agricultural development organisations. Farming First highlights the importance of improving farmers' livelihoods and agriculture's potential contribution to global issues such as food security, climate change and biodiversity.

Emerging Ag offers a multi-disciplinary approach to issues management and communications, with a particular emphasis on consensus building. Reporting to **Robynne Anderson**, Emerging Ag's co-founder, Morgane Danielou says that she will seek to "help Emerging Ag's clients in the global, national and local agriculture and food sector to navigate challenges, unlock potential and uncover opportunity." She adds, "We provide expertise to our clients in consensus building, public relations, government affairs, crisis management, social priorities, sustainability plans, goal articulation and coalition creation."

Calendar 2015

MAY

18-20

SYMPHOS 2015, 3rd International Symposium on Innovation and Technology in the Phosphate Industry, MARRAKESH, Morocco.
Contact: SYMPHOS Technical Committee
Tel: +212 5 23 34 51 22
Email: symposiumocp@ocpgroup.ma
Web: www.symphos.com

25-27

83rd IFA Annual Conference, ISTANBUL, Turkey.
Contact: IFA Conference Service
Tel: +33 1 53 93 05 25
Email: conference@fertilizer.org
Web: www.fertilizer.org

JUNE

5-6

Clearwater 2015, 39th Annual International Phosphate Fertilizer and Sulphuric Acid Technical Conference, AIChE Central Florida, CLEARWATER, Florida, USA.
Email: chair@aiche-cf.org
Web: www.aiche-cf.org

23-24

IFS Technical Conference, International Fertiliser Society, Geological Society, LONDON, UK. Tel/Fax: +44 1206 851 819
Email: secretary@fertiliser-society.org
Web: www.fertiliser-society.org

SEPTEMBER

14-16

6TH GPCA Fertilizer Convention, Intercontinental, DUBAI, UAE.
Tel: +44 (0) 20 7903 2444
Email: conferences@crugroup.com
Web: www.crugroup.com/events/gpca

21-23

IFA Production & International Trade Conference, TAMPA, Florida, USA.
Web: www.fertilizer.org/ifaevents

27-29

TFI World Fertilizer Conference, The Fertilizer Institute, BOSTON, USA.
Contact: Linda McAbee.
Tel: +1 202 515 2707
Email: lmacabee@tfi.org
Web: www.tfi.org

OCTOBER

5-9

IFDC/IFA Phosphate Fertilizer Production Technology, BERLIN, Germany.
Contact: IFDC Training
Tel: +1 (256) 381 6600
Email: training@ifdc.com
Web: www.ifdc.org

Welcome to Istanbul

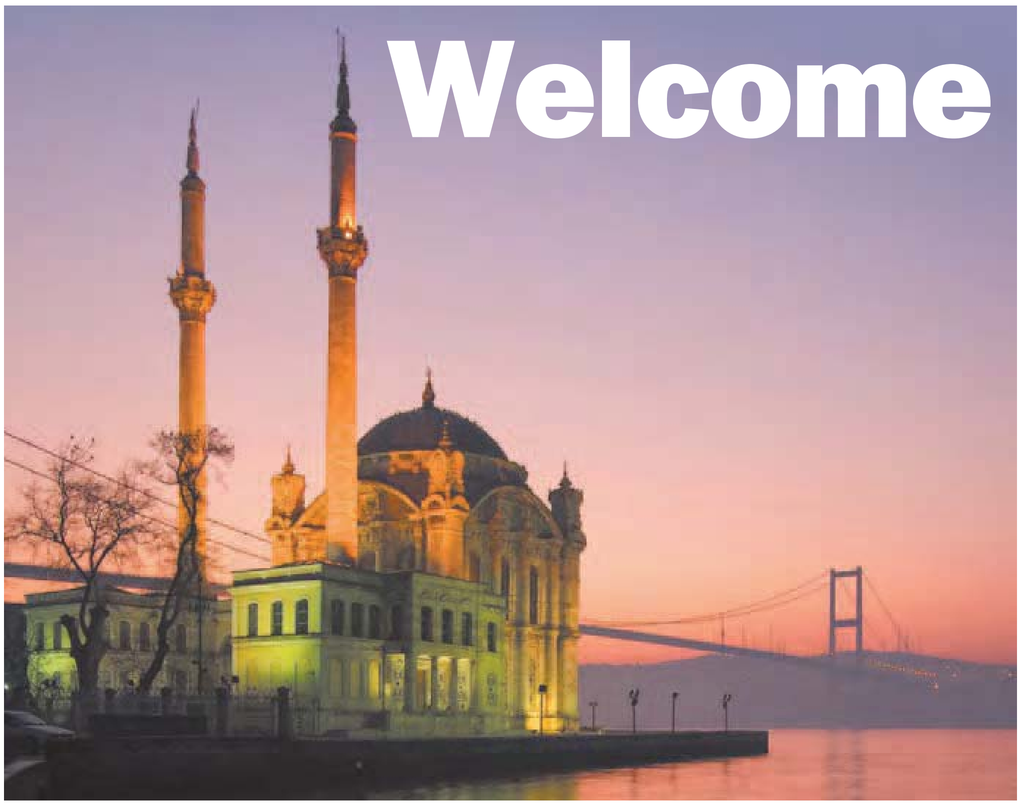

PHOTO: TIMDEBOECK/ISTOCKPHOTO.COM

IFA's long-standing yearly conference remains the most keenly anticipated event on the fertilizer industry calendar. This year promises be no exception with cosmopolitan Istanbul playing host to the 83rd IFA Annual Conference. Esin Mete, IFA President, extends a warm welcome to all delegates and highlights this year's main attractions.

It is my great pleasure to formally announce IFA's annual meeting to be held in Istanbul from 25-27 May 2015. Aptly referred to as the "City of all Senses," Istanbul will not only provide a great venue for our annual meeting, but also entice you with its wonderful sights, sounds and smells.

In response to your feedback, this year's programme has been shortened and additional networking space made available. We are keen to enhance networking opportunities but do ask that you attend the two main sessions being held on Monday and Wednesday, as your participation is important. This year's gala dinner is also being held on Monday evening, rather than the closing evening, to enable more of you to attend.

To mark the International Year of Soils, our keynote speaker on Monday will be Dr Pedro Sanchez, one of the world's most preeminent soil scientists. Dr Sanchez will speak on the role of fertilizers in soil health, a topic of great importance to our industry as well as to food security around the world.

Esin Mete, IFA President

Please note that IFA will host a special workshop and cocktail event for the industry's future leaders (aged 35 and younger) on Tuesday afternoon.

I look forward to seeing all of you in my hometown this May.

Conference programme

The conference opens on Monday with five presentations as part of the Fertilizer Demand Panel session. **Doug Hoadley** of CF Industries, convenor of IFA's Fertilizer Demand Forecast Working Group, will start by updating delegates on IFA's market intelligence work. **Rakesh Kapur** of the Indian Farmers Fertiliser Cooperative Limited (IFFCO), and chair of the IFA Production & International Trade Committee, will examine the impact of Indian fertilizer subsidies on domestic demand. Changes to China's national fertilizer strategy will also be explained by **Zhang Fusuo** of the China Agricultural University (CAU). **Terry Roberts** of the US International Plant Nutrition Institute (IPNI) will present the latest global trends in nutrient use efficiency. **Martin van Ittersum** of Wageningen University in the Netherlands will explore how the yield gap in different parts of the world is affecting fertilizer demand.

Later on Monday, myths about fertilizers and soil health will be debunked in the Commemorative Lecture by **Pedro Sanchez**, director of the Agriculture and Food Security Center at Columbia University's Earth Institute, and the 2002 World Food Prize Laureate. Professor **Michael McLaughlin**, this years IFA Norman Borlaug Award laureate (see opposite), will then give a presentation on developing more effective fertilizers.

Delegates will have the chance to hear the latest from IFA's supply and demand experts during Wednesday's Market Outlook Session. **Patrick Heffer** of IFA Secretariat will present the *Medium-Term Outlook for World Agriculture and Fertilizer Demand: 2014/15 – 2019/20.* His IFA Secretariat colleague, **Michel Prud'homme**, will then end the conference programme with his presentation on *Fertilizers and Raw Materials Global Supply 2015 to 2019.*

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IFA AWARD

Professor Michael McLaughlin was announced as the 2015 IFA Norman Borlaug Award laureate on 20 March. He was nominated by The Mosaic Company. IFA grants the award for research that has led to significant advances in crop nutrition. The award also recognises researchers who have successfully communicated the outcome of their work to farmers.

Professor McLaughlin is a Science Fellow at Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO) and Research Professor in Soil Science at the Waite Campus of the University of Adelaide. His long academic career includes more than 30 years of soil fertility and plant nutrition research in Africa, Australia and Southeast Asia. His research is receiving worldwide coverage and making a global impact thanks to the establishment of the University of Adelaide's Fertiliser Technology Research Centre.

Professor McLaughlin's scientific work involves studying the fundamental mechanisms of fertilizer behaviour in soils, and then linking these to field observations to improve fertilizer effectiveness. His research is also noted for its use of new methods to examine fertilizer behaviour and effectiveness. His adoption of isotope tracing and dilution methods has helped determine the fate of added fertilizers and allowed improvements in crop nutrition effectiveness to be benchmarked.

Professor McLaughlin is a remarkably apt and avid communicator and his ability to explain his research findings is of particular merit. Many growers and farmers requested information on how to manage fertilizers during and after Australia's severe drought in 2006. The effects of drought on fertilizer residual value and phosphorus fixation were poorly understood at the time. Professor McLaughlin and two colleagues quickly wrote and published a factsheet for growers. This summarised current scientific understanding of nutrient management under drought conditions and made recommendations for fertilizer management in the 2007 season. This factsheet has been widely used by growers in Australia subsequently. Professor McLaughlin's supervision of over 20 postgraduate research students from Australia, Brazil, China, Ecuador, Germany, Iran, Malaysia, and Sri Lanka is also a praiseworthy and a remarkable achievement. ■

Marginal producer with major muscle

China's role as swing producer for nitrogen is set to continue in the wake of a surge in first quarter urea exports linked to policy reforms and the falling cost of coal.

If anyone was in any doubt, China's pivotal role in the global nitrogen market has become clearer over the past 12 months. The record volume of Chinese shipments was the "overriding factor" in the urea market last year, according to Canada's PotashCorp.

China exported 13.6 million tonnes of urea in 2014. That figure itself tops the previous Chinese export record in 2013, when it sold 8.3 million tonnes of urea into a global market of 40 million tonnes. And the latest news from analysts CRU is that China exported 1.46 million tonnes of urea in March, lifting its first quarter total for 2015 to a "massive" 4.43 million tonnes.

While most of the world uses natural gas as a feedstock, much of China's nitrogen production is based on coal, particularly anthracite. Manufacturing urea from coal is relatively costly, as is the expense of shipping from China's vast interior to the major Atlantic markets. Because of this, China has acted as the marginal producer of urea internationally since 2012 – a role previously occupied by Ukraine –and its pricing generally sets the floor for the global urea market.

Swing producer drives the market

Due to its prevalence, urea prices also affect the value of other products in the nitrogen market. China's role in price setting, therefore, is not just limited to urea, but also influences the value of ammonia, CAN, UAN and ammonium sulphate. CRU's senior nitrogen consultant, Alistair Wallace, recently described China as the global swing producer for nitrogen, and suggested that what happens in China's nitrogen market will affect worldwide nitrogen pricing in the medium term. CRU believes that, although underpinned by strong demand fundamentals, China's huge capacity is devaluing the global nitrogen market (*Nitrogen+Syngas 334, p29*).

Integer Research has drawn broadly similar conclusions. "Continued additions to Chinese nitrogen capacity, falling production costs since 2012 and greater export freedom, have contributed to international nitrogen prices falling into a cyclically weak phase," Integer's lead nitrogen analyst, Laura Cross, wrote in February.

CRU puts China's ability to export urea cheaply in bulk down to three reasons: a liberalised export policy, chronic domestic oversupply and falling feedstock costs. Unlike other nitrogen producing countries such as the Ukraine, Chinese nitrogen production is overwhelming reliant on coal with eight out of ten of the country's ammonia plants dependent on this feedstock. Anthracite, powdered coal and bituminous coal costs have all fallen steadily over last 2 years, thanks to China's economic slowdown, and are now around a quarter to a third lower than they were at the start of 2012.

Table 1: **Classification of Chinese ammonia plants by size**

Plant size (t/a)	Units	Total capacity (t/a)	Total capacity (%)
<100,000	167	8,415,000	10.1
100,000–300,000	308	51,580,000	61.5
≥300,000	67	23,840,000	28.4

Source: Clariant

Policy and regulatory reforms in China are heralding a shift to larger-scale, more efficient nitrogen production. Cost and availability factors are also triggering major changes in Chinese feedstock use.

Ammonia industry shake up

A recent analysis by Clariant suggests that the 542 ammonia synthesis units in operation in China provide a total production capacity of 84 million t/a (*Nitrogen+Syngas 334, p 24*). Actual production in 2013 was 66.6 million t/a, suggesting a utilisation rate of 79%, although some of this capacity may have been switched to methanol production instead. Ten companies account for around 30% of China's ammonia production capacity with Jinmei, Yihau and Petrochem being the three top players.

China's four main ammonia producing regions are Shandong, Henan, Shanxi and Sichuan provinces. The concentration of capacity in Shandong, Henan and Sichuan, is unsurprising, given that they are traditional agricultural provinces with high populations. The ammonia production capacity of Shanxi, in contrast, is explained by its abundant coal reserves and the availability of anthracite as a feedstock.

Mid-size ammonia plants in the 100,000-300,000 t/a capacity range are the mainstay of the Chinese ammonia industry, accounting for some 60% of production, according to Clariant (Table 1). However, just 67 large ammonia plants (300,000 t/a and above) are responsible for nearly a third of Chinese ammonia production, a proportion that is only likely to grow. Nearly all of these large-scale units are dedicated to urea production.

Small, stand-alone ammonia plants (<100,000 t/a capacity) are likely to be gradually phased out in China – unless

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Fig 1: **New Chinese urea capacity**

Source: Integer

coupled to the downstream production of higher-value products. More stringent environmental regulations will also necessitate the shutdown or refurbishment of many of China's small and mid-size units.

One notable idiosyncrasy of the Chinese ammonia industry is the existence of small, aged plants dedicated to ammonium bicarbonate (ABC) production. Although their demise has been long predicted and closures are occurring, a number of these plants remain open. The fact that water-soluble ABC remains a preference for paddy farmers in China's southern regions helps explain their persistence.

China's nitrogen industry and its feedstock preferences have largely evolved due to the availability of coal and the commercialisation of gasification technology in the 1950s. The lack of access to natural gas and its high cost have also played a part.

Four fifths of the country's ammonia production capacity is provided by 450 coal-based units. A further 84 units run on natural gas and provide nearly a fifth of capacity. But their numbers are unlikely to increase in the near future due to the prohibitive expense of this feedstock. New regulations introduced in 2012 also generally prohibit the use of natural gas as a feedstock for new ammonia plants.

A handful of Chinese ammonia plants, eight according to Clariant, are fed on coke oven gas, a by-product of China's huge iron and steel industry, but account for less than 2% of capacity.

Geography critical for urea exports

The overwhelming majority of Chinese ammonia is processed into downstream products, particularly urea. China's urea capacity is estimated at 77.7 million t/a by the China Chemical Information Center. It is forecasting actual output of around 70 million tonnes in 2015. About 32 million t/a of China's urea capacity (around 45%) is 'energy integrated' and owned by coal or gas companies, according to Integer Research. Plants currently under construction in Inner Mongolia, Heilongjiang Province and Shanxi Province should add an extra 4.56 million t/a of capacity when they become operational in the second half of 2015, according to the China Chemical Information Center. This capacity increase is, however, expected to be largely negated by the simultaneous phase-out of around 4 million t/a of obsolete urea capacity.

CRU is currently predicting that China will add around 31.5 million tonnes of urea capacity (14.5 million tonnes on a nitrogen basis) between now and 2019. Integer Research previously predicted the addition of 24 million tonnes of coal-based urea capacity in China by 2020. Bituminous coal-based urea production will increases its market share from 20% to 37% over this period, in Integer's view, whilst anthracite's share is set to decline from 54% to 43%.

Three major new Chinese urea plants are currently in commissioning or under construction and should become operational this year, with a fourth plant scheduled for completion by 2017 (*Nitrogen+Syngas 334, p34*). The largest of these is Inner Mongolia Erdos Chemical Industry Group's 2,860 t/d urea plant. This Stamicarbon-licensed plant is being built at Ordos City, Inner Mongolia, by the China Chengda Engineering Company.

Although the urea capacity of coal-rich Inner Mongolia and Xinjiang is forecast to rise sharply in future, due to relatively low production costs, new plants in these provinces will mainly supply the domestic market (Figure 1). Urea plants located in Hebei, Shandong and Shanxi provinces, in contrast, are more likely to target the export market due to their proximity to sea ports. Around 55% of total urea exports (3.8 million tonnes), including major contributions from Shanxi and Hebei, were channelled through Shandong's sea ports in 2012.

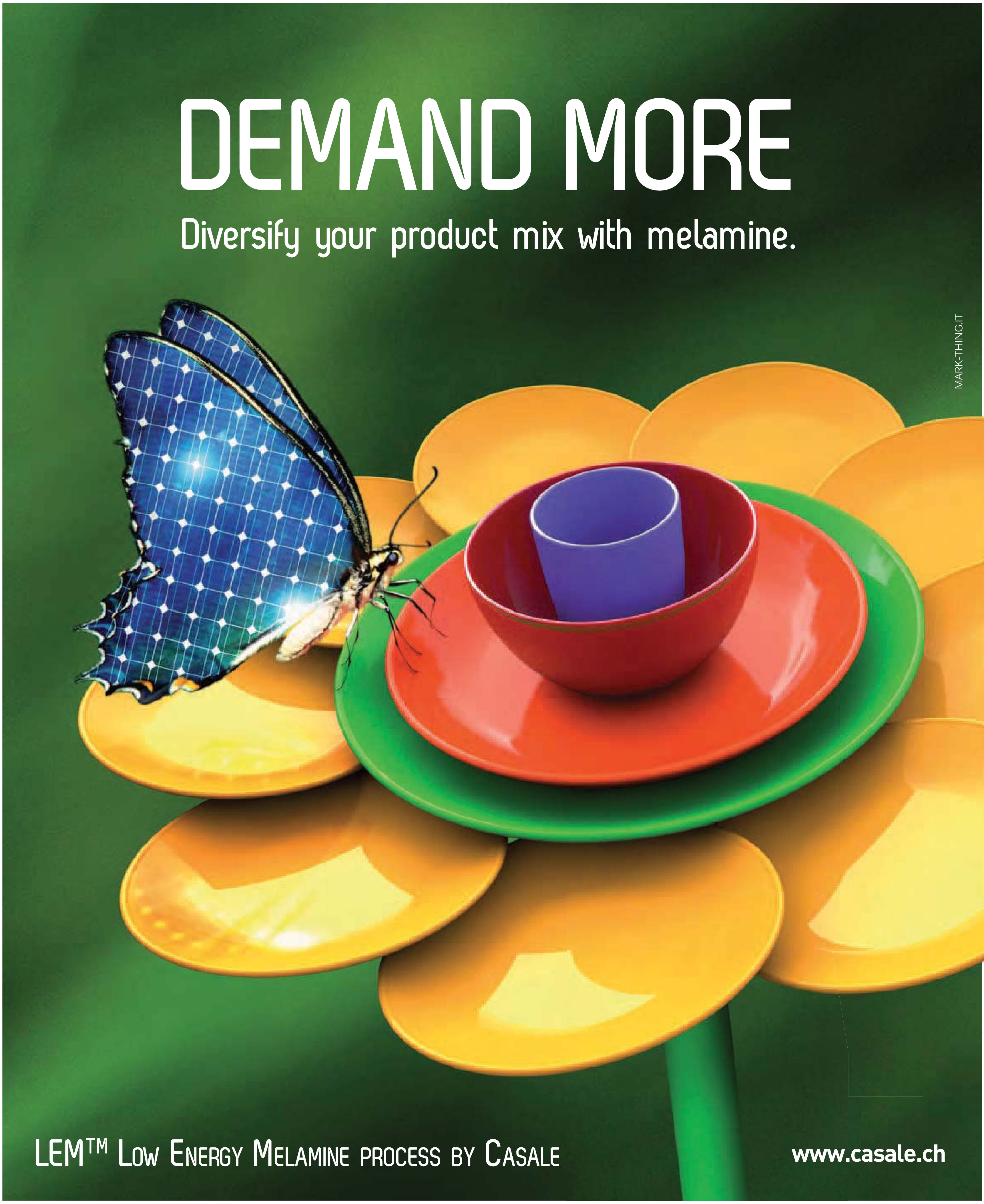
New rules driving change

China's industry and information technology ministry introduced a set of entry requirements for new Chinese ammonia plants at the end of 2012. The new guidelines were designed to hasten industry restructuring, improve environmental protection and promote investment in efficient processes and clean technologies. If successful, these regulations will see the use of anthracite and natural gas feedstocks decline and transform the industry by shifting production to larger ammonia plants co-located in coal-rich provinces.

Change in the industry is already happening with CRU reporting last year that new-build ammonia plants in China are "overwhelmingly" using thermal (bituminous) coal feedstock. This is a sign that China's nitrogen industry is "moving down the coal cost gradient", in CRU's view, by shifting its feedstock consumption away from lump anthracite to powders and thermal coals instead.

Clariant is predicting that ammonia production from large-scale plants (300,000 t/a and above) in China will grow from 23.8 million t/a in 2013 to 32 million t/a by 2017. Any increase in large-scale production is likely to be accompanied by further mid-size and small plants closures. Most new large-scale projects are expected to be located close to coal-rich regions.

Coal-to-liquids, coal-to-chemicals and coal-to-gas technologies – collectively known as CTX – are a booming, growing market in China, according to the London


DEMAND MORE
Diversify your product mix with melamine.
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Environmental Investment Forum. Last September, for example, Chinese state energy company Sinopec announced the go ahead for a $10 billion coal to gas plant in Xinjiang province – one of more than 80 CTX projects currently on the drawing board in China.

Coal price and export changes

Urea exports from China are now subject to a year-round flat rate duty of CNY80 per tonne under reforms introduced this year. The previous export duty regime attempted to maintain urea stocks at times of high domestic demand by taxing exports at CNY40 per tonne during the July-October low season and at 15% plus CNY40 per tonne the rest of the year.

Société Générale cut its price forecast for urea in January on the back of a warning that export tax reforms in China could spark a global price war this year. The French investment bank expects the new export regime to reduce urea price volatility and limit “sharp seasonal” price increases. But it also warned that extra supply from China on the international market could become a “catalyst for a price war”. The bank is forecasting “significantly higher urea exports from China” in 2015 linked to the weak price of domestic coal and the export policy relaxation. It highlighted a possible further fall in Chinese coal prices as a “key risk” for rival nitrogen fertilizer producers.

Integer’s Laura Cross agrees that “Chinese feedstock costs have a pivotal impact on the wider global market”. Nitrogen and coal price falls have a common origin in her view: “Weaker coal prices are in part a reflection of China’s slowing economy and there are parallels with the nitrogen industry. Both coal and nitrogen have undergone significant recent expansion and over-investment, resulting in oversupply and falling prices.”

CRU predicted a bleak outlook for the Chinese coal industry in March, blaming the price deterioration last year on domestic oversupply and weakening demand growth. Chinese thermal coal prices declined by 23% in 2014 and, according to the China Coal Association, around 70% of coal companies made losses for the year.

But Chinese coal prices may well have bottomed in Integer’s view. “The effect of falling oil prices on nitrogen prices will be moderated, because the Chinese coal market, which in turn determines costs of production for many marginal Chinese nitrogen producers, is already at the floor,” comments Laura Cross.

Cross points to evidence that that coal prices, which have recently been averaging $5.6/MMBtu for anthracite, have in fact “stabilised somewhat” so far this year: “The Chinese government has announced the introduction of supply cuts and restrictions in an attempt to move away from energy intensive production methods, suggesting that prices are now close to their floor. Chinese anthracite coal prices fell by almost 20% over the course of 2014, ensuring lower production costs to anthracite-fed plants.”

Profitability question marks

In March, evidence of “intense competition” and a drop in urea prices in response to strong Chinese shipments prompted Société Générale to issue a warning of a backlash from rival producers. “We see this potentially representing a first move towards making Chinese urea unviable,” said the bank’s analyst Rajesh Singla.

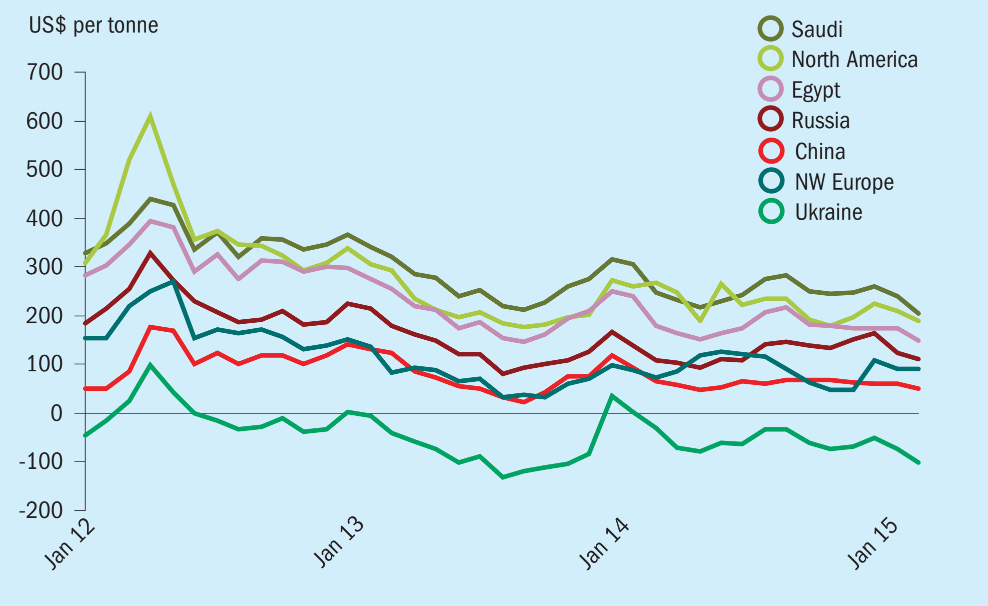
The bank is currently forecasting a 29% rise in Chinese urea exports in 2015 to 17.5 million tonnes. To date, the Chinese urea industry has held to a common price. Price discipline could disintegrate if producers using lower cost thermal coal decided to act unilaterally, in Société Générale’s view. “If the thermal coal-based producers continue to face resistance in gaining market share, we believe they could push down the floor,” commented Singla.

CRU interprets the situation slightly differently. Although record Chinese exports over the last two years have pushed prices down, CRU believes the current urea floor price is firm, and is not expecting coal prices to be significantly affected by lower oil prices. It believes typical Chinese factory gate prices are around $220/t currently, rising to $290-295/t f.o.b. once export taxes are included. Chinese urea industry costs are also set to rise over the next four years. CRU expects Chinese urea prices to increase to $340/tonne by 2019, linked to a 65% jump in labour costs, rising freight expenses, currency appreciation and a tightening coal market (*Nitrogen+Syngas 334, p29*).

The profitability of Chinese urea manufacturers at current cost levels already looks questionable, if the China national Fertilizer Center is to be believed. Its figures suggest that the combined income of China’s 332 nitrogen fertilizer producers dropped 5% to CNY190.28 billion for the first nine months of last year. Even worse, 164 of these producers reported financial looses totalling CNY9.5 billion.

Chinese nitrogen producers are operating at the periphery confirms Integer’s Laura Cross, typically making some of the lowest netbacks (revenue after costs) in the global industry. Gross margins for Chinese urea are well below $100/t (Figure 2) and profitability is believed to have fallen below that of traditionally high-cost European producers in recent months. “China is likely to continue in its role as the global industry’s marginal producer – and the prospects for rising coal prices in the country point towards even more of a squeeze in nitrogen margins,” concludes Cross.

Fig 2: **Typical urea gross margin per tonne**



Source: Integer

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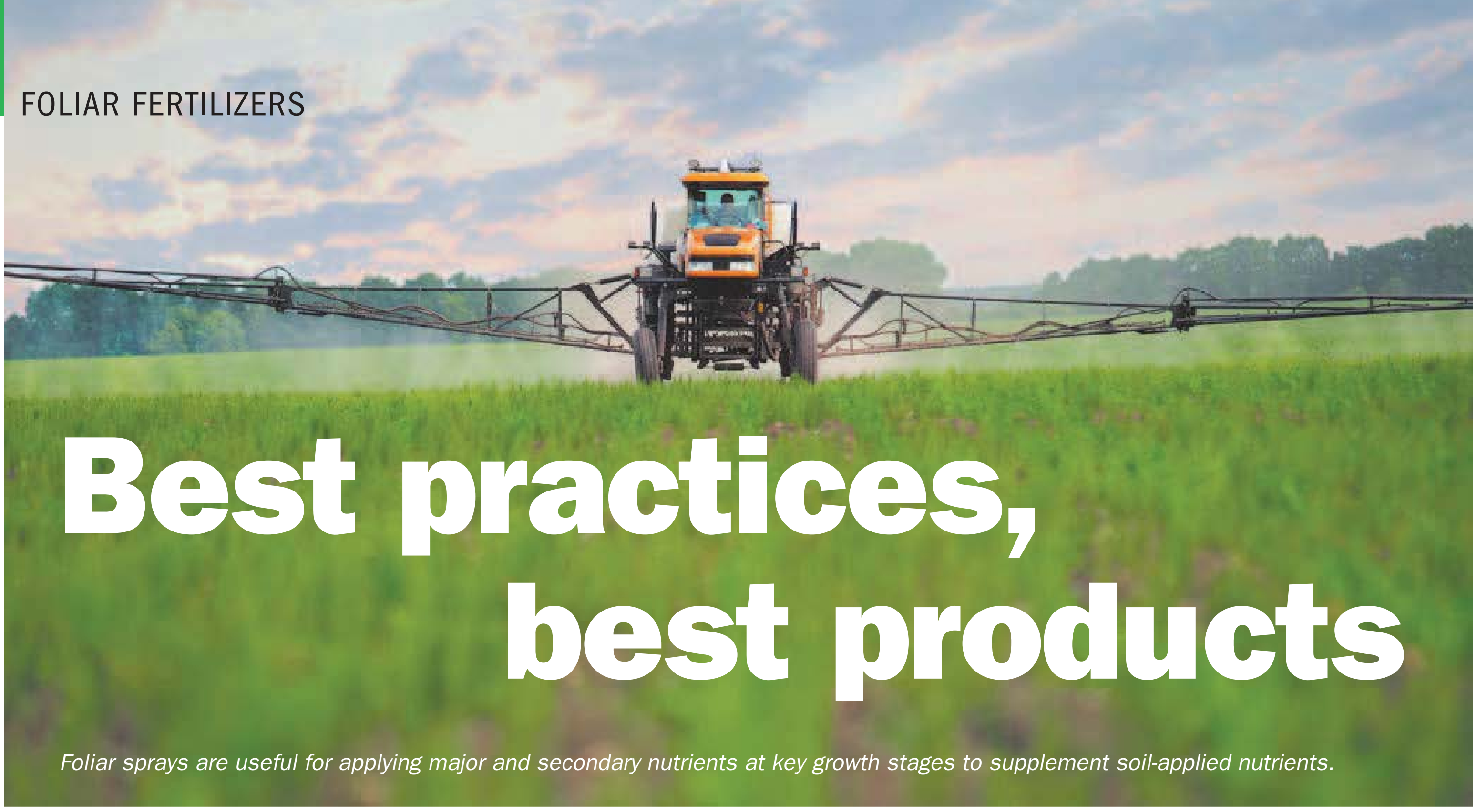

Best practices, best products

Foliar sprays are useful for applying major and secondary nutrients at key growth stages to supplement soil-applied nutrients.

PHOTO: STOCK IMAGE/SHUTTERSTOCK.COM

Foliar fertilisation offers specific advantages over soil fertilisation when plant demand for nutrients exceeds the capacity of the roots to absorb nutrients and when environmental considerations limit the effectiveness of soil-applied nutrients. We outline the expanding range of products that have been tailor-made for foliar fertilisation.

Foliar fertilisation is a method of feeding plants by applying liquid fertilizer directly to their leaves. The absorption takes place through their stomata and also through plants' epidermis. Transport is usually faster through the stomata, but total absorption may be as great through the epidermis. Plants are also able to absorb nutrients through their bark.

In certain circumstances, foliar feeding can be up to 8-10 times more effective than soil application, and up to 90% of a foliar-feed solution can be found in the roots of a plant within one hour of application. Foliar supplements can be an effective way to compensate for soil deficiencies and a poor soil's inability to transfer nutrients to the plant. However, for the major N, P and K nutrients, the quantity absorbed at any one time is relative to plant needs, and foliar application of these major nutrients may supply only a small fraction of the total needed for the plant, so foliar fertilisation should be considered primarily as a supplement to regular soil application of N, P and K. If the plant already has plenty of N, P and K, foliar application will be of only limited benefit: indeed, if concentrations in the foliar spray are too high, leaf damage could occur and in extreme cases could kill the plant.

Foliar sprays are thus recommended to supplement traditional soil applications of fertilizer nutrients. In this way, foliar fertilisation allows flexibility in the supply of nutrients related to improving the quality of the harvest. It also provides plants with certain nutrients (such as zinc and iron) that may not be readily available for root uptake.

Foliar uptake mechanism

During their normal seasonal development, most crops encounter certain stages of high nutrients demand. A whole group of macro-, meso- and micronutrients are involved in this upsurge. Typical examples of such stages are:

- Quick growth of seeding after germination in annual crops
- During tillering and grain filling in cereals
- Intensive shoot growth at early spring in all perennial crops
- During flowering and fruit-set in deciduous crops (when there is increased demand for B and Cu, required for pollen-tube development and growth)
- During rapid fruit growth in many types of fruit crops
- During the fast bulking-up process in bulb and tuber crops
- During the initiation of the lint production in lint crops.

These critical growth phases determine the yield and quality of the produce, but may coincide with inadequate soil supply, arising from such situations as:

- Waterlogged soils that inhibit roots' respiration and their adequate functioning
- Low soil temperature restricts nutrient uptake by the roots
- Uncontrolled weeds population, competing with the grown-up crop
- Internal bottlenecks within the plant.

Foliar feeding can address issues of nutrition in all of the above-mentioned circumstances. (*The Benefits of Foliar Feeding*, ICL Specialty Fertilizers International BV.) The big advantage is that foliar fertilisation can address an urgent need within a relatively short time, proving particularly efficient as a preventive treatment.

In order for a foliar fertilizer nutrient to be utilised by the plant for growth, it must first gain entry into the leaf prior to entering the cytoplasm of a cell in the leaf. To achieve this, the nutrient must either diffuse through stomata or effectively penetrate the outer cuticle and the wall of the underlying epidermal cell. Once penetration has occurred, nutrient absorption by the cell is similar to absorption by the roots. Of all the components of the pathway of foliar-applied nutrients, the cuticle offers the greatest resistance. (*Foliar fertilisation: principals and practices*, Dr Derrick Oosterhuis, University of Alabama [2007].)

The leaf cuticle is a thin covering on the outside of the leaf and other organs, which protects the plant from the extremes of the environment. The cuticle is dynamic and responds to changes in the environment and also to management. Cuticles are traversed

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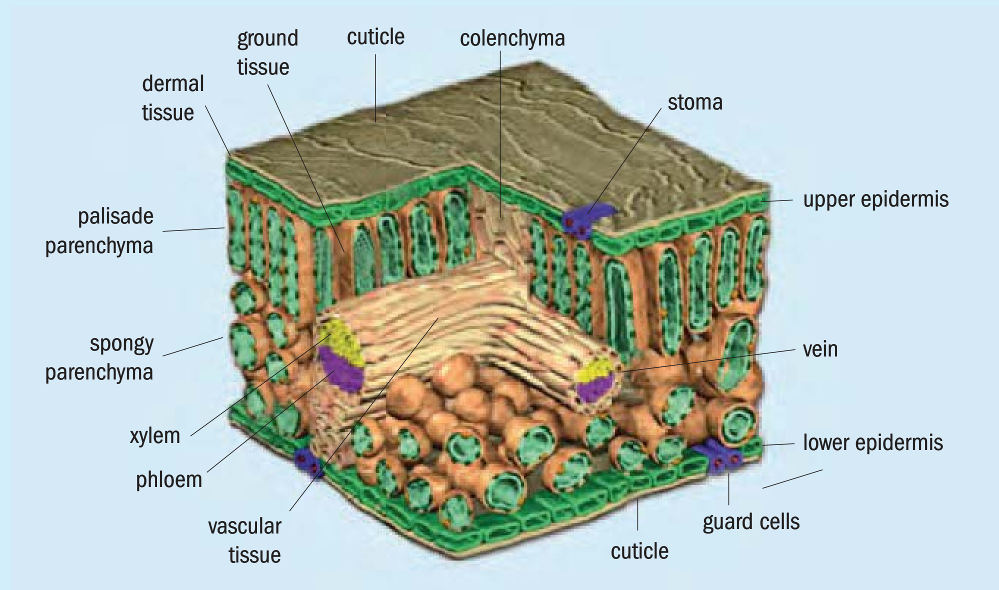
Fig 1: **Leaf tissue anatomy**



Source: Eyal Ronen, Haifa Chemicals

by numerous hydrophilic pathways permeable to water and small solute molecules. These pores have a diameter of <1 mm, with a density of about 10^{10} pores/cm and are lined with negative charges increasing in density towards the inside, facilitating the movement of cations. Actual movement through the cuticle depends on the nutrient concentration, molecular size, organic or inorganic form, time as a solution on the leaf surface, and charge density across the cuticle.

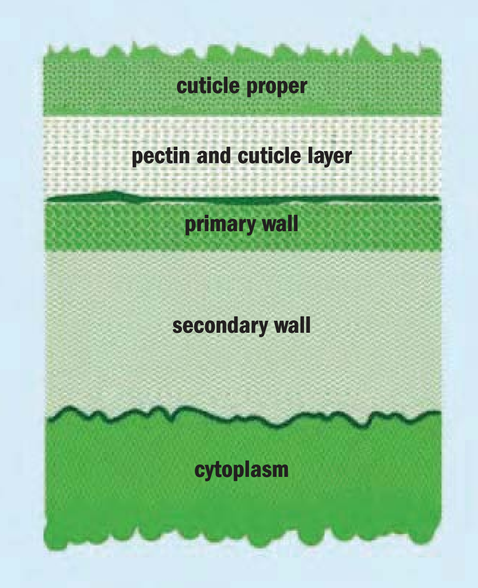
Figs. 1 and 2 show the various leaf layers that aid or restrict nutrient absorption by the leaf.

Because crop foliage is designed for photosynthesis and not nutrient absorption, a foliar nutrient application has to be absorbed by the leaf before it dries by entering stomata openings or passing through the cuticle. Due to this limitation, it is highly unlikely that a plant would have the ability to absorb large amounts of any given nutrient. A foliar programme would therefore be impractical to correct major large amounts of any given nutrient. (*What to expect from foliar fertilizer programs*, Ed Lentz, **C.O.R.N. Newsletter** [2012-18].)

In addition to supplemental doses of macro-, secondary and micronutrients, foliar feeding may be used to supply doses of plant hormones, stimulants and other beneficial substances. Plant response is dependent on species, fertilizer form, concentration and frequency of application, as well as stage of plant growth.

Foliar applications are often timed to coincide with specific vegetative or fruiting stages of growth, and the fertilizer formulae should be adjusted accordingly. Applications may also be used to aid plants in recovery from transplant shock, hail damage or the result of weather extremes.

Fig 2: **Leaf tissue section**



Crops' nutrient needs

Nitrogen is the element needed in the greatest amount and is often limiting. It is a constituent of proteins, nucleic acids, hormones and chlorophyll. In the case of cotton, some 30% of foliar-applied urea N can be absorbed in one hour, and 60% absorbed in 24 hours.

Potassium is important in plant/water relations, plant metabolism, photosynthesis and translocation, and fibre development and quality. Cotton is one of several crops which are relatively inefficient at absorbing K from soils compared to other crops. Root activity decreases as the boll load develops, just as the plant's demand for K peaks. Foliar K is therefore necessary to supplement soil-applied K. Four weekly applications may be required, beginning at early flowering for maximum yield effect. An average mature cotton crop in the United States requires about 100-220 kg K/ha.

Soybean plants also display a sharp decline in root activity during late seed development, with large nutrient translocations from leaves and pods into the developing seed. Small amounts of nutrients sprayed on to soybean foliage could supplement pre-plant fertilisation and increase nutrient supply at a time when roots and N fixing root nodules are not well developed. Furthermore, foliar fertilisation could enhance growth if soil conditions limit nutrient uptake when soil levels are adequate. (*Integrated Crop Management* [2008].)

While foliar fertilisation is being used on a wide variety of crops, its economic value is often deemed to be greater for horticultural than for agricultural crops. This is because horticultural crops are of higher value and their nutrient status is more carefully monitored.

Overall, the economics of foliar fertilisation are dependent on how successful the applications are and whether or not the same nutrition might have been supplied more economically through other means. Because weather can be a factor and because circumstances differ widely among farms, there is no simple determination. The individual grower should base any decision on need and monitor for indicators of success. (George Kuepper, NCAT Agriculture Specialist, *National Sustainable Agriculture Information Service* [2003].)

Limitations

Although foliar fertilisation is a potentially very powerful application method that may overcome a range of problems, it is not a perfect way and has its own limitations, including:

- Low penetration rates, particularly in leaves with thick wax/cuticles
- Run-off from hydrophobic surfaces and washing off by rain
- Rapid drying of spray solutions, disabling the penetration of solutes
- Limited rates of translocation of certain mineral nutrients
- Possible leaf damage (necrosis and burning).

Solution pH and the environment can influence leaf absorption, cuticle development and physiological reactions related to active absorption mechanisms. (*Foliar feeding – another successful way of feeding plants*, Eyal Ronen, Haifa Chemicals.)

Foliar sprays give the grower full control in respect of:

- Immediate application timing as soon as deficiency symptoms are recognised
- Application concentration and frequency that will address and resolve the deficiency
- The nutrients applied can be tank-mixed with other inputs, including pesticides and biostimulants, thus achieving a synergistic effect and saving application costs.

Guidelines for success

The prerequisite for the absorption of nutrients into the plant is a sufficiently moist leaf surface. There can be a large difference in the effectiveness of various fertilizer sources in actually penetrating the leaf surface and providing the desired nutritional benefit. The absorption of nutrients via the leaves takes place through diffusion. This assumes that the nutrients are available in a dissolved form, such as water-soluble salts and non-polar substances (such as chelates and urea). Insoluble suspensions are relatively unsuited to a rapid absorption via the leaf, as their nutrient ingredients are suspended rather than dissolved, such as magnesium hydroxide or elemental sulphur, which are finely ground and mixed with water. The nutrients contained in insoluble suspensions are therefore not fully water-soluble and consequently may not be wholly usable for the plant. (*How foliar fertilizers work*, K+S KALI.)

To prevent the drying out of the sprayed film on the leaf surface, spraying should preferably be carried out in the evening. The nocturnal formation of dew keeps the plants moist and enables a good absorption of nutrients and a high level of effectiveness. Already-dried-out spray is again dissolved by the dew and diffusion into the leaf continues.

Wetting agents can be used to optimally wet the leaf surface. These are often included in plant protection agents as a formulation aid. As the application of foliar fertilizer is normally carried out together with the application of fungicides or insecticides, the producer's recommendations regarding concentration and miscibility of the components should be followed. Certain additional guidelines should be also followed:

- To be efficient and to avoid crop damage, very dilute solutions of nutrient formulations are recommended. Excessively large doses of highly concentrated sprays risk causing leaf burn.
- Foliar products need to be correctly formulated in order to maximise the benefits and minimise the risk of damage when sprayed on to leaves or fruit.
- Spray solution pH should remain in the near-neutral range (5.5-8.5).
- The best effect is achieved when foliar sprays are finely atomised.
- Absorption is increased when sprays also reach and coat the leaf undersides, where most of the plant's stomates are located.
- Foliar fertilisation should be delayed until temperatures fall to 27°C (80°F) or below. Absorption at higher temperatures is very poor because plant stomates are closed.

- The addition of a surfactant to the solution decreases surface tension on the leaf and can increase absorption.
- Care should be taken over the compatibility of the chemical constituents of foliar mixtures.

Advances continue in foliar application technologies. Electrostatic sprayers are one common application technology. These impart a charge to the spray particles and cause them to adhere more readily to plants. Another technology, known as *Sonic Bloom*™, uses sound to increase the leaves' absorption of nutrients.

The concept of feeding plants through foliar spraying is a good method of feeding plants when ground application does not supply sufficient nutrition. However, this method cannot substitute the supply of nutrients through the root system when the uptake of all the nutrients through leaves involves considerable labour with a high risk of phytotoxicity. (Source: Ronen.) As long as the limitations associated with foliar fertilisation are recognised, the method provides a supplementary source of plant nutrition that achieves good plant yield and quality.

Speciality products

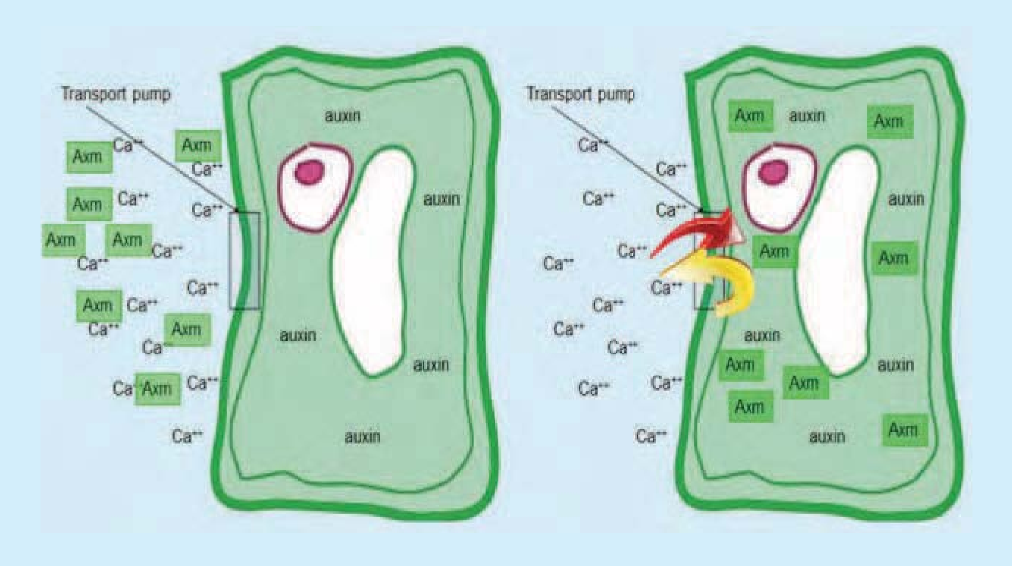
The speciality fertilizer producer Compo (now owned by Triton Group) markets the *Nitrophoska*® range of water-soluble fertilizers for foliar application. The range comprises a highly efficient combination of macro- and micro elements and offers superior dissolving speed and efficiency, with 99% of the products dissolving within ten minutes of application while leaving no residue. The homogeneous particle size ensures that there is no product segregation, and the risk of caking and dust is minimised.

Nitrophoska products incorporate fully chelated trace elements that ensure rapid leaf penetration, a highly efficient nutrient uptake, with full utilisation in the plant's metabolism and enhanced translocation to the place of maximum demand.

ICL Specialty Fertilizers has created a foliar portfolio with some unique organic and mineral active components that:

- Increase leaves' permeability to the sprayed volume
- Provide complete wetting of the leaves' surface by the spray droplets
- Firmly attach the spray's active ingredients to the leaf surface, thus prolonging its effect

Fig 3: Omex Agriculture's *AXM* acts as a pump primer to enhance nutrient uptake by plant cells



- Extend the effectiveness of the chelated ingredients
- Improve the effectiveness of the chelated ingredients
- Improve the metabolic activity of the target tissues
- Improve the nutrient utilisation
- Enhance plants' resistance against abiotic stresses.

ICL Specialty Fertilizers offers two kinds of foliar feeding product for the growers. ICL Specialty Fertilizers' foliar *WSF* product range includes the *Agroleaf Power* and *Nutrivant* brands. The *Agrileaf Power* offers speedy uptake, purity of minerals and advanced technology. The specially-designed *M-77* foliar package is added for the enhanced delivery of nutrients and stress-resistant plants. The *M-77* formula contains compounds that extend the effective range of the chelates and functional elements to improve the utilisation of nutrients and photosynthesis, while stress-reducing compounds maintain consistent plant productivity. In this way, *Agroleaf Power* offers a longer-lasting effect after delivering the immediate results. It is safe to use for most leaf crops and can be mixed with pesticides.

ICL Specialty Fertilizers' *Agroleaf Special* is a premium fully water-soluble foliar fertilizer that prevents and controls manganese and zinc deficiencies. *Agroleaf Special Manganese* and *Agroleaf Special Zinc* ensures fast absorption by the plant, enhancing plant metabolism. The product also contains X_3, a specific biostimulant that facilitates the absorption of this compound into plant leaves, providing an effective uptake. It incorporates an EDTA chelating agent, which can protect the metal atom complexed with it against precipitation and inactivation. It is used on a variety of crops, including cereals, vegetables, flowers and fruit trees.

Nutrivant formulations are especially designed for arable and big area crops, helping to improve crop quality and increase the size and number of fruits. The product range consists of fully-soluble formulations that contain macro- and micronutrients, as well as a specially-designed trace mix for every crop's needs. All *Nutrivant* products contain an advanced, continuous delivery system known as *FertiVant*. This unique ingredient has been developed for foliar application to allow nutritional elements and stimulants to pass through the leaf cuticle. It ensures the even spreading of the drops of spray on the surface, firmly attaches the active ingredients to the leaf surface and delays evaporation. For application procedures, *Nutrivant* requires a lower spray dosage, reducing the nutrient cost per hectare. Foliar feeds from *NutriVant* fit into all fertilisation programmes and are chloride-free and fully soluble.

Next to the water-soluble range, ICL Specialty Fertilizers introduces a liquid portfolio for foliar application, known as *Agroleaf Liquid*. Currently, there are four unique products designed to eliminate deficiencies and boost plant growth during critical growth stages. The products are aimed to fight deficiencies in manganese, zinc, boron and molybdenum.

Omex Agriculture is the UK's largest liquid fertilizer manufacturer. Additional manufacturing is undertaken at sites in Belgium, the United States and Canada, while Omex Agrifluids markets speciality fertilizers around the world, including foliars, plant health promoters, biostimulants, organic fertilizers and soluble powders. Extensive trials and research programmes, often in conjunction with independent organisations and universities, have enabled Omex to develop a specialist knowledge of fluid dynamics into several different industries, ranging from agriculture to wastewater treatment.

Omex liquid fertilizers and suspension compounds are tailor-made to meet crop requirements, leading to enhanced yields and quality. Omex has been at the forefront of developing a succession of enhanced calcium formulations, including *CalMax, Vitalize* and *Quad 14*, each delivering improved efficiency. *CalMax Ultra* is the next stage in this evolution and another major advance in calcium delivery technology. It contains a high concentration of Ca as calcium nitrate (21.8% CaO) plus trace elements and *AXM*, a novel ingredient which promotes efficient delivery of Ca to the cells where it is needed.

The *AXM* in the *CalMax Ultra* formulation effectively mimics auxins, without any of the growth effects that these natural hormones can induce and is readily absorbed by the cells. This is then exchanged for Ca in the same ways as auxins are, leading to enhanced uptake. In this way, *AXM* acts as a pump primer to improve the transport of Ca into the cells. (Fig. 3) The enhanced Ca uptake enables *CalMax Ultra* to be used at much lower application rates than other Ca products. The formulation also contains other important nutrients, including Mg, B, Fe, Cu, Zn and Mb to ensure maximum yields and enhanced quality produce.

In independent trials on apples and soft fruit in the UK, South America and the United States, regular use of *CalMax Ultra* resulted in a marked reduction in both the severity and incidence of bitterpit in apples and improved yields and quality in apples and soft fruit.

Haifa Chemicals has meanwhile launched a mobile app to support growers' foliar feeding practices. *FoliMatch*™ aims to assist growers with foliar nutrition calculations, providing them with a tool to optimise the foliar nutrition given to their crops. *FoliMatch* provides foliar nutrition data for ten different crops, with attention being paid to specific phenology stages in each crop. The app supplements two other mobile application tools, *FertiMatch*™ and *FloraMatch*™ dealing with foliar applications. Haifa Group now offers a complete set of mobile applications, assisting growers to optimise plant nutrition given also through irrigation systems and by applying controlled-release fertilizers.

Tessenderlo Kerley's sulphur-based liquid fertilizers are used on a variety of crops. Through its *Trisert*™ product range, the company offers a family of urea triazone-based slow-release N, clear liquid fertilizers that can be applied as a foliar or soil-applied solution. Derived from Tessenderlo Kerley's patented urea-triazone nitrogen solution *N-Sure*™, *Trisert* is available in several formulations and with varying levels of slow-release N.

AGRI Nova markets the *Foligreen 19-19-19* foliar NPK fertilizer range. It is enriched with B and Mb in mineral form, along with chelated Fe, Mn, Zn and Cu. The range has proved effective in foliar applications on citrus and fruit trees, as well as vegetables. ■

Russian government poised to intervene

Eugene Gerden weighs up the prospects for Russian state intervention on export duties and a fertilizer price freeze.

Ever growing complaints by farmers about spiraling fertilizer prices – caused by Russia's economic troubles and the ruble's devaluation – have raised the prospect of government-imposed export duties on Russian fertilizers.

Since the start of the year, the prices of Russian agriculture's most popular fertilizers have increased significantly. In the case of ammonium nitrate, the average price has increased by 40% year-on-year to RUB16,091/t. Urea prices have also risen by 37% to RUB18,646/t and potash by 13% to RUB13,230/t in the last 12 months. These hikes have left Russian farmers without sufficient funds to purchase the fertilizers they need for spring sowing – posing a threat to the entire Russian growing season.

Legislative measures

Against this backdrop, the Russian government and national parliament have decided to intervene in the market and introduce a package of measures designed to ensure Russian farmers have access to fertilizers. The planned state measures include duties on the exports of Russian fertilizers and a freeze on fertilizer prices throughout the Russia sowing season. Added to this, the government and the Russian Federal Anti-Monopoly Service have launched an investigation into suspected price fixing in the Russian fertilizer market, the results of which will be announced later this year.

Nikolai Pankov, who chairs the Agrarian Issues Committee of the Russian parliament, the State Duma, says intervention is necessary to stabilize the domestic fertilizer market and reduce prices.

"All the Russian facilities for the production of mineral fertilizers use domestic raw materials and energy in their production. [But] at present local fertilizer producers sell their products in the domestic market at the prices of imported products – which is unacceptable," comments Pankov.

He adds: "At present about 90% of Russian mineral fertilizers are exported to abroad, while the volume of supplies to the domestic market remains insignificant. We have a huge domestic production of potash, nitrogen and phosphate fertilizers, however the majority of local producers continue to focus on the sale of their products to foreign markets."

> **Export duties are not an effective tool for foreign trade or support of domestic farmers and producers.**

Members of the State Duma are calling for an end to rising Russian fertilizer prices and plan to achieve this by imposing duties on fertilizer exports. The government and the national parliament are pressing ahead with an export duty proposal, despite the huge potential losses this could inflict on Russian fertilizer producers.

The government is proposing to set the new export duty at a level of up to 35% and introduce this as early as June, subject to market conditions. The proposal has the backing of the Russian Ministry of Agriculture, which favours differential pricing for fertilizers supplied to the domestic and foreign market.

Discounts to farmers

To their credit, some of the country's leading producers have already agreed to offer Russian farmers a 15-20% fertilizer discount, and have even discounted certain products by as much as 30%. But the Ministry of Agriculture believes that such discounts are insufficient and that export duties are still vitally necessary.

Farmers also view fertilizer discounts as an ineffective way of stabilising the current market because they do not take account of price volatility. Arkady Zlochevskiy, chair of the Russian Grain Union, wants to see a new approach to regulating the fertilizer market which will end the domination of national producers.

The country's leading fertilizer producers have already opened negotiations with both farmers and the Russian government in an attempt to kill off the export duty proposal. The other legislative option – freezing fertilizer prices during the spring planting season in Russia – is likely to be less harmful to the country's producers.

Many Russian analysts have been vocal in their criticism of current state plans. Galia Gafurova, a Humanities teacher at the Russian State University and a well-known Russian agricultural and fertilizer analyst, concludes that a levy on exports will not help farmers or anyone else. "Export duties are not an effective tool for foreign trade or support of domestic farmers and producers," says Gafurova. "Introduction of the duties will not make local farmers more competitive in the domestic or foreign markets."

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BCInsight

Producer criticism

Major Russian fertilizer producers have been similarly critical of the proposed levy on exports. The imposition of export duties is unreasonable, will hurt the industry and make the current situation worse at a time of recession in Russia, says Dmitry Konyaev, CEO of leading fertilizer producer Uralchem.

He points out that global fertilizer prices are steadily declining at a time when many Russian producers have a large debt burden. But, despite this, many producers are continuing to implement major investment programmes, something which is especially important during the economic downturn. Export duties could place future investment in the fertilizer sector at risk, in Konyaev's view.

"Imposition of duties will result in the suspension of many investment projects in the industry," says Konyaev. "In fact, fertilizer producers have already started subsidising Russian agriculture by providing a discount for their products in the volume of 30% and we believe that this will be enough for them."

For ammonium nitrate, one of the best-selling fertilizers on the Russian market, Konyaev believes the yearly price increase has actually been 20% – and therefore broadly comparable to the annual rate of inflation in Russia. Large agricultural holdings in Russia have already purchased all the fertilizers they need for the current sowing campaign in advance, according to Konyaev. He contrasts this with the difficulties currently facing smaller farming enterprises which generally have insignificant fertilizer reserves.

Large Russian fertilizer producer Uralkali declined to comment about the plan to introduce export duties, although sources close to the company claimed it was unhappy with the proposal. Igor Kalugsky, head of the Russian Association of Fertilizer Producers (RAFR), the organization representing Russia's main producers, points out that the introduction of export duties simply adds to existing import duties imposed by the United States and Ukraine on ammonium nitrate. Export duties will lead to a reduction in fertilizer production in Russia, in his view, which in turn will result in further price increases.

Much pain for little gain

Analysts at the Russian Ministry of Industry and Trade have concluded that farmers' fears over higher fertilizer prices have been exaggerated. This is because fertilizer costs only account for 10% of the final price of agricultural products and could double without a negative impact on farming businesses, in their view.

Ministry calculations suggest that state intervention, such as a price freeze, would have severe, adverse consequences for the Russian fertilizer industry. In the case of Uralkali, the resulting losses could be as much as 11% of operating profit (EBITDA). The effect of a price freeze on Phosagro and Akron is even worse, with each facing potential losses of 25% and 18% of EBITDA, respectively. Export duties would be likely to inflict significantly higher losses on the industry, were these to be introduced.

The markets are certainly concerned by this threat and reacted to the news of possible export duties by wiping RUB30 billion from the combined market capitalisation of PhosAgro, Akron and Uralkali at one point this spring. ■

Advances in sulphuric acid technology

We summarise some of the most recent innovations, with a focus on economies in energy consumption, reduced emissions, and enhanced corrosion resistance and plant reliability.

At **Sulphur 2014**, MECS described its recently-commercialised *SolvR* regenerative SO_2 recovery technology, which represents the culmination of over 90 years of R&D in devising effective catalyst technologies. With a continuing focus on energy savings and performance improvement, MECS has expanded its catalyst portfolio with the *GEAR*® that utilises a unique hexa-lobed ring shape. By geometrically optimising the catalyst shape, the MECS *GEAR*® catalyst offers more surface area for access to active sites. When loaded into a catalyst bed, the hexa-lobed ring shape creates a catalyst bed configuration which increases spacing between the catalyst rings, lowering pressure drop significantly.

Compared to the longer-established ribbed ring or daisy-shaped catalyst, *GR-330 GEAR*® catalyst offers approximately 10-15% lower pressure drop at plant start-up. As the plant continues to operate, dust accumulates in the lower passes, creating the possibility of increased pressure drop across the converter. The hexa-lobed ring shape provides enhanced dust-handling capability. Over time, the pressure drop benefits expand, reaching a potential of approximately 30% less pressure drop after 24 months of service. This typically translates into between 2-6 months of extended operating time before the system pressure drop reaches the plant blower limit. The extended production campaign offers savings to sulphuric acid plants, including extended plant up-time, increased acid production, lower maintenance and operating costs.

MECS estimates that in a 200 t/d spent acid regeneration plant, using a *GEAR*® catalyst in place of a daisy-shaped one can save over $2,000/year over a two-year period. A much larger sulphur-burning plant of 2,000 t/d could save over $17,000/year, while savings of almost $28,000/year could be achieved in a 3,500 t/d metallurgical sulphur plant.

The latest product enhancement developed by MECS is an upgrade to the caesium *SCX-2000* catalyst, offering customers higher performance in the fourth and fifth converter passes. The improved-formula catalyst enables customers to achieve lower SO_2 emissions (a reduction of up to 80 ppm) through higher catalyst activity and better conversion or the ability to operate at a lower bed inlet temperature of 385°C.

How catalysts perform

The converter is the heart of modern sulphuric acid production, in which SO_2 is oxidised to SO_3 over a V_2O_5-based catalyst. Haldor Topsoe has also extended catalyst capability, launching the *VK59, VK69, VK-701 LEAP5*™ and *VK38* 25-mm dust protection catalysts. Fig. 1 shows the range of Topsoe daisy-shaped catalysts.

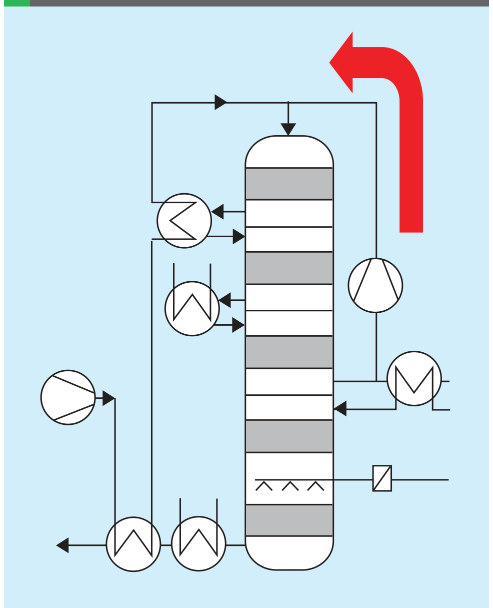
Topsoe notes that the reaction rate for a catalyst may be limited by external mass and heat transfer to the pellet surface, by internal mass transfer in the porous support or by the intrinsic reaction rate. For sulphuric acid catalysts operating at a low temperature, the main limitation is the intrinsic reaction rate, which depends on the chemistry in the catalytic melt and also on the distribution of the catalytic melt on the support, as well as gas solubility and transport through the melt. (*From nano-scale studies of working sulphuric acid catalysts to improved industrial-scale sulphuric acid production*, K. Christensen et al, Haldor Topsoe A/S. Paper presented at **Sulphur 2014**.)

Catalysts are dynamic systems which interact to a great extent with the local environment in which they operate. As a result, *in situ* studies at relevant temperatures, pressure and gas composition are necessary to get a true picture of the working catalysts. Topsoe has recently introduced new advanced *in situ* techniques, including Raman and high-resolution transmission electron microscopy (TEM) to resolve directly the dynamic state of catalyst samples interacting with an $SO_2/O_2/SO_3$ gas mixture at temperatures up to 600°C. These techniques provide unprecedented insights into sulphuric acid catalysis.

In situ TEM studies combined with lab-scale results show how the active phase takes up SO_3 and becomes mobile. The high-resolution TEM images show the rate of dynamic changes and the final wetting characteristics and melt distribution that can be derived. The results from Raman indicate that the vanadium changes from a

Fig 1: **Sulphuric acid catalysts from Topsøe in the Daisy shape**

Fig 2: **LUREC™ recirculation**



dimeric V(V) complex in hot air to primarily V(IV) compounds in SO_2/O_2 gas at 380°C. When the temperature is increased to 480°C, vanadium is reoxidised, while the spectral information obtained supports that the active phase of the phase of the *VK-38* catalyst at 480°C corresponds to an equilibrium between predominantly monomeric and to a minor extent dimeric vanadium (V) oxosulphate species. The studies undertaken by Topsoe suggest that the melt distribution and chemistry interact and that the physical state is just as important as the gross composition of a sulphuric acid catalyst.

Clariant identifies catalysts as the heart of the sulphuric acid process, offering the *SulfoMax*® V_2O_5 catalyst series. This is now in use in more than 100 sulphuric acid plants around the world and is available in different shapes and sizes. For sulphuric acid producers, the ideal catalyst needs to offer maximum activity and a long catalyst lifetime. However, there is always a balance between catalyst and mechanical strength. A catalyst with high mechanical stability lasts longer, but at the expense of reduced activity. On the other hand, a highly porous catalyst will offer excellent activity but low mechanical strength, thus reducing its lifetime. Catalyst manufacturers must therefore strike the right balance between activity, mechanical strength and operating lifetime.

Selecting the best catalyst is a prerequisite for the desired best outcome. For example, converters with low velocity have the option of using catalyst in pellet form to provide optimum gas distribution, while those with higher superficial gas velocities need a high geometric surface area and thus catalysts with low pressure drops. *SulfoMax RR* in its ribbed ring form is tailored to meet such low pressure drop requirements. The design is well-suited for higher SO_2 concentrations, lower ignition temperatures, greater attrition resistance and reduced screening loss.

Clariant's *SulfoMax HV* has been designed for high SO_3 environments, offering greater conversion in passes before intermediate absorption. *SulfoMax CS* is a caesium-promoted catalyst which offers better equilibrium yield with increased energy recovery. It can be used in both first and final passes, where the inlet temperatures are practically lower. A further improved version of the caesium-promoted *SulfoMax CV* is designed for lower ignition temperatures, especially suitable for the final pass, where it significantly improves conversion and thus reduces stack emission.

Digitalisation and improved plant performance

The options offered by process control technology pave the way towards improved plant performance, particularly via optimising power generation and water consumption. This is achieved by the appropriate selection of temperature and pressure conditions for HP steam generation and the recovery of heat in the condensate system.

Outotec has paid particular attention to harnessing digital technology to enhance plant efficiency. (*Digitalisation – chances to improve plant performance*, Stefan Bräuner et al, **Sulphur 2014**.) There are several examples and cases which demonstrate how much value can be obtained from digital content created in the sulphuric acid production sector:

- Process simulators
- Advanced control systems
- Remote diagnostics and maintenance.

Simulations have been used in the sulphuric acid industry to train plant operators or as clones of the real plant to test and optimise the process itself, including equipment, while advanced process control via the predictive control of processes can improve overall efficiency by using an internal model of the process as well historical data collected during plant operation. Reliability improvements have been achieved through remote diagnostics which led to reduced maintenance costs by avoiding unplanned shutdowns.

Energy recovery is high on the agenda at an ever growing number of sulphuric acid plants. The basis for power production in metallurgical acid is the SO_2 concentration and sufficient oxygen at inlet of the SO_2 converter. A high SO_2 concentration corresponds to a high surplus of useable energy. In addition, the operation at high SO_2 levels offers benefits as lower investment due to smaller equipment sizes, operating costs and lower emissions.

Outotec has devised the *LUREC*™ process that recirculates SO_3-rich gas to enhance the conversion of SO_2. The recirculation process ensures a maximum of heat recovery from the process gas at a valuable high-temperature level. (Fig. 2)

Another source of heat recovery is the intermediate absorber. Saturated steam can be generated in a typical heat recovery system, as per the Outotec *HEROS*™ design. The system comprises a hot acid circuit connected to a venturi absorber and a conventional intermediate absorption tower. Most of the SO_3 is absorbed in the venturi and used for the production of LP steam, while the remaining SO_3 gas is absorbed downstream in a standard intermediate absorption tower.

Both the *LUREC*™ and *HEROS*™ processes have been successful in operation and when combined, offer a further potential to boost the energy recovery of an acid plant.

To improve the reliability of the plant operation, Outotec has developed the *PORS* (Plant Operability, Reliability and Safety System) system, which can guide and support operators, creating an awareness of potential operational issues. Through digitalisation, *PORS* provides additional information about the process, plant and individual equipment, guiding operators and creating an early awareness of potential operational problems. The stand-alone system is based on Outotec's ACT platform and can be an integral part of a new installation or retrofitted at existing plants.

Optimising water and energy balances

The quest continues to maximise the power generated in sulphuric acid plants, while limiting the environmental impact from high water consumption. The combustion of sulphur in the plant generates high-quality heat that can be recovered for steam and electrical power generation. The two main chemical reactions occurring in the gas phase of a sulphuric acid plant are exothermic. The heat balance of the gas phase indicates that the total heat entering the gas system is approximately 1 Gcal/t of acid produced, from which around 82% can be effectively recovered through the production of HP steam, the remaining portion being taken by the hot gas going out of the system (14%) and the heat loss from equipment (4%). (*Optimisation of water and energy balances in sulphuric acid plants*, Philippe Malsan, Technip.) Such heat recovery performances can be achieved through optimising the plant design by using low temperature economisers, optimising the location of the main air blower and ensuring a sufficiently high temperature for the dry air at the drying tower outlet.

Independently from the quality of heat recovered from the process, the generation of electrical power in the plant can be optimised by the adequate selection of the pressure and temperature conditions for the HP steam generated in the plant. Both higher temperature and pressure for steam increases the power generated in the plant, resulting in increased electrical production of approximately 5% from 40 bara/410°C to 65 bara/410°C, or from 40 bara/410°C to 40 bara/500°C. If both pressure and temperature are increased from 40 bara/410°C to 65 bara and 500°C, electrical production can be increased by 9%.

This 9% increased electrical production represents a substantial amount of additional power, corresponding to approximately 70% of the energy required by the sulphuric acid main blower or 45% of the overall power requirement for the sulphuric acid plant. The advantage is however counterbalanced by an increase in the CAPEX of the plant due to the use of additional equipment and higher alloys. Thus, while operation with HP steam superheated at 400-410°C will require only one superheater recovering heat from the gas from the first pass of the converter, operations at the higher temperature of 500°C will require the use of a second superheater to recover additional heat from the fourth pass outlet gases.

The production of sulphuric acid from water reacting with SO_3 is also an exothermic reaction that occurs in the liquid phase. The amount of heat that has to be removed from the system is in the range of 450 Mcal (1.88 106 kJ) per tonne of acid produced, representing around 82% of the total heat evolved from the acid system: the remaining portion is taken by the gas going out from the absorption towers. The heat is removed from the system by cooling water flowing through acid coolers and finally evacuated in cooling towers and thus wasted.

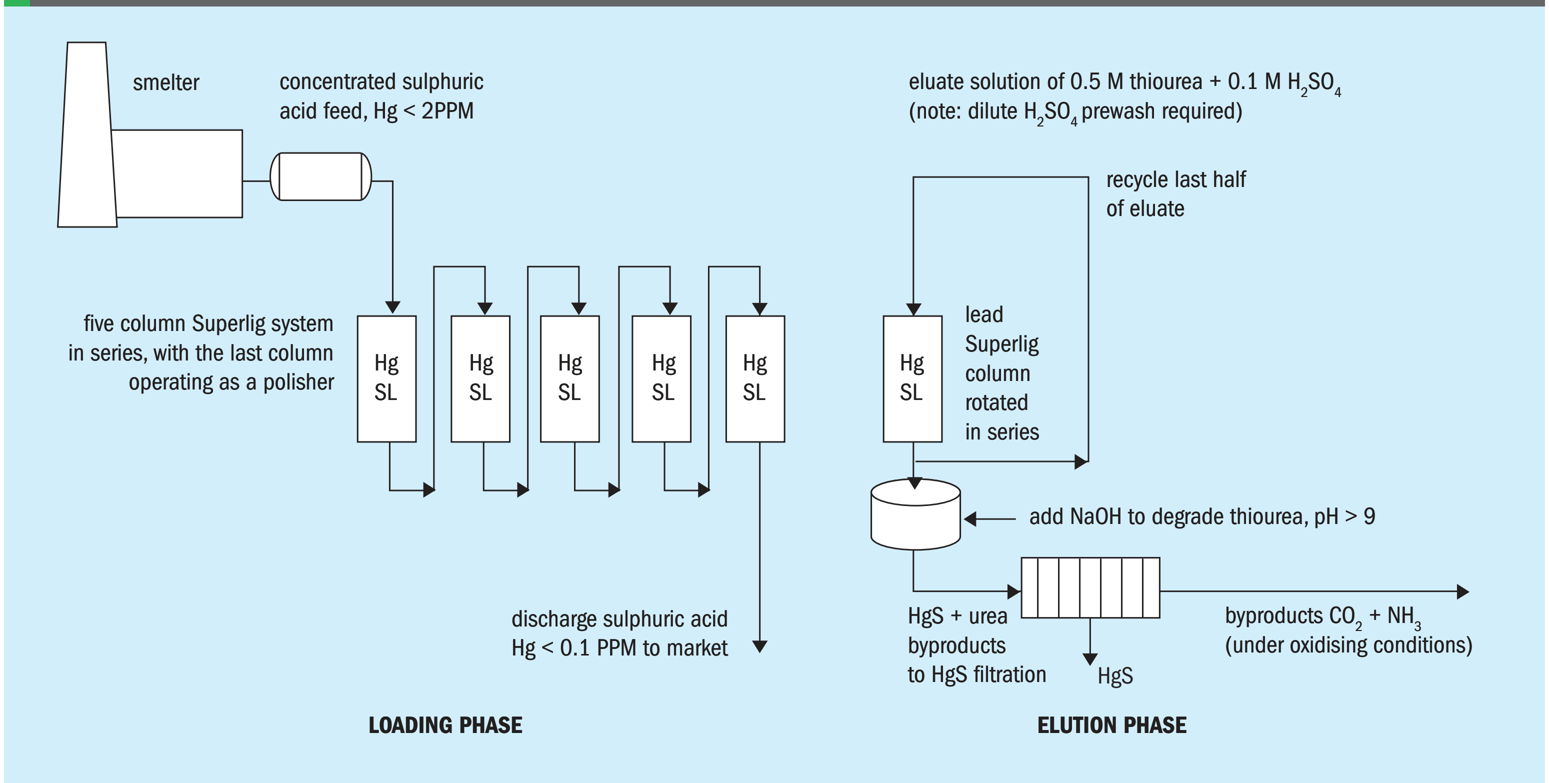
Technip indicates several options to partially recover this heat:

- Partial recovery in the boiler feed water (BFW) preparation and condensates return
- Partial recovery by production of hot water
- Recovery of heat with the production of MP steam.

A fraction of the heat evolved in the acid system can be recovered by reheating the water make-up for the preparation of BFW and the condensates returned to the boiler. The portion of energy recovered is however small and around 10% or less of the total heat to be removed from the acid system.

Heat produced in the acid system from the interpass tower, where acid temperature is high enough, can be used to generate hot water for various users in the sulphuric acid complex. Depending on the process, a significant part of the energy can be recovered in this way when

Fig 3: **Extraction of Hg from concentrated H_2SO_4 at Britannia Zinc, Ltd. using the MRT process in polishing mode**



hot water is used as an alternative to LP steam. In this case, additional steam can be sent to turbo generator for the production of electricity and more power is generated. The process design must however be optimised for the use of hot water rather than LP steam.

The use of a heat recovery system which allows the production of additional MP steam is another efficient way to recover the heat generated by the absorption of SO_3 and the dilution of the acid.

MRT for Hg recovery

IBC Advanced Technologies has developed molecular recognition technology (MRT) which can remove mercury from process streams down to less than 0.1 mg/l. The company's *SuperLig® 88* product has been designed to remove mercury from concentrated sulphuric acid.

Due to its high affinity for sulphur, mercury (Hg) is widely found enriched in sulphide ores of Zn, Pb, Cu, Au and Mn. (*Recovery of mercury from sulphuric acid to sub-mg/l concentration levels using molecular recognition technology*, Neil Izatt et al, IBC Advanced Technologies, Inc.) When these ores are treated in thermal processes, the Hg present volatises and will appear in downstream sulphuric acid and other products. Without any treatment for Hg removal, approximately half of the Hg originally present in the ore will be found in the product acid. The present standard for commercial H_2SO_4 is <1 mg Hg/l, while a content of <0.5 mg/l is required for fertilizer-grade sulphuric acid. Removal of Hg to these levels is challenging. Older-established methods for Hg removal involve gas absorption, which requires high CAPEX and is insufficiently flexible to deal with changes in Hg input levels. Hydrometallurgical processes may also be used for Hg removal, including precipitation, solvent extraction and ion exchange, but these become less effective as the concentration of the metal to be removed decreases. (Fig.3)

The introduction of molecular recognition technology represents a breakthrough in the design of separation systems. These systems involve incorporation by chemical binding of ligands on solid supports such as silica gel or polymer substrates. The supported ligand product is termed *SuperLig®*.

MRT has many advantages over other separation technologies, arising in part from the large ligand-target metal binding energies, rapid reaction kinetics, a high degree of selectivity by the ligand for the target metal, and the ability to carry out selected metal separations and recover pure metals over wide metal concentration levels.

For commercial use, *SuperLig®* products consist of small (0.5 mm) particles which are packed into fixed bed columns. These columns are fully automated for continuous operation and have a small space requirement. MRT processes operate on a system-cycle basis. A complete system cycle consists of the following sequences:

- Loading: the target ion is loaded from feed solution on to a *SuperLig®* product charged into the column.
- Pre-elution wash: any remaining feed solution is washed from the column.
- Elution: the target ion is eluded with a small amount of eluent to form a solution containing the concentrated metal product.
- Post-elution wash: any remaining eluent is washed out of the column, and the cycle begins again.

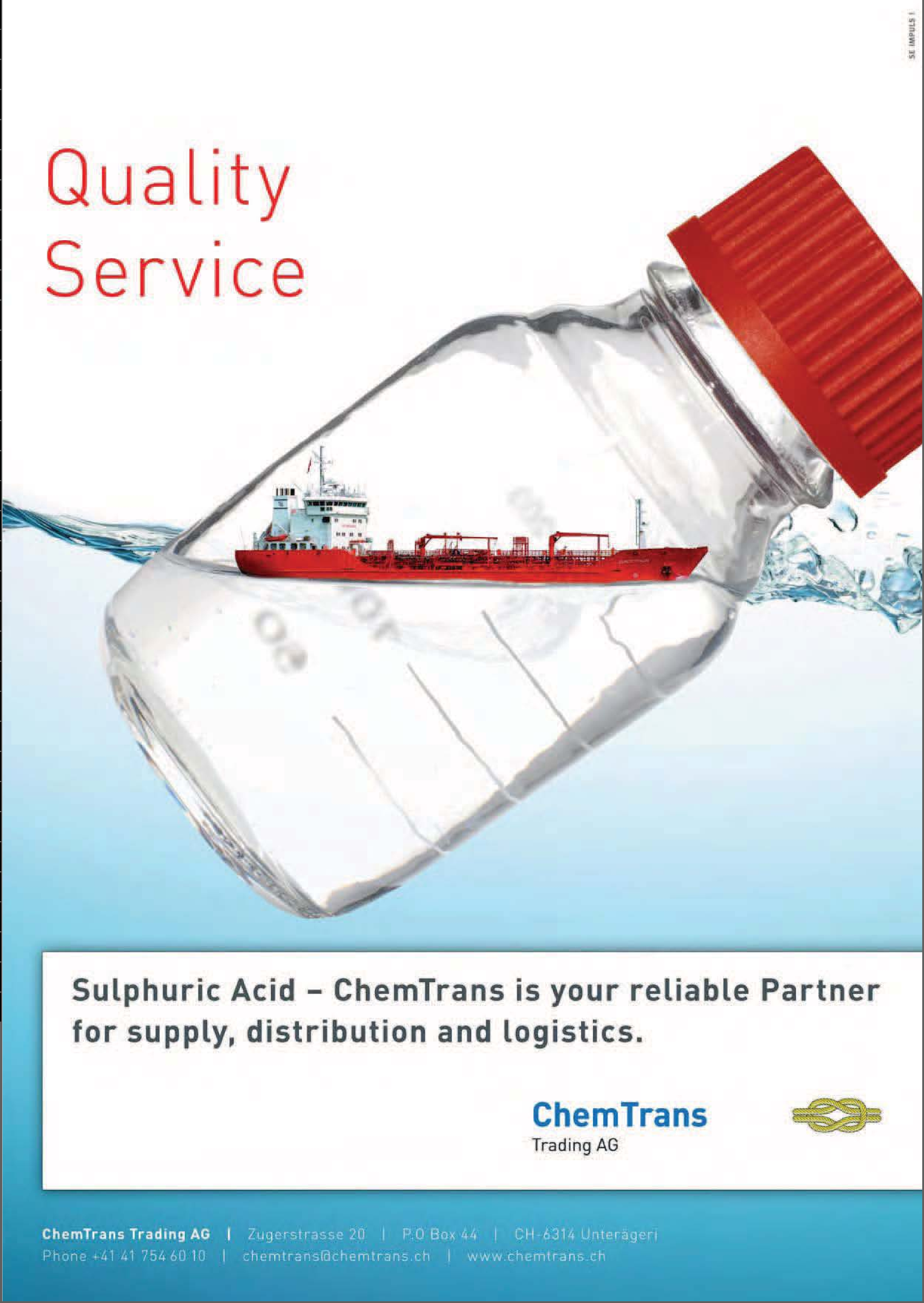
The advantages of the MRT process include:

- Significant improvement in process conditions
- Short process time
- High selectivity for target species
- Operational advantages.

The high selectivity of *SuperLig®* products for Hg^{2+} and Hg_2^{2+} results in large column loading capacities. The MRT process is simple in design and effective over a wide concentration range.

The importance of maintenance

Sulphuric acid plants operate in highly corrosive environments, and regardless of the protection system used, parts of the facility will have to be replaced over time, for example the gas inlet in the drying tow-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ers or quenching towers. A wide variety of materials are available for corrosion protection. These encompass liners, linings using rubber or thermoplastic sheeting and combined systems.

In terms of process technology, sulphuric acid is primarily generated these days using the contact method in which the required SO_2 is produced at a roasting facility in a fluid bed roasting furnace or by combusting S in a sulphur combustion furnace. Due to the reaction temperatures of between 1,200-1,600°C required by the process, these facilities have to be protected with a refractory masonry lining. This lining can become damaged over time, leading to temperature breakouts into the steel and other parts of the process.

The chemical protection required for the steel structure is usually provided by a rubber-lined membrane that is created either as an in-plant manufactured membrane or as one applied on-site. To protect the rubber lining from too extreme temperatures, appropriate protection in the form of masonry has to be applied. An insulating ply of foam glass is applied as a first layer over the rubber lining, while a further ply structure can be made of light refractory brick and, as a contact layer with the media, another of acid-resistant ceramic brick, jointed with potassium silica cement. The nozzle ceiling also has to be lined with these temperature-reducing plies. As an inner ply facing the media, a variety of different brick grades has to be used depending on the temperature. These are generally graphite bricks. In the damp area, the lining will have at least three plies, with the first usually consisting of acid-resistant ceramic brick and the second comprising carbon brick to cope with fluoride conditions.

Irrespective of the corrosion protection system used, parts of the facility will over time inevitably need replacement. The gas inlet in the drying or quenching towers may be particularly vulnerable to long-term damage and will require a new muff, but this is easily achieved. The cement joints in the upper part of the venturi often become washed out. The use of potassium cement ensures greater durability compared with conventional potassium silica cements.

The range of effective corrosion protection materials continues to expand, encompassing liners, linings using rubber or thermoplastic sheeting and combined systems. When failures in the lining occur after a long period of use, any resulting damage can be repaired properly, with minimal downtime.

Table 1: **Typical weld factors with fluoro-thermoplastic welding**

Fluoro-thermoplastic	Polymer thickness, mm	
	No particular permeation load	Increased permeation to expect
PVDF	2.3–3.0	4.0
ECTFE	2.3	3.0–4.0
FEP	2.3	2.8–3.8
PFA	2.3	2.8–3.8

Source: Quadrant EPP

Enhanced materials and installation methods

Linings made from fluoro-thermoplastics have gained increased favour for applications of heavy-duty corrosion protection in sulphuric acid plants. Typical installation methods are liner sheets or liner pipes, reinforced with FRP (fibre-reinforced plastics), structures from mild or stainless steel with bonded fluoro-thermoplastic linings, or liners with mechanical fixation. (*Fluoro-thermoplastic liners for sulphuric acid applications – an update on installations methods and materials*, Mirko Lotz, Quadrant EPP AG, **Sulphur 2014**.)

The criteria when selecting the liner material include chemical resistance and permeation and liner material thickness. Fluoro-thermoplastics possess excellent non-stick properties and low susceptibility for chemical modification. Surface modifications or bond-conferring surface layers are required to achieve sufficient bond strengths in bonded lining applications. For this, knitted fabric backings are used, which need to allow a good embedding into resins and adhesives, but must also allow a facile processing by thermoforming. The fabric backings are directly embedded into the fluoro-thermoplastics and therefore can provide very high bond strengths.

The knitted fabric backings can vary a lot in shape and their properties are product-specific. Knitted fabrics made from glass are available for fluoro-thermoplastics, offering good all-round properties for most applications. Several synthetic fabrics are also available. Standard polyester fabrics are usually used for applications running at less demanding conditions, but these can suffer a hydrolysis by permeating water and potential bond strength loss after time. Special hydrolysis-resistant synthetic fabrics offer improved resistance against permeating strong mineral acids (in particular hydrofluoric and hydrochloric acids). Manufacturing advantages of synthetic knitted fabric backings include an easier weld seam preparation for plastic welding in FRP-duallaminate fabrication and lesser adhesive uptake in bonded steel lining application.

The resins and adhesives used for FRP-duallaminate constructions and bonded steel linings should be chosen appropriately against the background of the process conditions. Major parameters include the resin viscosity, chemical resistance, resistance against hydrolysis and resistance against mechanical impact. Curing conditions can also be important, since many resins for high temperature applications in bonded steel lining also require elevated curing temperatures.

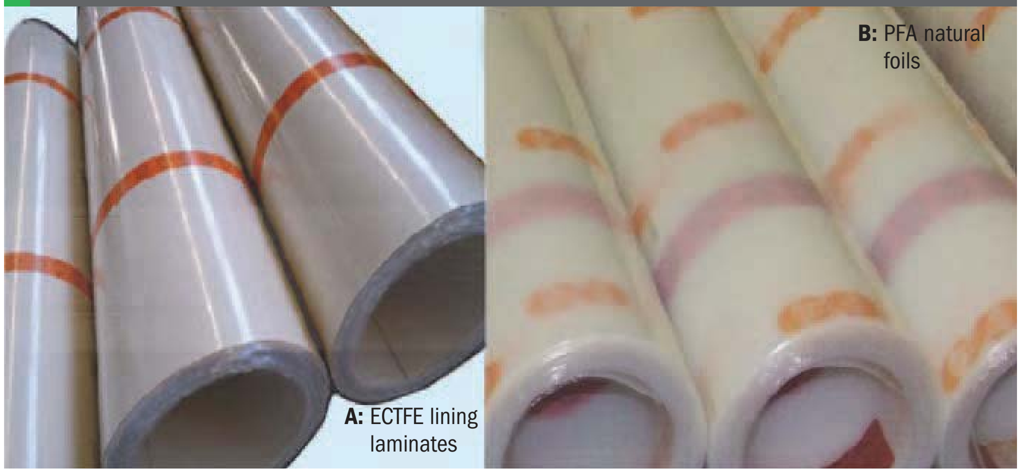
In order to achieve a media-tight lining, the joints between the liner material pieces need to be closed using fluoro-thermoplastic welding. High weld strengths can be reached due to property of the materials to form a liquid melt, and due to the fact that the same polymeric materials are used for the weld rod and the semi-finished products. Table 1 indicates the high weld factors achievable with fluoro-thermoplastic welding.

Fabric-backed (laminates) or non-fabric backed (natural foils) lining materials are usually supplied as rolls, typically in lengths of 10-20 m and widths of 1,250-1,500 mm. Liner pipes can be used as ready fabric-backed pipes or created from lining laminates. The mechanically-softer fully-fluorinated materials FEP and PFA offer the additional advantage of being able to be rolled without thermoforming. (Fig. 4)

The first step in the fabrication of an FRP-duallaminate is the manufacturing of the inner liner from fabric-backed lining laminates or liner pipes, followed by FRP-reinforcement in the second step. FRP-duallaminates can be used for all kinds of outer shapes, tanks, vessels, columns, reactors and pipelines. Linings of flanges and nozzle

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

Fig 4: **Fluoro-thermoplastic lining materials**



regions are usually thermoformed, in order to bring the weld out of the corner region, which further reduces stresses in the weld seams and hence contributes to the long-term resistance of the weld work.

For the manufacture of bonded steel linings, the pieces of lining materials need to be matched into the inner shape of an existing steel structure. For parts with pronounced three-dimensional structure (such as dished bottoms or flanges), thermoforming is required. The vacuum sack method is widely used for holding the liner pieces against the walls during the adhesives' curing time and is also occasionally used for the prior thermoforming. The fluoro-thermoplastic welding is done at the end and from the later media-exposed inside. For PFR and FEP, non-fabric backed cap strips are occasionally used for welding. For partially-fluorinated thermoplastics, like PVDF and ECTFE, no cap strips should be used from the media site, as these materials are unable to take the stresses indicated by this procedure.

Fluoro-thermoplastic linings are excellent materials for applications in sulphuric acid plants, including processes with mixtures with other aggressive and hazardous media. Many lining materials are available, enabling applications with almost every chemical media up to high temperatures. Differences in the chemical processes should be considered for the choice of optimum materials, and the particularities of the installation technologies should be known in order to reach optimum performance of the equipment.

Plastic materials in H_2SO_4 plants

Fully fluorinated polymers such as PTFE, PFA and FEP offer excellent chemical resistance to high concentration sulphuric acid. For most polymers, there is a strong correlation between the maximum concentration and the temperature. The sulphuric acid industry has also turned to FRP as a cost-effective material choice for lower-concentration sulphuric acid of below 80 wt-%. Butyl rubbers can also be used as lining materials on steel.

While polyethylene is not usually recommended for concentrations above 80%, HDPE has been in used sulphuric acid plants at concentrations up to 96 wt-% at low temperatures (at up to about 20°C). Care should be taken when selecting HDPE as possible welds and internal stresses could influence the material suitability. (*Plastic materials for sulphuric acid services*, Karin Jacobson et al, Swerea KIMAB AB, **Sulphur 2014**.) ECTFE generally performs better than PVDF at high H_2SO_4 concentrations and is not considered to be as sensitive to stress corrosion cracking as PVDF.

Acid plant retrofits

A strong sulphuric acid system (>80 wt-% H_2SO_4) is necessary for the formation of sulphuric acid via the hydration reaction of SO_3. The system is also required to carry out the mass transfer operations that capture water from ambient air or process gas in drying systems. (*Strong sulphuric acid system upgrades – opportunities in acid plant* retrofits, Andrés Mahecha-Botero et al, NORAM Engineering & Constructors, **Sulphur 2014**.) Typically, acid plants have 2-4 strong acid towers with continuous exchange of acid to maintain certain concentrations and temperatures constant. Strong acid systems include:

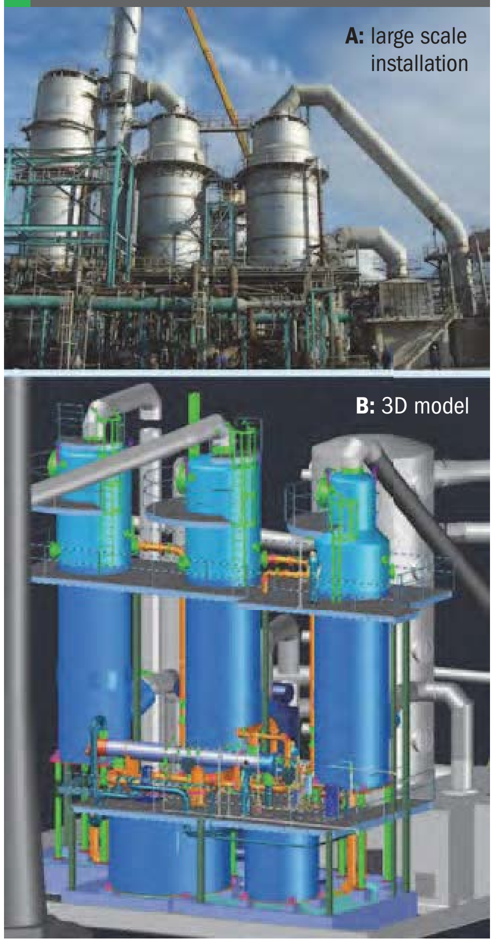
- Drying acid systems (absorption of H_2O into H_2SO_4)
- Interpass absorption acid systems (SO_3 into H_2SO_4)
- Final absorption acid systems (SO_3 into H_2SO4).

A strong acid system can be upgraded to reduce the emissions to the environment. These upgrades include modifications to the interpass system to reduce SO_2 emissions via improved catalyst equilibrium, and minimising the mist carryover of the existing tower. With upgrades of final acid absorption system, a separate final acid pumping loop eliminates SO_2 stripping from the final acid tower. (Fig. 5)

A plant upgrade from single-absorption to double-absorption technology can reduce stack emissions from 2,000-10,000 ppm (with SO_2 capture rates of 97+%) to 50-400 ppm (SO_2 capture rates of 99.7-99.95+%). Double-absorption technology offers several advantages, including zero losses of water from the plant stack, no production of by-products or waste, no requirements for scrubbing chemicals, no steam consumption, and lower operating costs. To upgrade a plant to double-absorption, the plant hydraulics should be reviewed to accommodate the additional pressure drop in the order of 7.4 to 12.5 kPa. Compared with a single-absorption plant, there is some reduction in available energy for recovery.

New equipment will be required for the final absorption system, including a new gas-to-gas heat exchanger(s) and a new acid

Fig 5: **NORAM absorption systems**



system. The duty of the existing absorption system typically does not change significantly, and it can be used as an interpass absorption system. However, a new acid tower is required for the conversion to double-absorption, as is a new cooler to remove the heat of SO_3 absorption from the product sulphuric acid and to cool the process gas. Also required are a new acid circulation pump and new acid piping. The SO_2 conversion capability must be reviewed under the upgraded conditions, and increased catalyst volumes are required to achieve the new emissions targets.

Among other upgrades for increased capacity and debottlenecking, the acid plant gas hydraulics can be debottlenecked by reducing the pressure drop of the acid towers. When the capacity of an acid plant is increased, there is an associated increase in duty in the acid system. This can be addressed by increasing the heat removal from the acid coolers. The energy recovery of the acid plant can be increased by modifying the existing acid systems, including changing the location of the dry tower and optimising acid tower inlet temperature.

NORAM Engineering and Constructors Ltd. specialises in system and equipment upgrades. Typical projects deal with upgrades (such as upgrading from single to double absorption) and upgrades for equipment replacement. Some of the NORAM advances in sulphuric acid technology include:

- The NORAM HP™ Saddle, with a 50% reduction in pressure drop compared to standard saddles.
- The Smart™ acid distributor, which allows external clean-out.
- NORAM acid towers and pump-tanks, with high-performance internals and high reliability. These can be lined with acid-resistant bricks or made of NORAM SX alloy.
- The Radial Flow Hot Sweep Cold Exchanger, with significantly less fouling than conventional cold exchangers.
- The Radial Flow Hot Sweep SO_3 Cooler, which reduces the size of the blower, exchanger and ducting by reduced air recycle flow to keep metal temperatures above the dew point.
- The Radial Flow Cold Sweep Preheater Exchanger, which reduces the size of the blower, furnace and exchanger by allowing a higher furnace temperature while keeping the metal temperatures within acceptable limits.
- The NORAM converter, which reduces the diameter required for the same cross sectional area compared to converter designs with a centre support column.
- The NORAM AP acid cooler with the improved cathode design, which provides better passivation protection.
- NORAM SX alloy equipment for strong sulphuric acid service, including acid towers, pump-tanks, acid coolers, acid piping and acid distributors.
- The NORAM sulphur burner for small- to world-scale SO_2 production. NORAM currently supplies pressure-atomised and air-atomised sulphur combustion furnaces. This includes cyclone-flame and spiral-flame Cellchem burners and complete SO_2 plants.
- NORAM can also supply tail gas scrubbing solutions *Turboscrubber®* technology.

NORAM can also provide engineering services and equipment to upgrade metallurgical, sulphur-burning and spent acid regeneration sulphuric acid plants, to achieve higher reliability, lower emissions, increased capacity and improved energy utilisation.

Who's who in plant revamping

We profile the principal players in the fertilizer plant refurbishment and modernisation business

Why revamp?

The growing number of fertilizer plant revamps in recent years has been driven by factors such as rising feedstock prices and increasingly stringent emissions standards. For producers, plant modernisation delivers the dual benefit of higher capacity and improved energy efficiency. Adopting the latest production technologies also offers the opportunity to remove plant bottlenecks and improve reliability. But securing a prompt return on investment also means keeping capital outlay low and production interruptions to a minimum.

The revamp market is potentially lucrative with sums invested by some fertilizer producers running into the hundreds of millions each year. Uralchem, for example, spent $174 million upgrading infrastructure and technology in 2013 alone, as part of a long-term investment programme. Fortunately, payback on revamp investments can be rapid. Ostchem's $18.2 million investment in the overhaul of the Cherkassy Azot fertilizer complex in 2013 probably paid for itself in just over a year. CRU calculated that reduced natural gas consumption and power savings at the revamped complex would deliver annual cost savings of $15 million.

Contractors and licensors

The delivery of a revamp project usually requires an engineering, procurement and construction (EPC) contractor, ThyssenKrupp and SNC-Lavalin are two examples, working in tandem with a technology licensor, such as Stamicarbon and Prayon. The divisions between contractor and licensor are frequently blurred though. Some licensors, such as Casale and KBR, also have strong EPC capabilities and so are able to fully implement and execute projects on their own. The breadth of expertise possessed by large conglomerates is also advantageous. ThyssenKrupp, for example, is both an EPC contractor and the licensor of Yara's urea granulation technology globally – as well as possessing its own patented technology for ammonia plant revamping.

The initial stage of a revamp typically involves the owners of proprietary technology securing a licence and either a Process Design Package (PDP) or Front End Engineering Design (FEED) contract from the plant operator. A cost estimate for the revamp project to show whether it is commercially feasible is also usually provided at this stage.

Ammonia

As a market leader in ammonia technology with over 200 plants worldwide, Houston-based KBR, formerly Kellogg, Brown & Root, believes it is well positioned to capitalise on the demand for plant revamps. It expects revamp opportunities will continue to arise in regions with high production and feedstock costs as plant operators seek to make energy efficiency improvements.

KBR has carried out around 80 ammonia plant revamps since 1990 (*Fertilizer International* 448, p36). The need to increase plant capacity, reduce energy consumption, cut maintenance costs and meet more exacting environmental/emission standards have been the main drivers for this.

KBR's ammonia plant revamps in China, India and elsewhere – using proprietary *KRES* (KBR Reforming Exchanger System) and *PURIFIER* process technologies – have typically increased plant capacity by up to two fifths and cut energy consumption to levels close to that achieved by new grass-roots ammonia plants.

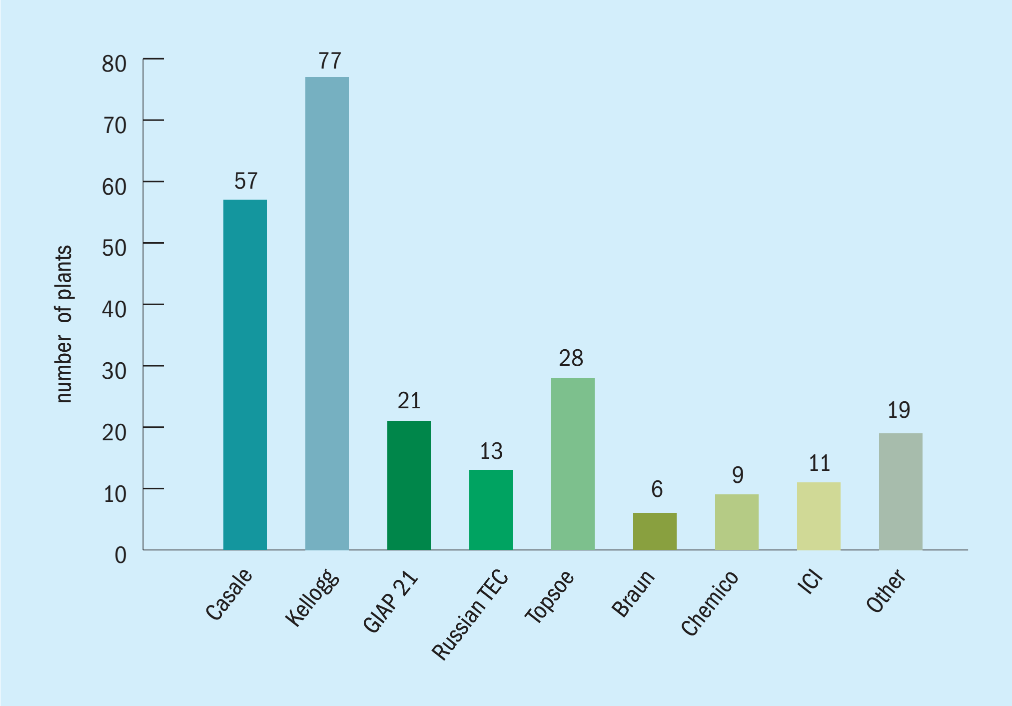
KRES is used to revamp the reforming section of an ammonia plant. It boosts front-end capacity for raw synthesis gas by working in parallel with conventional primary and secondary reformers. *KRES* captures the high-temperature process heat that exits the secondary reformer and produces syngas from this by reforming an additional flow of natural gas and steam. *KRES* revamps are typically able to increase ammonia plant capacity by a quarter and delivering an energy saving of 0.13-0.60 Gcal/tonne, according to KBR figures. The technology is tried and tested having been in operation at ammonia plants in Methanex, Canada, since 1994 and in Liaohe, China, since 2003

KRB also offers KRES-Energy Substitution (*KRES-ES*) as a low cost, revamp solution for ammonia plant where the supply of natural gas is either expensive or uncertain. The technology can dramatically reduce dependence on natural gas whilst maintaining or boosting ammonia production capacity. By adding a new reforming exchanger to the existing primary and secondary reformers, KBR claims that *KRES-ES* can reduce natural gas consumption to less than 6.35 Gcal/tonne of ammonia. However, plants revamped using *KRES-ES* do requires the import of additional steam (and oxygen) sourced from either a fossil fuel or non-fossil source. *KRES-ES* revamps of two ammonia plants have boosted production by 61,200 t/a and 149,600 t/a with a payback period of 2-3.2 years, respectively, according to KBR.

Adding KBR's *PURIFIER* cryogenic gas purification system to an existing plant removes bottlenecks from the ammonia synthesis loop and saves energy. It simultaneously removes impurities such as methane, argon from synthesis gas by washing with excess nitrogen and adjusts the hydrogen to nitrogen ratio to 3:1.

KBR says there is potential for further revamps of Kellogg-type ammonia plants in India – even though nearly all of these have already been upgraded to operate 30-80% above nameplate capacity (*Nitrogen+Syngas* 334, p31). Revamp options include *KRES*, improving CO_2 removal, add-on reactors for

Fig 1: **Casale ammonia revamp projects since 1985, by technology**



ammonia synthesis and refrigeration system improvements.

KBR has secured two major revamp projects in the last 12 months. In December, Mosaic awarded KBR a licensing and FEED contract for the expansion of its St James ammonia plant, south of Baton Rouge, Louisiana. KBR will advise on how to debottleneck the KBR-designed plant and increase ammonia production capacity by 20% using its proprietary technology. This followed the award of a similar licencing and engineering contract from Algerian fertilizer producer Fertial in September last year. KBR will supply technology to improve reliability and increase production capacity and energy efficiency at Fertial's two ammonia plants.

In July 2013, the Togliattiazot Corporation (ToAZ) selected KBR to carry out a preliminary revamping study on its seven ammonia plants in Togliatti, Russia. ToAZ asked to KBR to evaluate the plants and identify bottlenecks prior to licensing KBR technology. The revamp of these seven plants would be world's largest ammonia upgrade project, if and when it happens.

In January 2013, KBR secured a basic engineering design and licencing contract from Hungarian producer Nitrogenmuvek for the revamp of its Petfurdo ammonia plant. KBR will increase capacity of the 1970s plant from 1,000 t/d to 1,650 t/d whilst cutting energy consumption.

Black & Veatch have secured major EPC contracts for four US ammonia plant revamps since 2011. These include revamps for two PCS (PotashCorp) plants in Augusta, Georgia, and Lima, Ohio, as well as engineering overhauls at Koch Nitrogen's Enid Oklahoma plant and Rentech Nitrogen's East Dubuque, Illinois facility.

The potential for revamping the "several dozen" GIAP ammonia plants built in Russia and other parts of the Soviet Union in the 1970s was outlined by **ThyssenKrupp** at this year's Nitrogen+Syngas conference in Istanbul (*Nitrogen+Syngas 334, p31*). ThyssenKrupp's revamp of one such plant in 2010 – Kuibyshev Azot's Togliatti plant – increased production to 1,800 t/d, a 12.5% production increase and 32% above nameplate capacity. The revamp added an extra ammonia converter to the synthesis loop, operating in parallel to the existing converter.

Haldor Topsøe has an established track record of ammonia plant revamps, particularly in India. The Danish catalysis firm offers a debottlenecking solution for reforming sections known as *HTER*, the Haldor Topsøe Exchange Reformer (*Fertilizer International 448, p36*). Installing an *HTER* unit in parallel with the primary reformer of an ammonia plant can boost production capacity by as much as quarter. Similar to KBR's KRES technology, *HTER* extracts reaction heat from the exit gas of the secondary reformer and utilises this waste heat for the reforming process instead of for high-pressure steam production. *HTER* is well-suited for large, standalone ammonia plants (4,000-5,000 t/d) as it offers an excellent way of reducing steam export.

Haldor Topsøe also markets the *S-300* ammonia converter – an innovative three-bed, radial flow design converter with inter-bed heat exchangers – as an efficient, high-performance replacement for conventional bottle-shaped, two-bed converters.

Ammonia revamps have become **Casale's** core business since it first helped pioneer plant revamping as a business concept thirty years ago. The company has been instrumental in several breakthrough technologies, including the development of hybrid axial-radial flow catalyst beds in reactor design. Casale regards itself as the market leader in the design of ammonia synthesis reactors and related process technologies.

Impressively, Casale has revamped 241 ammonia plants globally since 1985. These encompass a wide range of technologies (Figure 1). Opportunities for revamping Russian GIAP and TEC technology plants were highlighted by Casale at this year's Nitrogen+Syngas conference (*Nitrogen+Syngas 334, p31*). A recent root-and-branch revamp by Casale of a 40-year old TEC plant at Nevinnomyssk in the south of Russia increased production to 2,000 t/d from a nameplate capacity of 1,350 t/d.

Casale's reputation as a leading revamp contractor and licensor is confirmed by BCInsight's 2015 nitrogen project list (*Nitrogen+Syngas 334, p34*). Although not exhaustive, this snapshot of current nitrogen projects reveals that the Swiss-based firm is a contractor for over 20 ammonia and urea revamp projects globally, with activity in Russia, Eastern Europe and China particularly strong (Table 1). Casale acts as both licensor and contractor for many of these projects but also works in tandem with other technology licensors such as NIIK in Russia as well as KBR, ThyssenKrupp, UFT and Haldor Topsoe elsewhere.

Urea

Casale is also a strong player in the urea plant revamp market. Its *Split Flow* and *Full Condenser* technologies are proven, effective technologies for boosting CO_2 stripping plant capacity. Casale has also developed *VORTEX* granulation technology as a way of raising urea prilling plant capacity .All three proprietary innovations were successfully installed in a Chinese urea plant for the first time last spring (*Fertilizer International 465, p29*). The aim was to boost production capacity from 1,500 t/d to 1,740 t/d on average.

Table 1: **Nitrogen revamp project listing 2015**

Contractor	Licensor	Company	Location	Country	Product	mt/d	Date
CASALE							
Casale	Casale	Koch Nitrogen	Brandon	Canada	Urea	700	2016
Casale	Casale	Inner Mongolia Manshi	Erdos	China	Ammonia	1,630	2016
Casale	Casale	Air Liquide China	LianJiang	China	Ammonia	890	2015
Casale	Casale	Henan Junhua	Zhumadian, Henan	China	Ammonia	2,000	2016
Casale	Casale	Henan Jinkau	Kaifeng, Henan	China	Ammonia	2,000	2016
Casale	Casale	Shenua Ningxia	Ningxia	China	Ammonia	500	2016
Casale	Casale, UFT	Borealis Chimie	Grandpuits	France	Urea	850	2016
Casale	Casale	Krubhco	Shahjahanpur	India	urea	1,310	2015
Casale	Casale, INS	Grupa Azoty	Kedzierzyn	Poland	Ammonia	1,350	2015
Casale	Casale, Topsoe	Grupa Azoty	Police	Poland	Ammonia	950	2014
Casale	Casale	Grupa Azoty	Pulawy	Poland	Urea	2,000	2015
Casale	Casale, Toyo	EuroChem	Novomoskovsk	Russia	Ammonia	1,700	2015
Casale/NIIK	Casale/NIIK	EuroChem	Novomoskovsk	Russia	Urea	2,000	2014
Casale/NIIK	Casale/NIIK	EuroChem	Nevinnomyssk	Russia	Ammonia	2,000	2014
Casale/NIIK	Casale/NIIK	Kuibyshev Azot	Togliatti	Russia	Ammonia	1,340	2015
Casale	Casale	PhosAgro	Cherepovets	Russia	Ammonia	1,700	2015
Casale	Casale	Togliatti Azot	Togliatti	Russia	Ammonia	1,200	2015
Casale	n.a.	Togliatti Azot	Togliatti	Russia	Urea	2,600	2017
Casale	Casale, ThyssenKrupp I.S.	Fertiberia	Puertollano	Spain	Ammonia	600	2015
Casale	Casale	PCS Nitrogen	Point Lisas	Trinidad & Tobago	Ammonia	1,150	2015
Casale	Casale, KBR	PCS Nitrogen	Lima, OH	USA	Ammonia	1,650	2015
Casale	Casale	Rentech Nitrogen	East Dubuque, IL	USA	Ammonia	1,180	2016
Casale	Casale	El Dorado Ammonia	El Dorado, AR	USA	Ammonia	1,210	2016
Casale	Casale	Severodonetsk Azot	Severodonetsk	Ukraine	Urea	1,600	2015
Casale	Casale	OJSC Maxam Chirchiq	Chirchick	Uzbekistan	Ammonia	1,500	2015
CHEMOPROJEKT							
Chemoprojekt	Casale	Azomures	Targu Mures	Romania	Ammonia	2 x 1,050	2016
Chemoprojekt	Stamicarbon	Azomures	Targu Mures	Romania	Urea	1,425	2016
Chemoprojekt	Haldor Topsoe	Duslo Sala	Sala	Slovakia	Ammonia	1,600	2018
Chemoprojekt	Stamicarbon	Duslo Sala	Sala	Slovakia	Urea	900	2014
NIIK							
NIIK	NIIK, Stamicarbon	Minudobrenija Perm	Perm	Russia	Urea	1,720	2016
NIIK	NIIK	PhosAgro	Cherepovets	Russia	Urea	1,600	2015
NIIK	NIIK, Topsoe	JSC Acron	Novgorod	Russia	Urea	4 x 2,000	2015
KBR							
n.a.	KBR	Huajin	Kuche, Xinjiang	China	Ammonia	1,500	2014
KBR	Stamicarbon, UFT	Agrium	Borger, TX	USA	Urea	1,800	2015
KBR, Casale	KBR, Casale	Agrium	Borger, TX	USA	Ammonia	1,900	2016
BLACK & VEATCH							
Black & Veatch	KBR, Casale	Koch Nitrogen	Enid, OK	USA	Ammonia	1,680	2016
THYSSENKRUPP							
ThyssenKrupp I.S.	UFT	EFC	Ain Sukhna	Egypt	Urea	2,250	2015

Casale strengthened its market position last July by buying a majority stake (60%) in Czech urea plant revamp specialists Chemoprojekt. Safichem Group holds the remaining share. In January, Casale also added to its downstream capabilities by acquiring proprietary process technologies for nitric acid, AN and UAN production and fertilizer granulation from Borealis (*Nitrogen+Syngas, 333, p10*).

Stamicarbon, part of Italian parent group Maire Tecnimont, has more than 60 years experience in the development and licensing of urea technology. Its technology is currently employed in more than 260 urea production plants globally. The 90 revamp and debottlenecking projects carried out to date make Stamicarbon the major international player in urea plant modernisation.

Stamicarbon's main innovation in recent years has been the introduction of its *Urea 2000plus* technology. This improves on Stamicarbon's well-known CO_2 stripping process by introducing either a high-pressure pool reactor or a high-pressure pool condenser combined with a smaller vertical reactor. *Urea 2000plus* simplifies overall urea plant design, pipework and construction and its horizontal configuration substantially reduces plant height.

> **The breadth of expertise possessed by large conglomerates is advantageous.**

In February, Stamicarbon agreed to license *Urea2000plus* production technology to Russian nitrogen fertilizer manufacturer Uralchem as part of a major contract to modernise the PMF urea plant in Perm. This was originally constructed in 1981 using technology supplied by Japan's Toyo Engineering Corporation. Subsequent modernisation of the ammonia unit in 2009 increased production to 1.650 t/d. The current RUB4.2 billion revamp project is expected to boost the plant's performance from 1,930 to 2,700 t/d and increase annual production capacity by 40% to 250,000 t/a when its completed in 2019. NIIK is also involved in the project as a subcontractor.

Stamicarbon, as a leading licensor of urea process technology, has partnered with a number of EPC firms. KBR is authorised to license Stamicarbon's urea plant technology to its clients, for example. Chemoprojekt has also been entitled to build urea plants using Stamicarbon's CO_2-stripping technology under a long-standing licence agreement dating back to 1969.

Chemoprojekt is a recognised contractor for Stamicarbon's *Urea 2000Plus* and *AVANCORE* production processes. In August 2013, Stamicarbon signed a licensing and PDP deal with Chemoprojekt for the revamp of the Azomures urea melt plant at Targu Mures, Romania. The existing 1970s design is being replaced by Stamicarbon's *Urea 2000Plus* pool reactor as part of a revamp to increase capacity from 900 t/d to 1,425 t/d. Casale subsequently announced it had secured the EPC contract to revamp Azomures' two ammonia plants. Azomures went on to secure €66 million of loan finance for the urea plant's modernisation in May last year.

In 2012, Stamicarbon also signed a licensing and PDP contract with Chemoprojekt for the revamp of a urea plant in Sala, Slovakia, operated by Duslo, part of the Agrofert Group. Modernising the plant using Stamicarbon's *Mega Plant* technology and *Safurex* high pressure steel equipment should increase the plant's capacity from 600 to 900 t/d.

Stamicarbon also agreed a licence and process design contract with the engineering firm First Global to revamp a urea plant operated by Iraq's State Company for Fertilizer North Area (NFC) in Baiji. The contract is currently on hold but would have seen the capacity of the 1989 Stamicarbon-designed CO_2–stripping plant expanded from 1,750 to 2,200 t/d..

Three technologies developed by **NIIK** have extended the working life on many urea plants in Russia and other CIS states. These proprietary technologies, *URECON 2006*, *URECON 2007* and *90 bar stripping*, all use internal heat recovery to improve urea plant energy efficiency (*Fertilizer International 458, p32*). Other recent advances in revamp technology by NIIK include a high-speed drum granulation method, for increasing urea plant capacity and improving urea quality, and an energy-efficient vortex mixer for urea reactors (*Nitrogen+Syngas 334, p31*).

NIIK is a contractor on at least three Russian urea revamps currently. It is also a licensor for a further three Casale revamps in Russia at present (Table 1).

Netherlands-based **Uhde Fertilizer Technology** (UFT), established in 2005 as a subsidiary of German industrial conglomerate ThyssenKrupp, is a leading licensor of urea fluid bed granulation technology. It has extensive experience in building and revamping urea granulation plants and holds exclusive worldwide rights for Yara's *YFT* (Yara Fertilizer Technology) fluid bed urea granulation technology. Its market share of urea fluid bed granulation plants worldwide is more than 80%, based on installed capacity. The company works with leading engineering contractors such as KBR, Maire Tecnimont (Stamicarbon), Technip, Saipem and Chiyoda corporation.

In the last four years, ThyssenKrupp has revamped two urea plants in Suez, Egypt, for the Egyptian Fertilizer Company and increased the production capacity of each from 1,925 to 2,250 t/d (17%) (*Nitrogen+Syngas 334, p31*).

Phosphoric acid

SNC-Lavalin's long track record of engineering refurbishments includes 30 phosphoric acid plant revamps. The Canadian construction and engineering giant works closely with technology licensors Prayon and Yara. SNC-Lavalin has successfully modernised phosphoric plants operating under Technip (formerly Rhône-Poulenc) and Nissan licences by upgrading to Prayon's *Mark 4 DPP* (Dihydrate Prayon Process).

In 2010, SNC-Lavalin restored a Jordanian phosphoric acid plant for the Indo-Jordan Chemicals Company (IJC). The revamp boosted the plant's production to 30% above nominal 700 t/d capacity with the help of Yara, who originally licensed the single stage hemi-hydrate process to IJC. Also in 2010, SNC-Lavalin won a contract to upgrade phosphoric acid plants at OCP's Jorf Lasfar complex (Maroc Phosphore 3 and 4) to *Mark 4 DPP* technology by installing new reactors, agitators and flash coolers. This boosted production to 1.72 million t/a P_2O_5. SNC-Lavalin also adapted the complex to receive phosphate slurry feed from the new Khouribga-Jorf Lasfar pipeline.

The firm previously carried out similar *Mark 4 DPP* upgrades on four of OCP's Rhône-Poulenc process phosphoric plants at the Maroc Chimie complex in Safi and improved flue gas emissions by installing best available technology (BAT). SNC-Lavalin and Prayon's modernisation of the Indo Maroc Phosphore (IMACID) phosphoric acid plant at Jorf Lasfar – a joint venture between OCP, Biria Group and Chambal – increased P_2O_5 production by 40% to 1,400 t/d.

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46
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Table 2: Sulphuric acid revamp project list 2015

Contractor	Licensor	Company	Location	Country	Application	Capacity	Date
n.a.	Grillo Werke	Grillo Werke	Duisberg	Germany	Spent acid regeneration	+120 t/d	2015
Outotec							
Outotec	Outotec	Nyrstar	Port Pirie	Australia	Smelter off-gas	n.a.	2015
Outotec	Outotec	Codelco	Potrerillos	Chile	Smelter off-gas	n.a.	2016
Outotec	Outotec	Ural Mining	Svyatogot	Russia	Smelter off-gas	n.a.	2018
Outotec	Outotec	Norilsk	Nadezhda	Russia	Smelter off-gas	n.a.	2015

Sulphuric acid

SNC-Lavalin has extensive experience installing DuPont's *MECS* (Monsanto Enviro-Chem Systems) sulphuric acid plant technology. This system has been used to design more than 1,000 plants across 56 countries globally.

Notably, SNC-Lavalin modified EuroChem's Belorechensk sulphur-burning sulphuric acid plant between 2010 and 2013, installing a heat recovery system and expanding capacity from 1,600 to 2,940 t/d. The firm had previously increased the production capacity of EuroChem's Kingisepp sulphuric acid plant from 2,074 to 2,940 t/d by installing MECS as part of a 2007 revamp.

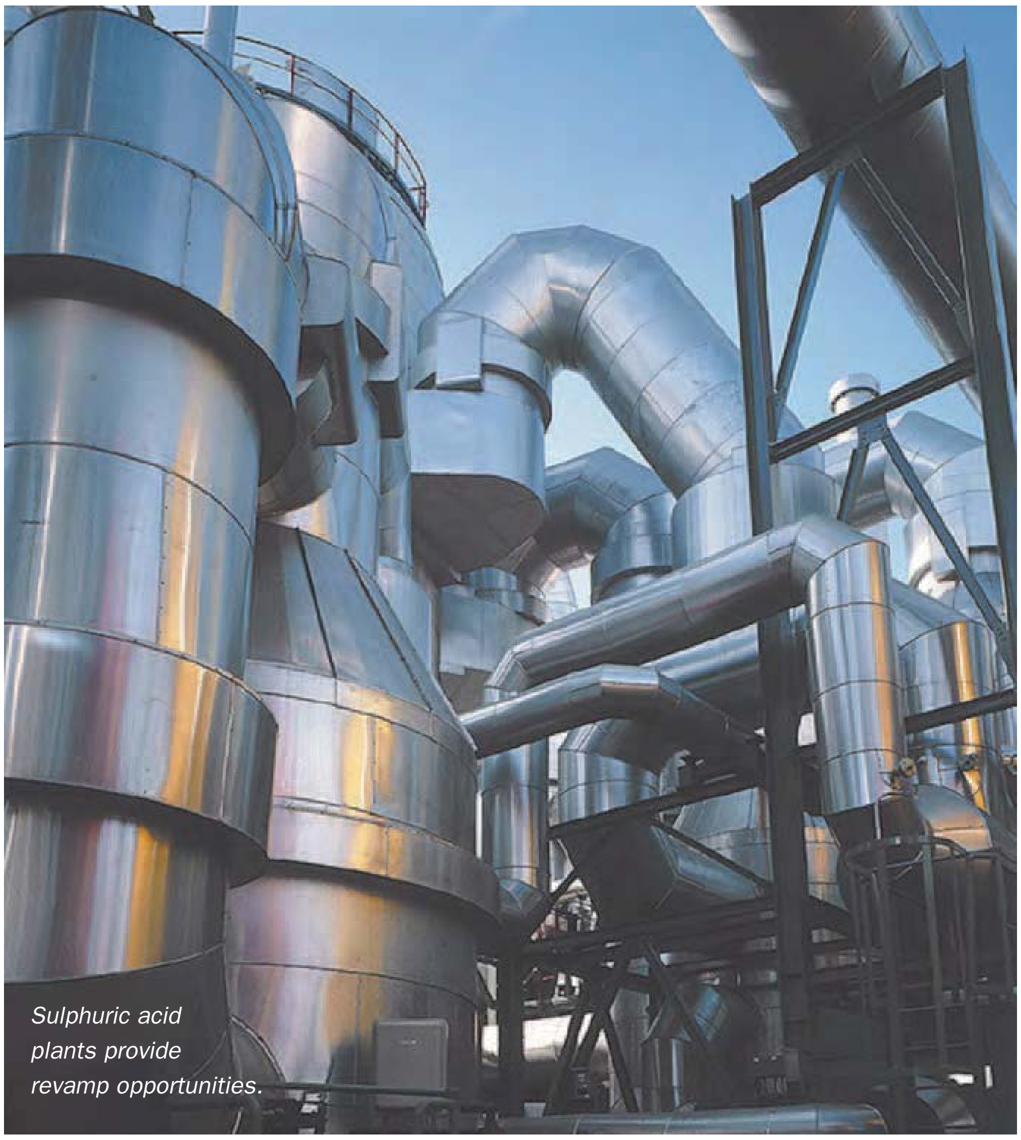
EuroChem also brought in SNC-Lavalin for the revamp of its Novomoskov NPK plant in Russia. The existing 3 NPK lines, based on Peck technology, were reconfigured in 2009 to produce 1,200 t/d of CAN and the plant's granulators upgraded by the installation of a fluidized bed. SNC-Lavalin purchased equipment and provided know-how, basic engineering and technical assistance for the project during construction and commissioning.

The 650 sulphuric acid plants installed by **Outotec** worldwide accounts for over one third of global capacity, making it a leader in sulphuric acid plant design and construction. Part of the Finnish Outokumpu Group, the firm is currently revamping four sulphuric plants for which it is both the licensor and contractor (Table 2).

Potash

Over the last decade, London-headquartered **AMEC Foster Wheeler** have established themselves as engineering, procurement, and construction management (EPCM) specialists for potash debottlenecking. AMEC provided EPCM services for PotashCorp's CDN$1.7 billion expansion of its Lanigan, Cory, Rocanville and New Brunswick operations in Canada. Debottlenecking, rehabilitation and other modifications increased annual production at Cory to 3.0 million t/a, brought back 1.5 million t/a of idle capacity at Lanigan and boosted production at Rocanville by 700,000 t/a. The Penobsquis facility at New Brunswick was also expanded by 1.2 million t/a.

In 2008, **Hatch** secured a CDN$500 million contract with Mosaic for debottlenecking and upgrading the potash mill and mine production facilities at Colonsay Saskatchewan, Canada. The contract covered, feasibility and EPCM services needed to execute the project. The 1.1 million t/a expansion of Colonsay's facilities, which date from the late 1960s, is due to be completed this year. Mosaic also awarded Hatch a separate CDN$500 contract to expand production at its K1 and K2 Esterhazy potash mines in Saskatchewan. This project will expand production capacity at Esterhazy from 5.3 million t/a to 7.1 million t/a by 2017.



Sulphuric acid plants provide revamp opportunities.

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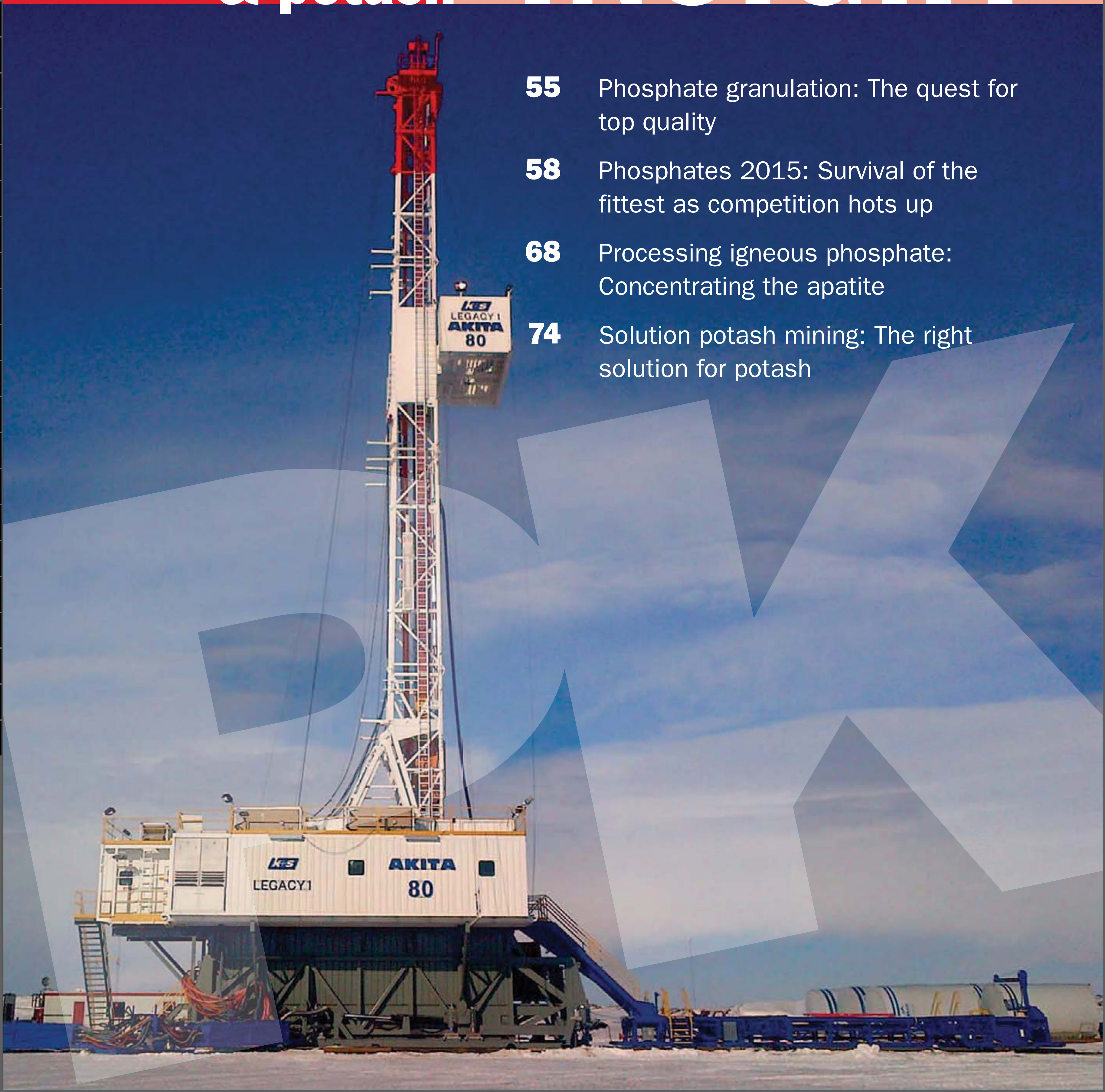


The quest for top quality

Curtis Griffin, Process Engineering Supervisor, PegasusTSI, outlines the history of phosphate granulation and describes the latest state-of-the-art technologies.

The use of phosphate as a fertilizer can be traced back to the mid-19th century, when it was discovered that P promoted growth in plants and animals. The earliest phosphate fertilizers were derived from the crushed bones of animals. Phosphate rock was first mined in England for use as a fertilizer, while the first discovery of Florida's rich resource of phosphate pebbles was made in 1881. Production of mono-ammonium phosphate (MAP) began in 1920, while production of granular superphosphates by the Oberphos process began in around 1929.

In the 1950s, fertilizer manufacturing facilities were relatively small and produced fertilizers tailored to the soil needs of local farmers, generally within a 100-mile radius. The Tennessee Valley Authority (TVA) undertook basic laboratory and pilot plant work on the production of diammonium phosphate (DAP) in the early 1950s, culminating in the patenting of the ammoniator-granulator. TVA's work resulted in larger-scale production, and many of the ammoniator-granulator's concepts are still used today. (Fig. 1)

Early technology and processes

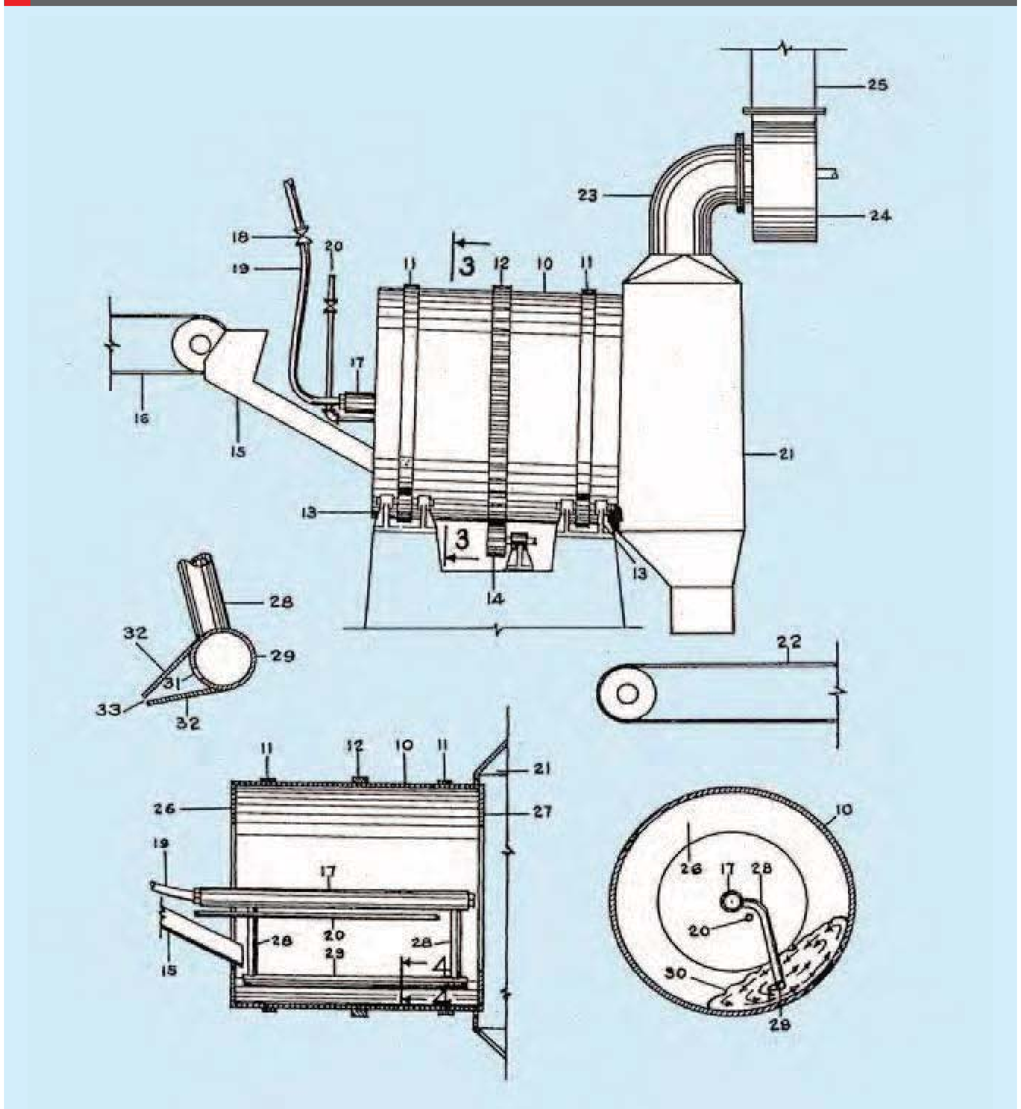
The Eyman process uses a batch mixer with modified flights and a special sparger for the ammoniation of the solution. Either superphosphate or potash is used in granular form in the desired size range, which is then combined with ammoniated solutions containing 6% water. Sulphuric acid is used as needed to provide the heat of reaction for drying. The formulation supplies just enough liquid to cement the fines in a thin layer on the original granules. The granular product from the batch mixer is cooled in a rotary cooler and then goes to storage.

In the Glaspey process, the batch mixer is used for ammoniation only and granulation takes place in a dryer operated at high temperatures. The formulations are designed to avoid the generation of sticky mixtures that could cause operational issues. Less sulphuric acid is used than in other processes, as the ammoniating solutions have lower water content. Granulation takes place in the dryer, as the low temperature in the batch mixer prevents granulation. A higher temperature in the dryer is used to fuse soluble salts and produce enough liquid phase for granulation.

The Davison Trenton process is the best-known method that uses a pug mill ammoniation. Most of the pug mills used today are of the twin-shaft type. (Fig. 2) Solid raw materials and recycled fines are fed into the inlet end of the pug mill, and liquids are injected under the bed. The kneading action of the pug mill gives a harder, stronger granule. Other advantages are that high ammoniation rates can be achieved and more variation in operating conditions can be tolerated. Among the disadvantages are high maintenance costs, high power requirements, poor fume control, and problems with non-uniform distribution of liquids under the bed.

Granulation in the Davison Trenton process starts in the pug mill and is controlled by formulation, recycling fines or adding water. In some cases, the pug mill discharges to a separate granulator, but in most cases, it discharges to the dryer, where additional granulation occurs. The dryer is usually of the co-current type. From

Fig 1: **Frank Nielsson patent of the ammonia-granulator**



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the dryer, the product goes to a cooler and then to screens. The oversize is crushed and returned to the screen, while the undersize is crushed and returned to the screen, while the undersize is recycled to the pug mill.

The Swift process involves the use of the patented Swift reactor for ammoniation and granulation. The reactor is a continuous rotary drum, the first section of which has a lifting flight zone. The lifting flights are staggered and designed to shower the dry material through the gas stream. Ammonia and the ammoniated solution are injected through a nozzle mounted in the seal plate of the feed end. Sulphuric or phosphoric acid is injected through an opening around the ammonia nozzle. The reaction of the acid generates steam which serves as the carrier gas. The granular product from the process will go directly to a cooler or to a dryer and then a cooler. The downstream equipment (such as screening, crushing and recycle) follows the typical design.

Pan granulators consist of a disc fitted to a peripheral wall, which is rotated while in the horizontal position. (Fig. 3) Additional feed and moisture are added to the pan, the moisture being typically in the form of fine sprays. Scrapers are used to prevent build-up of material on the disc and to control the material flow pattern on to the disc. Granulation occurs on the disc and when the granules attain the desired size, they are discharged from the pan. The damp granules are fed to a dryer and then to a screen. The major parameters controlling the pan output and movement of material on the pan are the pan diameter, the angle of incline from the horizontal, speed of rotation, and the height of the peripheral wall. These parameters need to be optimised to assure correct granulation.

The original Dorr-Oliver process was carried out in three reaction vessels with recycle ratios of 12:1 (Fig. 4). In the modified Dorr-Oliver process, partial ammoniation is carried out in two reaction vessels and the remaining ammonia is added in the pug mill. The technique achieves a recycle ratio of 8:1.

In the TVA process, large quantities of ammonia are injected beneath a rolling bed of wet solids in a rotary drum. Only one pre-neutraliser or reactor vessel is used, operating at the point of maximum solubility (mole ratio 1.40-1.45) to minimise the slurry moisture (16-20%). As originally designed, this achieved a recycle ratio of 5:1, but subsequent process modifications have brought the recycle ratio down to 4:1.

The basic TVA process unit consists of an open, slightly reclined rotary cylinder with retaining rings at both ends and with a scraper mounted inside the shell. A rolling bed of solid material is maintained in the unit, and liquids are introduced through horizontal, multiple outlet distributor pipes set lengthwise of the drum under the bed. With the earliest installations, drum length ranged between 5-15 ft and between 5-8 ft in diameter.

Granulation mechanisms

In the layering process, ammonium phosphate slurry is sprayed on to 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 the 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. Product formed by layering has good hardness and is spherical.

In the agglomeration process, recycled particles are cemented together by the fertilizer solution, forming salt bridges between individual particles. The mechanism is typical of low recycle processes. Product formed by agglomeration is much less spherical in appearance and more difficult to dry, since the moisture is deep within the granule and more prone to breakage as the bonds are not strong.

Product quality standards

The US industry quality standard is typically 2-4 mm granules between 93-95% with SGN 225-300 and UI 50-60. SGN (Size Guide Number) is the median diameter multiplied by 100, equivalent to the size at which 50% of the product is retained

Fig 2: **Pug Mill**

Fig 3: **Pan Granulator**

Fig 4: **Dorr-Oliver Process**

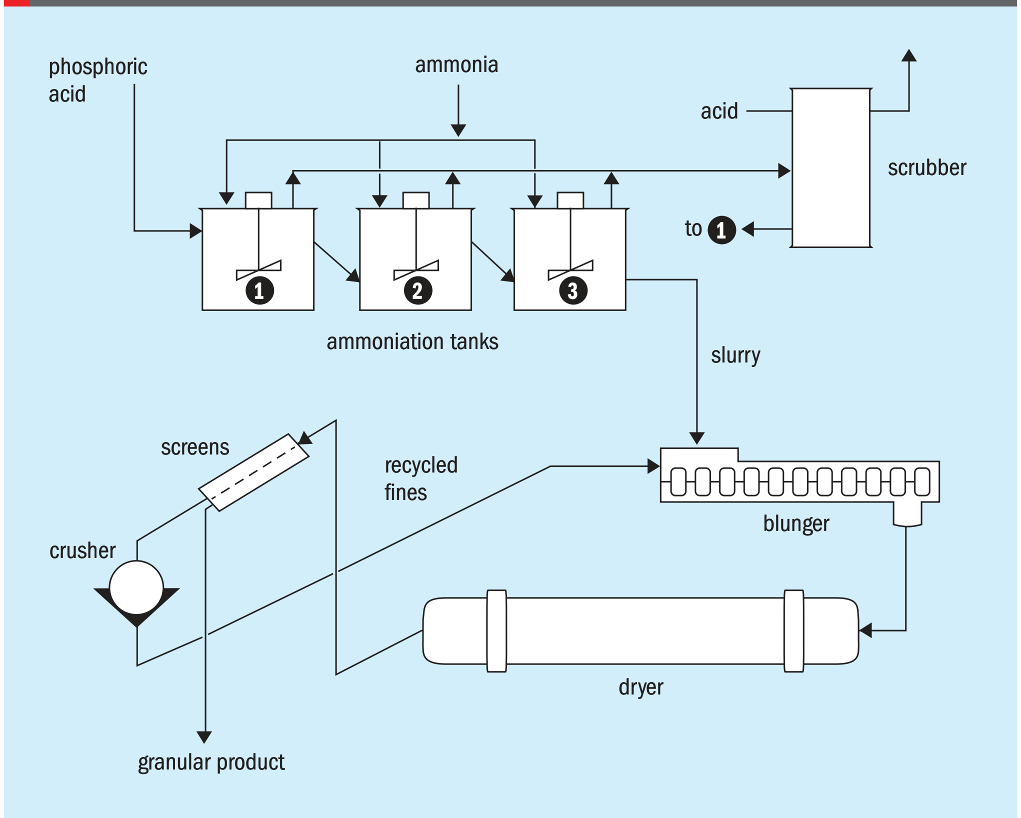
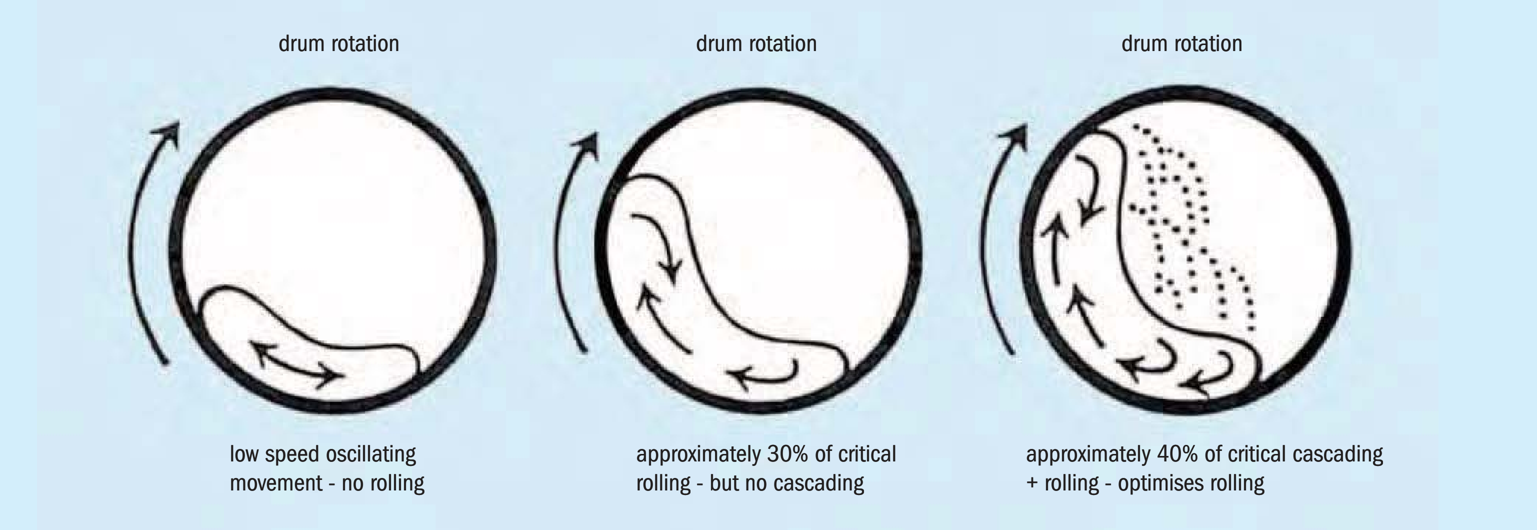


Fig 5: **Granulator speed**



expressed in millimetres multiplied by 100. UI (Uniformity Index) is the ratio of small granules (particles retained at 95%) to large granules (particles retained at 10%) multiplied by 100. A UI of 100 means that all the granules are the same size.

Today's start-of-the-art equipment

The granulation process starts in the reactor, and good control of the reactor is critical to controlling the downstream parameters that impact granulation. Granular MAP and DAP are produced by a slurry process that begins by adding a ratio of 54% and 30% phosphoric acid to the reactor. The 54% and 30% mixture is added at the correct ratio to give a total of 40% into the reactor. Ammonia is then added at a mole ratio of 1.42 for DAP and 0.6 for MAP forward titration to produce a slurry. The slurry is then pumped to the granulator to complete the reaction and start the main granulation process. The design of the reactor is critical for good slurry production and to minimise citrate insoluble (CI) losses. CI losses increase with residence time and acid impurities, such as iron, aluminium and magnesium. To minimise CI loss, the newest reactor design has a smaller diameter in the lower section to reduce retention time.

The main design parameters for good granulation in the granulator are:

- Ammonia sparger location
- Slurry header location
- Slurry spray nozzle configuration
- Granulator speed
- Down leg support locations
- Shell cleaning mechanism (typically rubber panels).

The typical design criteria are:

- Retention time: 1.5-2.0 minutes
- Length-to-diameter ratio: 2.3
- Bed volume, % drum volume: 12-20
- Slope: 3/8-5/8
- Peripheral speed (ft/min): 285
- Discharge dam height: 25% of drum diameter
- Recycle ratio: 4:1

Deviations from these recommended design parameters may affect granulation performance. Granulator speed is critical for good granulation: the granulator should be designed for 40% of critical speed, thus ensuring that the material inside the granulator has a cascading action to allow the granule to free-fall inside the granulator and produce good quality material. If the speed is too slow, the material will slide inside the granulator or start to roll, failing to cascade properly and thus resulting in poor granulation. The critical speed is defined as the rotational speed at which the centrifugal force equals or exceeds the gravitational force and the material no longer rolls or slides. (Fig. 5)

The location and type of slurry nozzles are also critical to good granulation. Slurry nozzles should be designed to produce an even flow pattern on the granulation bed and be uniformly distributed along the length of the granulator. This will also help reduce ammonia losses from the granulator.

Plugged nozzles will cause irregular spray patterns and poor distribution of slurry, resulting in poor granulation. If the nozzle angle is not correct, it can cause build-up on supports inside the granulator. The correct number of nozzles and location along the length of the granulator is also important for good granulation.

The ammonia sparger must provide equal distribution of ammonia: this is accomplished with the careful design of the sparger holes and the distribution chamber. The position of the ammonia sparger is critical: it should be directed downward and opposite the granulation rotation.

A plugged ammonia sparger or poor distribution of ammonia causes poor granulation. Excess ammoniation results in a dry, dusty and smaller product and increase ammonia losses. Under-ammoniation causes the granulator to run wet and lead to an increase in oversize material, as well as plugging chutes and increasing the build-up in the downstream material. Screening is critical to good granulation. The critical design considerations include screen mesh size, screen loading feed rate, screen area, vibration, slope, feed distribution on screens and maintenance.

The feed acid used by the granulation plant has a significant impact on granulation, and impurities (such as Fe, Al and Mg) will affect granulation. Too much Mg causes the granulation to be dusty and increases the amount of fines. Fe and Al can improve granulation by acting as seed crystals that start the initial granulation. The amount of solids in the feed acid also has a significant impact on granulation. If the solids in the feed acid are too low, there will not be enough seed crystals to start the granulation mechanism and granulation will be poor. Each plant has its own unique chemistry, but optimising these parameters will allow for improved granulation.

Using the state-of-the-art granulation technology will produce the best granular product and meet the highest quality standards. Granulation plants can consistently meet the industry quality standard, typically 2 x 44 mm granules between 93-95%, with SGN 225-300 and UI 50-60. ■

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Survival of the fittest as competition hots up

Over 400 delegates gathered in Tampa Florida between 23-25 March for CRU's Phosphates 2015 conference

The conference opened with a refreshingly candid keynote address from Mosaic's senior vice president, **Rick McLellan**. Innovation is important to "how this company survives and thrives going forward", McLellan told delegates.

"Innovation doesn't just happen, it needs leadership, commitment and the development of a culture within your business," said McLellan. "Innovation has to focus on continuous improvement. If you do something one time and call that innovation, it's just luck."

He was keen to dispel the myth that the phosphate industry is not innovative: "Good innovation delivers value – if it doesn't then you have to question why you're making the change. We need to get rid of the rumour that this, the world's second oldest profession, has not been involved in innovation during the last 40 years."

The development of Mosaic's *MicroEssentials* premium product range was one example of innovation for the benefit of customers – although this had to have credibility. "Kids, dogs, farmers… you can't fool them. If you're going to deliver something it better be worth it," McLellan said.

Having "created a two million tonne market for this product", *MicroEssentials* has become integral to Mosaic's success, with an increasing percentage of phosphate production likely to be dedicated to its manufacture in future, as McLellan made clear. The plan was to "take up production to 50% for this product", he said.

Water use and land reclamation were two areas where innovation was necessary and where advances had already been made. Mosaic was now recycling 90% of the water it handled, for example. "We're huge users of a major resource in Florida– water, a non-renewable resource," said McLellan. "We need to be good stewards of water. It creates value for the communities we live in as well as a return for us."

McLellan suggested that cost reduction, and staying in the lowest quartile of the cost curve, was an essential part of phosphate innovation: "We've been able to do that for the last four years – we have a zero growth plan for cost. In fact, we're going to take $200m dollars out of our cost structure over the next three years."

Joining the Global Reporting Initiative in 2010 had changed Mosaic's approach to sustainability and transparency. "It's forced dialogue based on facts with people who think differently from us. One of the things we've learnt is that we don't own the truth," said McLellan.

Improving nutrient use efficiency and a commitment to sustainable intensification were part of Mosaic's DNA, according to McLellan. The industry needed to step forward and take responsibility for nutrient stewardship and the presence of phosphate in surface waters in his view. "We've got to figure out ways of keeping phosphate in the crop, whether it be rice, whether it be corn, whether it be soya beans. We can no longer absolve ourselves of this responsibility. We believe it's part of our DNA to drive sustainable agriculture," he said.

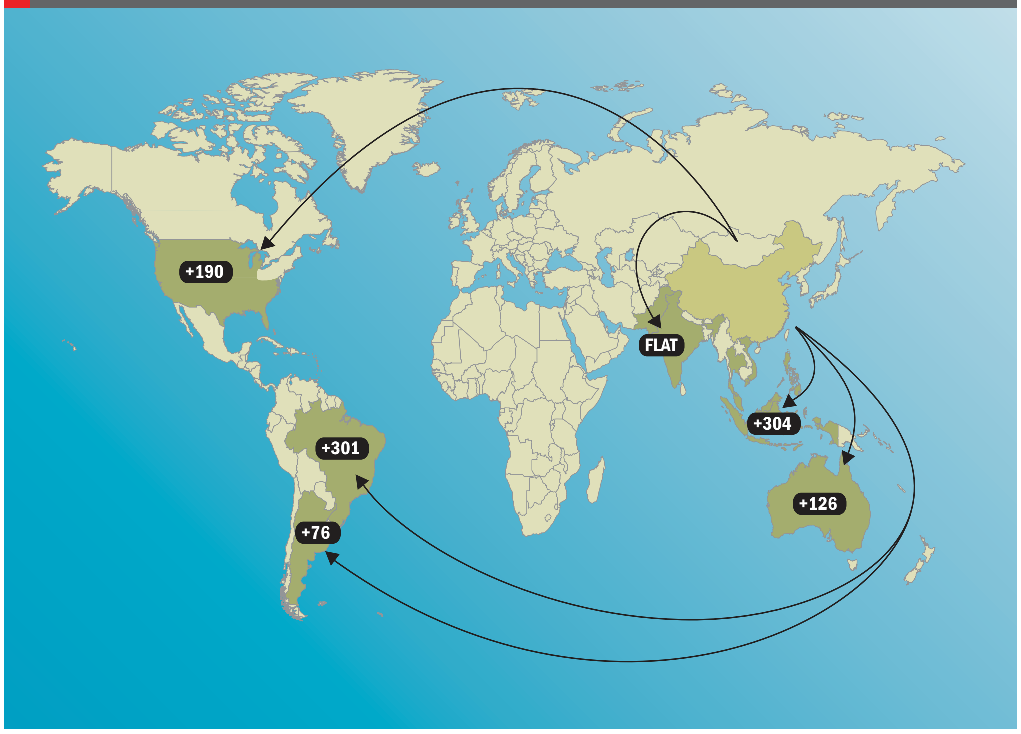
Pricing pressure from capacity ramp-ups

CRU's phosphate team leader, **Juan von Gernet**, warned of a "worrying amount of new capacity" sparking intense competition between suppliers. Quoting from *The Hunger Games* movies, von Gernet told delegates: "Winning will make you famous… losing means certain death".

"I think competition is intensifying in the industry. As we look into the future, I suspect it will intensify further which will require producers and incumbents in the industry to make difficult decisions which could affect survival," he said.

von Gernet looked back at CRU's annual forecast at last year's conference compared to the actual market outcome. CRU's predicted consumption for four key countries – China, India, Brazil and the US

Fig 1: **China's 2014 export destinations** DAP, MAP and TSP, K tonnes P_2O_5



–which together account for 54% of global consumption. "With respect to China and the US, we were fairly spot-on with what happened. With respect to India and Brazil, we were a little too bullish," von Gernet admitted.

CRU estimates that merchant grade phosphoric acid (MGA) capacity reached 55.0 million tonnes and combined DAP/MAP/TSP capacity reached 46.7 million tonnes last year.

China has been the engine of growth in global phosphate production over the last two decades with DAP, MAP and TSP production ramping up from 0.7 million tonnes in 1995 to 31.1 million tonnes last year, its market share increasing from 4% to 45% over this period. CRU figures show that China exported more internationally in 2014, particularly to South East Asia, Brazil, the US, Australia and Argentina (Figure 1). Stable DAP prices last year ($438-505 f.o.b. Tampa) also show that this export surge did not stem from price cutting by China's 'Big 4'

Four factors – the strength of the dollar, the rouble's weakness, a Chinese export slowdown and growing Indian demand – will have the most impact on phosphate markets in 2015 in CRU's view.

CRU expects world phosphate demand to remain stable this year, increasing by just 0.1 million tonnes over the next 12 months to 43.0 million tonnes by the end of 2015. Greater land area, particularly in India and South East Asia and Brazil, is likely to boost P_2O_5 demand (+394 thousand tonnes). But this is expected to be offset by falling application rates in Europe, North America and Russia (down by 0.4 kg/ha, -298 thousand tonnes P_2O_5) – linked to lower affordability. Less corn, wheat and rice in the crop mix will also depress demand (-17 thousand tonnes P_2O_5). Factoring in animal feed and industrial phosphates should take total world P_2O_5 demand to 49.7 million tonnes this year.

The dollar's strength means DAP affordability is likely to weaken further in India, whereas Brazil, as an agricultural commodity exporter, may benefit from the dollar's appreciation: "They're exporters of crop products and will get dollars in – which for farmers means they'll have more money to spend on inputs," commented von Gernet.

CRU expects India to import and consume more phosphate this year. It predicts India will import 4.5-5.0 million tonnes of phosphate products in 2015 to help meet demand of around 8.0-8.5 million tonnes. India's P&K budget allocation has been set at INR225.0 billion, an 8% year-on-year rise, whilst DAP subsidies are expected to remain flat when the extra allowance for secondary freight is stripped out.

> **"We need to be good stewards of water. It creates value for the communities we live in as well as a return for us.**

The weaker rouble, which has lost 40% of its value against the dollar since last August, should give Russian phosphate exports an edge. "We estimate their costs have declined by about 20% year on year because of that devaluation. I suspect our model underestimates that – but the point is Russian exporters are going to be more competitive this year."

CRU predicts phosphoric acid production will rise from 43.6 million tonnes in 2014 to 44.1 million tonnes this year. But lower Chinese DAP/MAP/TSP exports in 2015, following record exports last year, and falling Chinese domestic phosphate consumption may combine to limit the country's production, according to von Gernet: "In terms of production, we continue to forecast that China will eventually catch a cold."

"There's a glut of Chinese exports that needs to adsorbed into the market in 2015. Additionally, producers are going to compete a lot more aggressively against the Chinese product this year," he said.

CRU expects DAP prices (f.o.b. Tampa) to be stable until October but to eventually fall to around $438/t by the year's end. "The short term outlook is moderately bullish through to Q3 but then capacity ramp ups are likely to start putting pressure on prices," said von Gernet. "In the last quarter, where generally demand tails off, we expect raw material prices to start to put downward pressure on phosphate prices."

Looking further ahead, OCP expansion plans for Jorf Lasfar, if they come to fruition, could see Morocco's share of the DAP/MAP/TSP export market increase from 17% (2.1 million tonnes) currently to 27% by 2022. Fierce international competition is the most important consequence of this, with rising OCP export market share putting the squeeze on phosphate producers in China and the US. This is not a foregone conclusion though.

"One hope, in terms of moving away from aggressive competition, is developing demand in areas it could grow. Africa is one of those areas."

Africa, with its vast agricultural land area of around 230 million hectares, currently consumes just 1.3 million tonnes of phosphate; Egypt, Morocco, Ethiopia and South Africa account for around 60% of the continent's demand. Bringing Africa's application rates up to US levels could eventually increase consumption to 9.3 million tonnes P_2O_5.

"There's a pretty big untapped resource which the industry may get access to but they will have to work to develop that demand," said von Gernet. "There is a real challenge in Africa to educate farmers to use fertilizer but the key barrier is accessibility. If that could be overcome, potentially, we have a winner here."

Investors constructive but treading cautiously

Investors are intrigued by the fertilizer sector's strong fundamentals but are not rushing to make sizeable investments currently. So says **Glenn Gatcliffe** of BMO Capital Markets. He summed up investor sentiment towards the fertilizer sector as "treading cautiously into the future".

In the past, investors viewed fertilizers as a safe commodity with highly attractive long-term fundamentals. But the potash price wars that followed the breakup of the Belarus Potash Corporation (BPC) export cartel ended the perception of the sector as a safe haven. This, together with government subsidy and tax uncertainties in India/China and stricter environmental regulation, has undermined investor confidence in what remains fundamentally a healthy sector, in Gatcliffe's view.

Fertilizer majors with ample capital have the ability to pursue expansions, explained Gatcliffe, whereas juniors are struggling to raise capital for their projects. In North America, investor interest in nitrogen projects is capitalising on low cost shale gas and "favourable price dynamics". But recent completion of major potash expansions means this is viewed as an oversupplied market. Investor sentiment for phosphate, however, is "mostly constructive" in Gatcliffe's view.

Summing up the view of capital markets, Gatcliffe said: "The good news right now is that I would say we're more bullish on phosphates, then nitrogen, then potash, in that order, [that] would be our pick for the next short term."

Gatcliffe pointed to strong correlation between phosphate stock performance and underlying commodity prices (DAP f.o.b Tampa) with current share prices of phosphate producers being "largely in line" with their level two years ago. Nitrogen, in contrast, is an investor darling with share prices outperforming underlying commodity prices.

Since 2007, the fertilizer industry, particularly large, diversified players, has been able to access finance through a mixture of bank debt ($87 billion), the bond markets ($37 billion) and the sale of equity ($17bn). The decline in equity finance in recent years reflects negative investor sentiment towards junior developers.

Rationalisation and moves to secure phosphate and potash supply have been behind many of the mergers and acquisitions (M&A) within the sector. The importance of securing a fertilizer distribution foothold in Brazil is also making this country the centre of much M&A activity.

Freights costs in China and Brazil's 4Fs

Senior CRU consultant, **Isaac Zhao**, delved into the intricacies of the Chinese phosphate market, especially the effects of recent export tariff changes, the introduction of VAT and new environmental obligations. "Constantly rising" transport costs are becoming a key factor for Chinese phosphate exports, explained Zhao. Domestic freight charges of up to $80 are possible from the 3rd quarter of this year. This could make it cheaper for producers in China's south to ship phosphate products to Brazil than it is to transport them internally to domestic agricultural consumers. For industrial phosphates, Zhao expects to see a structural shift in China away from thermal phosphoric acid (TPA) to purified wet acid (PWA) production. This is partly due to the high electricity costs of TPA but is also being driven by manufacturing demand for food-grade phosphates.

Phosphate demand from the 4Fs of Brazilian agriculture – food, feed, fibre and fuel – will continue to drive production and imports over the next decade, according to an analysis by Professor **Luiz Guilherme** of Brazil's Federal University. He forecast a 37% increase in Brazilian phosphate demand, an 84% increase in phosphate production and a 45% increase in phosphate imports over the 10 years up to 2023. Phosphate (35 kg/ha P_2O_5) makes up a sizeable share of Brazil's 112 kg/ha NPK consumption. Around 100 million hectares of land is available for crop expansion in Brazil. A further 100 million ha of degraded cattle pasture provides additional fertilizer demand. Greater lime and gypsum application would help Brazil meet the challenge of improving nutrient uptake and use efficiency, Guilherme concluded.

Balancing bulls and bears

Near term factors affecting the phosphate outlook for North America were explored by **Michael Rahm,** Mosaic's vice president of market and strategic analysis. He told delegates: "Mother Nature and how she impacts the global harvest and commodity prices will be critical."

Rahm was fairly optimistic on pricing: "We saw a rally in agricultural commodity prices last October and since then those prices have remained fairly stable at levels that underpin a decent outlook for fertilizer demand worldwide. In the near term, bull and bear factors… are pretty well balanced right now which is consistent with how the market has traded over the last five months."

"On the bearish side, the market is worried about the strength of the dollar," noted Rahm. The correlation between a strong dollar and weaker commodity prices is a particular concern for agricultural commodity markets. Market sentiment was also cautious because of the weak macroeconomic outlooks in key countries such as China and Brazil. The expectation that record 2014 Northern Hemisphere and 2014/15 South American harvests will lead to stock building is another bearish factor.

"On the bullish side", Rahm identified the "tremendous increased demand" for grain and oil seeds in food, feed and biofuels (linked to more moderate crop prices) as the main factor. Russian export restrictions and a "somewhat worrying" US drought monitor map were other bullish drivers. Nutrients also remain affordable compared to the "crazy days" of 2007 and 2008.

Similar to CRU, Rahm expects the beginning of a rebound in Indian demand in 2015 with imports forecast to climb to 5.0-5.5 million tonnes, up from around 4.0 million tonnes in 2014.

"On Indian demand we have high expectations," said Rahm. "Everyone is forecasting Indian imports of 5-5.5 million tonnes. Internally, we're saying we wouldn't be surprised if that tops 6 million tonnes in 2015."

He added: "India has been a huge drag on demand over the last three to four years. We think that will change. We think India will get back on a growth trajectory… and will get close to 10 million tonnes by the end of this decade."

"Strong and steady" North American shipments of 9.7 million short tons are also expected in 2015/16, down only slightly on 2014/15 shipments of 9.9 million short tons – the second highest in the modern era. The US exports around 5.5-6.0 million tonnes today with much going to Canada, Mexico, Central and South America.

"Our destinations have become increasingly focussed on the Western Hemisphere and the Americas in particular, with much growth in terms of the *MicroEssentials* or premium products," Rahm said.

North America has adjusted to significant recent supply reductions (Table 1) by importing more and exporting less, according to Rahm: "You can easily get 5 million

Table 1: **Recent phosphate supply reductions**

Country	Company	Facility	Year closed	Capacity
Permanent closures				
Spain	Fertiberia	Huelva	2010	740
USA	Agrifos	Pasadena	2011	740
USA	PotashCorp	Suwannee River	2014	470
USA	MissPhos	Pascagoula	2014	840
			Subtotal	2,790
Temporary shut-downs or reduced operating rates				
Tunisia	GCT	Gabes	Ongoing	1,000
Russia	UralChem	Voskresensk	Ongoing	650
Philippines	Philipos	Leyte	Ongoing	860
			Subtotal	2,510
Total				**5,300**

> **China is the wild card for what happens to phosphate demand growth.**

tonnes of supply that has disappeared either permanently or over a period of time." China and Saudi Arabia have stepped in to fill the void with the Chinese exporting 8.1 million tonnes in 2014 up from 5.3 million tonnes in 2013.

"China is always the wild card in terms of what happens with phosphate demand growth," in Rahm's view. "We still think, with no increases, that significant restructuring of that sector is going to take place. The number one [export] driver in our view is the availability and affordability of phosphate fertilizer for farmers in China."

Rahm concluded by raising the prospect of a windfall from falling raw material costs: "With $260 urea being sold all over the world, hopefully that provides respite for phosphate producers and enables phosphate prices to moderate and keep processing margins at a decent level as well."

Sustainability agenda rises

Phosphate sustainability is moving inexorably up the legal and policy agenda in the US, explained **James Elser**, a professor of ecology, evolution and environmental science at Arizona State University. The cyanobacteria event in Lake Erie, which affected Toledo's water supply in 2014, was a watershed moment for nutrient management in his view. It mirrors similar harmful algal blooms in Lake Atitlan, Guatemala in 2009 and a lake supplying water to Wuxi city in China's Jiangsu province in 2007.

The Ohio House reacted to Lake Erie's problems by passing rules preventing the application of manure, sludge and fertilizers on soggy or frozen fields in the northwest of the state. This year has also seen Maryland introduce phosphate management tool regulations. As well as this, a Washington state district court ruling on dairy farm waste handling in January risks the "manure world being turned upside down".

The sector has reacted to these developments by setting up the North American Partnership for Phosphorus Sustainability (NAPPS). This is being modelled on the European Sustainable Phosphorus Platform set up in 2013. NAPPS is current recruiting founding partners and is holding an inaugural meeting on the future of phosphates in Washington DC on 19 May.

Outlook for phosphate rock and raw materials

The net merchant market for phosphate rock is limited and mainly in the hands of OCP, CRU's senior phosphate consultant, **Alberto Persona**, told delegates. He also predicted that the merchant market will probably contract further in future.

The size of the merchant market is currently around 20 million t/a. Joint ventures and long term contracts account for 5.3 million tonnes of phosphate rock exports globally. Just three countries – Morocco Egypt and Algeria – have significant spare export capacity for merchant sales, once locked in sales and flexible sales are factored in.

Production from Bayovar has seen the emergence of Peru as a rock phosphate export hub for destinations such as Brazil, Florida and Mexico. OCP remains the largest rock phosphate exporter with the Middle East ranked as the second export hub. CRU's analysis suggests that, generally, the rock phosphate market is tightening east of Suez and loosening to the west.

Opportunities for juniors developing new capacity do exist within an overall shrinking market for rock phosphate. But being cost competitive is unlikely to be enough in Persona's view. Junior companies may well need to displace existing suppliers and "steal" contracts to secure production.

A decreasing price trend for both ammonia and sulphur was forecast by CRU senior consultant, **Sheena Patel**. The pricing of both raw materials is highly significant as they are vital to – and a key cost component of – DAP production.

Although self-sufficiency has been a long-cherished dream, the US is likely to remain dependent on ammonia imports, in Patel's view. This is despite the shale gas revolution and its supposed transformation of the nitrogen outlook for North America. CRU has concluded that, whilst some new builds/expansions will go ahead, other projects are not attractive as initially advertised. Inflation in engineering, procurement and construction (EPC) costs will also take its toll. CRU estimates that new projects are likely to provide an extra 0.7 million tonnes of North American merchant ammonia by 2018.

> **Junior companies may well need to displace existing suppliers.**

Phosphoric acid consumption (30 million tonnes) accounts for over 50% of global sulphur demand (56 million tonnes). Patel confidently predicted that continuing investment in sulphur capacity will materialise this year – and that key projects will emerge to move sulphur production into surplus. The capital investment already committed made it very unlikely that the oil price shock would affect sulphur projects under development in the Gulf, Kazakhstan, Russia and Turkmenistan. CRU therefore expects sulphur prices to start to decline next year, should these projects progress as expected.

Minor miners

Four junior companies discussed the prospects of developing new phosphate deposits in a lively panel debate on the first day of the conference. **Cris Tziolis** executive director of Rum Jungle outlined the state of play of the Ammaro project in Australia's Northern Territory. The project, with inferred resources of 1,145 million tonnes, is currently at the preliminary feasibility stage. The site benefits from access to an underused rail line to Darwin and the Amadeus gas pipeline. Low cost, shallow, truck-and-shovel mining should also help keep costs in the bottom half of the global cost curve for DAP and NPK production.

Colin Ikin, chairman of Cominco Resources, explained the progress to date of the Hinda project in the Republic of Congo. Described as the world's largest undeveloped phosphate deposit, a 2013 advanced prefeasibility study confirmed phosphate reserves of 433 million tonnes at 10.5% P_2O_5 grade. The phosphate ore is thick, friable, easy to dig and amenable to conventional beneficiation. The deposit is located 40 km from port with good roads, grid power, an abundant freshwater supply and stranded gas nearby. The results of the definitive feasibility study are expected imminently.

Focus Ventures is developing the Bayovar 12 project in northern Peru, adjacent to the existing giant Vale/Mosaic/Mitsui mine. The deposit is low fluorine, high carbonate and highly reactive with reserves of 188 million tonnes (12.4% P_2O_5). The firm's director, **Ralph Rushton**, described the current investment environment for juniors as the worst in 30 years. Because of this, Focus Ventures is targeting the direct application phosphate rock (DAPR) market in countries with acid





soils such as Peru, Argentina, Mexico and Colombia. Producing for the direct application market is advantageous for junior miners, explained Rushton, as it keeps capex costs to within a "few tens of million dollars".

GB Minerals is developing the Farim phosphate project in Guinea-Bissau. Farim is a high-grade deposit and is one of just eight current projects to have a P_2O_5 content above 25%, according to **Luis da Silva**, CEO and president of GB Minerals. The sedimentary deposit can be extracted by free digging down to 55m. Capex of $166 million would be required for a 1 million t/a operation at Farim, around half the industry norm, with production costs "just inside the 2nd quartile", explained da Silva.

All on track at OCP

OCP's industrial development director, **Redouane El Omni**, updated delegates on the progress of his company's massive $16 billion investment to double mining capacity and triple fertilizer production between 2008 and 2023. The company is planning a 22 million tonnes expansion in mining capacity and 6 million tonnes expansion in fertilizer capacity (P_2O_5 basis) as part of a two-phase development programme over this period.

Initially, phase one development will see ten million tonnes of mining capacity and 1.8 million tonnes of fertilizer capacity added between 2008 and 2016. A second phase between 2016 and 2023 will then develop a further 12 million tonnes of mining capacity and add 4.2 million tonnes of fertilizer capacity, if all goes according to plan.

Mine capacity will be expanded at three phosphate deposit sites, Khouribga, Gantour and Meskala. OCP also plans to build five new rock beneficiation plants– three at Khouribga, one at Gantour, one at Meskala and another at Laayoune. The planned exploitation of the Meskala deposit after 2020 is particularly significant as it contains 15% of known Moroccan reserves.

As a cornerstone of the development, OCP is replacing train freight between the interior and the coast with two slurry pipelines: the already operational 38 million t/a Khouribga-Jorf Lasfar pipeline and the planned 10 million t/a Gantour-Safi pipeline. Additionally, 10 new integrated fertilizer plants will be built at Jorf Lasfar 'phosphate hub' together with an expansion of the site's port and storage infrastructure. A separate phosphate hub and port at Safi and another new port at Laayoune is also planned.

El Omni confirmed that phase one of OCP's investment programme was "well underway" with many mining, infrastructure and chemical projects either under construction or complete. The Merah El Ahrach (MEA) beneficiation plant was now supplying the 187 km Khouribga-Jorf Lasfar pipeline with phosphate slurry, for example, as was the adapted Daoui washing plant. The 450,000 tonne capacity 'Line E' phosphoric acid plant and two 850,000 tonne capacity DAP fertilizer plants ('107 B&C') at Jorf Lasfar are also operational. The El Halassa mine and beneficiation plant project at Khouribga are currently in commissioning as is a 25 million cubic metre reverse osmosis seawater desalination plant at Jorf Lasfar.

Four new integrated fertilizer units, each of 1 million tonne DAP capacity, are currently under construction at Jorf Lasfar. These are due to come on-stream at six month intervals over the next two years from the second quarter of 2015 onwards. The first integrated unit, consisting of a DAP plant, a phosphoric acid plant, a sulphuric acid plant with a 62-megawatt turbine generator and two storage units, is currently being commissioned. A third of the turbine generator's output is surplus to requirement and available to power the desalination plant.

Handsome margins for food-grade phosphates

Ajay Mahajan, senior president of Aditya Birla Chemicals, was upbeat in his assessment of the Asian demand outlook for food-grade phosphates and phosphoric acid. He expects increasing consumption of high-value food products, linked to rising incomes, to have a positive impact on the phosphate market.

"In countries where income levels are increasing, purchases shift from carbohydrate-rich staple food towards more expensive sources of calories such as meat and dairy," says Mahajan. "And where it happens it is good for the consumption of phosphates."

> "Where income levels are increasing, purchases shift from carbohydrate-rich staple food towards more expensive sources of calories such as meat and dairy.

Currently, 7% of global phosphoric acid production goes to food and industrial markets – with end use in food and beverages accounting for a fifth of this. Food-grade phosphate therefore remains a niche market, albeit a high-value one with potential for growth. The use of food-grade phosphoric acid in beverages, yeast production, edible oil refining, sugar refining and pet food, for example, is growing at 3.1% per annum. Annual growth for food grade phosphate products, such as sodium phosphate, SALP and MCP, used in meat poultry and seafood, bakery and dairy products and potato processing is even higher (4.2%).

Mahajan expects East Asia and South East Asia's status as the major consuming regions for the use of food grade phosphate to continue with annual growth of 9.5% expected over the next five years. North America and Western Europe look set to remain major consumers of phosphoric acid used in beverages and yeast. But Mahajan predicts strong future demand for food grade phosphoric acid in East and South East Asia, with year-on-year growth of 7% expected in some segments up to 2020.

"The demand growth for food phosphate and acid... will continue at 3-4%. So, if no new capacities are added, there will be a squeeze on the price and there will definitely be handsome margins in this business," Mahajan concluded.

All about Asia and Latin America

The outlook for phosphate in the feed market was outlined by **Clay Hackney**, PotashCorp's international sales manager. Feed and industrial markets make up just 10% of phosphoric acid use globally but are likely to account for for nearly two-fifths (39%) of PotashCorp's phosphate sales volumes this year, making these important markets for the company.

Market demand for feed phosphate over the next five years will be driven by the growth in animal protein production, with two regions playing a pivotal role. "It's all Asia and Latin America where the growth is taking place," said Hackney.

Between 2015 and 2020, production growth for pork in China (2.7 million

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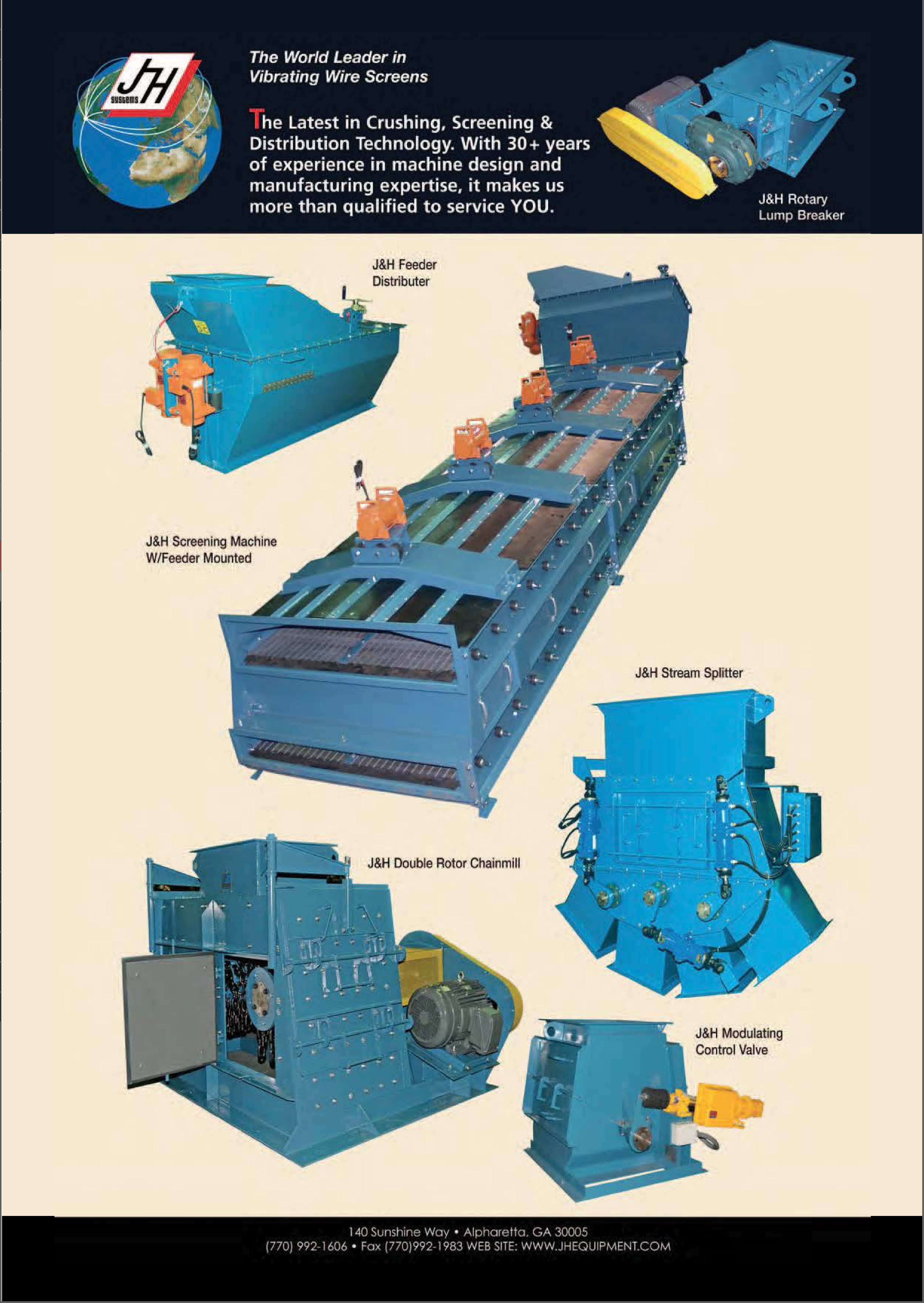

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tonnes), poultry in the rest of Asia (3.4 million tonnes) and beef in Latin American (1.5 million tonnes) is expected. Aquaculture will be another fast growing segment of the global feed sector, predicts Hackney, with Latin American and Asian countries such as Chile, Vietnam and Thailand leading the way.

Hackney is forecasting radical shifts in feed phosphate trade flows over the next two years. He expects African exports to almost double (90%) and Chinese exports to drop by around a third (30%) by 2017. EU imports are also likely to grow by 3-4 times over this period and the Middle East is likely to switch from being a net importer to becoming an exporter of feed phosphate.

Question marks remain over the supply/demand balance for feed phosphate (Figure 2) and whether capacity will outpace demand growth. However, Hackney does expect competition from substitute products such as phytase to continue.

Agricultural demand

JR Simplot's market analyst, **Wayne Welter**, told delegates that the rising populations of the emerging economies, and their growing middle class, will be good for phosphate's agricultural markets, as they will ensure that food demand and production continues to increase. Africa's population, for example, will grow by 26% over the next decade boosting the continent's crop demand by 27% and protein demand by 36%. However, the future actions of government remain important, cautioned Welter, as their policies will still have the largest impact on how the agriculture and the phosphate sectors develop.

Opportunities for micronutrient fertilizers and their application in precision farming were explored by **Julia Presnova**, vice president of strategic intelligence and marketing at Prayon. Micronutrients are a million tonne volume market globally with the main markets, Asia-Pacific (520,000 tonnes) North America (210,000 tonnes) and Europe (130,000 tonnes), expected to grow at 6%, 6.3% and 3.7%, respectively, over the next five years. Micronutrient products are sub divided into non-chelated and chelated types with the former having a 96% market share.

Iron is an important plant micronutrient as deficiency results in a failure to produce chlorophyll (chlorosis). Presnova presented cucumber, tomato and strawberry growing trial results for Prayon's new *micronutriFe* product. This non-chelated PK fertilizer contains 42% P_2O_5, 48% K_2O and 2.8% Fe and is water soluble and biodegradable. Prayon are planning to develop similar micronutrient products for zinc, copper and manganese.

The likely impact of global weather patterns on fertilizer demand this year was covered in detail by **Drew Lerner**, president and senior agricultural meteorologist at World Weather. The outlook for India is for lower than average rainfall in the north of the subcontinent between June and October. But there was no reason to assume that the period of prolonged dryness in Russia and western CIS states – partly a hangover from last year – would persist, suggested Lerner. He forecast "some" below average precipitation in China this spring which may harm early season corn, rice and sugarcane. The prospects for rain in parts of North America also remain a concern because of a stagnant weather pattern and persistent dryness in the north portion of the US plains, the upper Midwest and California.

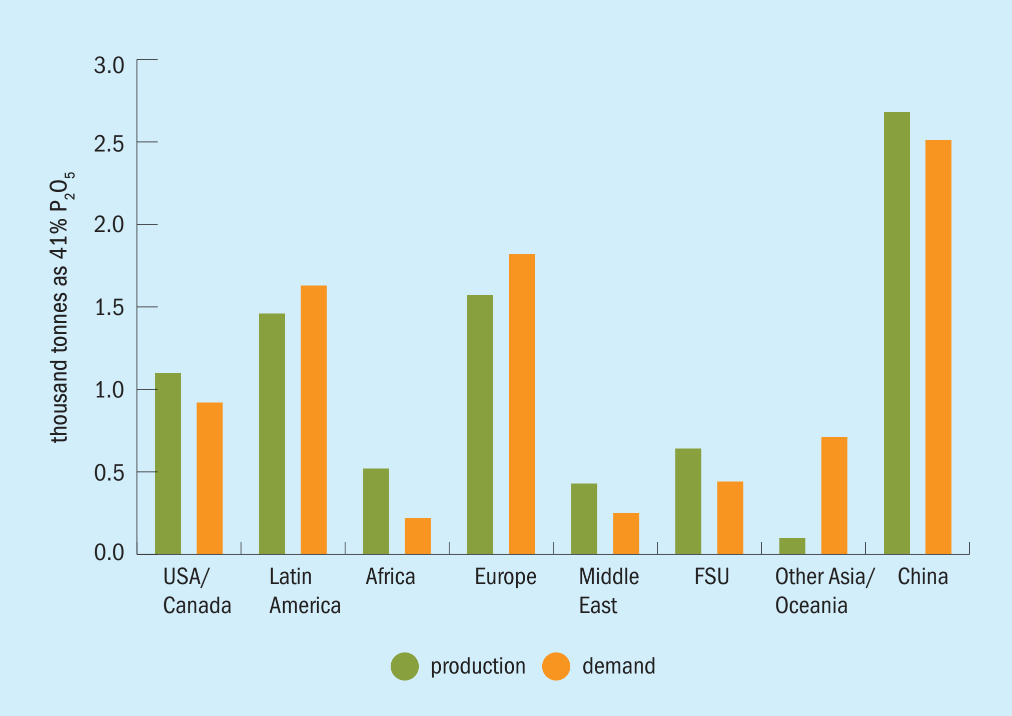
> **"Question marks remain over the supply/demand balance for feed phosphate and whether capacity will outpace demand growth.**

Technology and innovation

Technical sessions at Phosphates 2015 provided an informative insight into the latest developments and innovations in beneficiation and phosphoric acid technology. **Mike Baker**, minerals beneficiation and chemical technologies manager at Tenova Bateman Technologies, reviewed the different ways of processing phosphate ores, both igneous and sedimentary. Similarly, **Guoxin Wang**, global director of mining chemical technologies for ArrMaz products, provided a thorough overview of reagent selection for phosphate flotation. A thermal method for removing carbonate and cadmium from phosphates using fluidised bed technology was outlined by **Ludwig Herman**, senior energy consultant for Outotec. **Patrick Zhang,** beneficiation and mining research director, Florida Industrial and Phosphate Research institute (FIPR), presented the findings of controlled acid leaching trials on high-dolomite phosphate rock.

Leif Bouffard, Hatch's director of process engineering, briefed delegates on preliminary test results for an innovative cooling water treatment process for phosphoric acid plants. Jacobs process engineer, **Stephen Hilakos**, highlighted the potential of an oxalic acid wash process for removing iron from phosphoric acid. **Faustino Prado**, president of Prado Technology outlined a method for removing minor elements during wet acid processing using silica fluoride precipitation. ■

Fig 2: **Forecast global feed phosphate supply and demand for 2017**




HYUNDAI

Concentrating the apatite

Igneous phosphates are often highly amenable to mineral processing. With the right flowsheet, they can be concentrated by a factor of between five and six to yield high purity products.

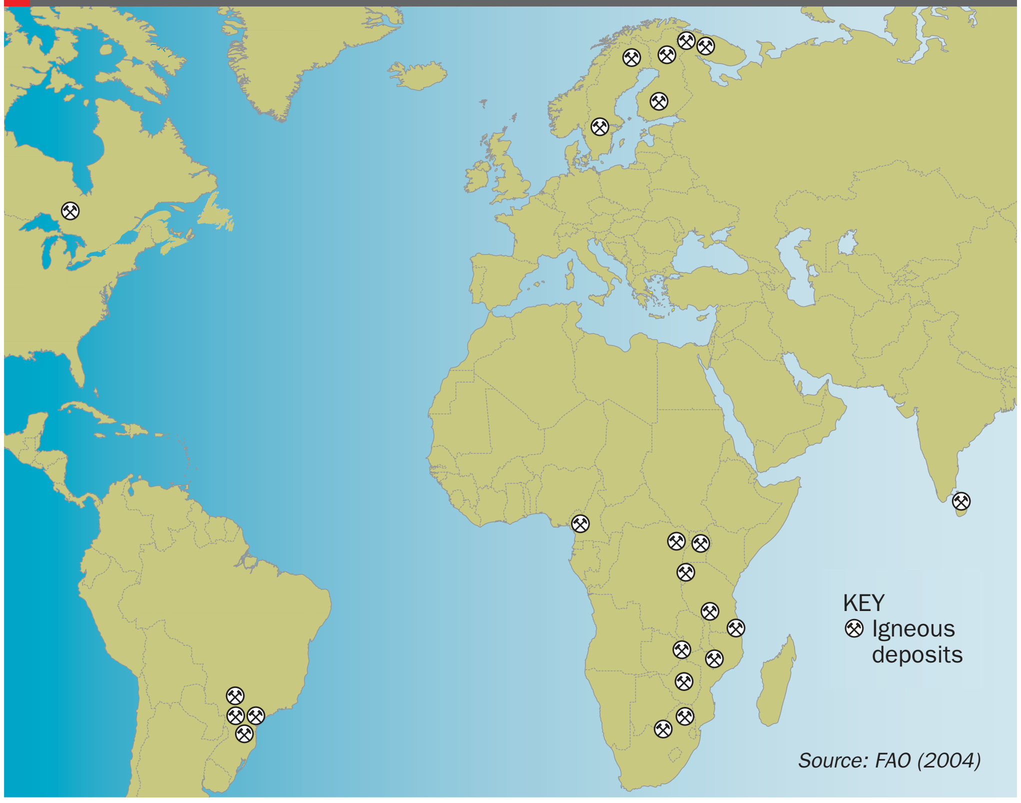
Igneous phosphates account for around 15-20% of global production with sizeable deposits in Brazil, Russia, Finland, South and East Africa and Canada (Figure 1). Their mineral processing characteristics are very different from those of sedimentary phosphates due to their distinctive mineralogy, texture and mode of origin.

The three main types of igneous phosphates, carbonatite, nepheline-syenite and pyroxenite, are generally coarse-textured and contain well-formed apatite crystals. They are also rich in fluorapatite ($Ca_5(PO_4)_3F$) in contrast to the collophane or francolite typical of sedimentary phosphates. Mineral processing requirements of the three main igneous phosphate ores vary due to their gangue mineral content.

However, igneous phosphates have a number of characteristics that generally make them easier to process than their sedimentary counterparts (see Box). In particular, their crystalline and non-porous nature makes them more amenable to froth flotation. Sedimentary phosphates, in contrast, are disadvantaged by a large surface area, high slimes content and chemical substitution within apatite crystals.

Direct froth flotation of apatite is universally-employed in the upgrading of igneous ores due to its ability to separate phosphate minerals from silicates. Fatty acids, such as tall oil or rice bran oil, are highly effective anionic collectors of apatite under basic conditions between pH 10-11.5. Magnetic separation of magnetite and flotation of copper, barite and calcite are widely used as processing methods, either before or after igneous phosphate recovery, and may produce saleable co-products.

Fig 1: **Global occurrences of igneous phosphates**



Source: FAO (2004)

Brazil: column flotation pioneers

With estimated reserves of 270 million tonnes, Brazil is the major producer of phosphate rock in South America and extracted 6.75 million tonnes in 2014. Concentrates of around 35% P_2O_5 are typically obtained from Brazilian igneous phosphates at recoveries ranging between 45-78%, depending on the locality.

Brazilian rock phosphate production is controlled by four major players (Table 1). Vale Fertilizantes mines igneous phosphate from carbonatites at five locations in the country. Three of these mines, at Araxá (Barreiro Carbonatite Complex), Tapira and Patos de Minas, are sited in Minas Gerais state. The firm also mines and processes igneous phosphate at Cajati (Jacupiranga Carbonatite Complex), Sao Paulo, and at Catalão (Catalão Carbonatite Complex) in the state of Goiás.

Mining giant Anglo American, Brazil's second largest fertilizer producer, also extracts phosphate at its Ouvidor mine in Catalão, as does Fosbrazil at Cajati. Galvani operates three phosphate mines at Angico Dias and Irecê in Bahia state and Lagamar in Minas Gerais, and is 60% owned by Norwegian producer Yara, Canadian-owned MBAC mines phosphate at Itafos Arraias site in Tocantins state.

Brazil is notable for pioneering the recovery of apatite concentrates from slimes by froth flotation in the 1980s. Slimes flotation was later improved with the widespread adoption of column flotation technology at Araxá – and subsequently Cajati, Catalão and Tapira – in the 1990s. By 2003, around 0.6 million tonnes (12%) of the 5.1 million tonnes of phosphate produced by Brazil was apatite recovered from slimes in this way.

The phosphate mined at Araxá is from a residual oxidised ore zone containing apatite (28%), iron oxides (28%), magnesium silicates (14%), quartz (10%), barite (7%) and carbonates (3%). Ore is firstly processed by crushing, grinding and classification. This is followed by low-field magnetic separation, desliming, apatite and barite flotation and then high-field magnetic separation (Figure 2). The phosphate concentrate obtained is then filtered and dried.

Apatite flotation takes place at roughly 60% solids concentration at pH 10-11.5 using a fatty acid collector (tall oil or rice bran oil) with iron oxides depressed by adding gelatinised, causticised starch. For the coarse fraction, pre-flotation of barite is necessary, using a cetyl or stearyl sulphate collector, when run-of-mine barite content exceeds 3%. Alternatively, barite can be suppressed with corn starch at pH 12 during apatite flotation – although caustic soda demand makes this an expensive option.

Significant quantities of phosphate used to be lost during processing at Araxá due to ore desliming at a 30 micron a cut point. The installation of flotation columns in 1992 improved recovery by capturing apatite particles down to 5-10 microns. Araxá's column flotation circuit generated 830,000 tonnes of phosphate concentrate in 2004, a third (34%) of the plant's total production.

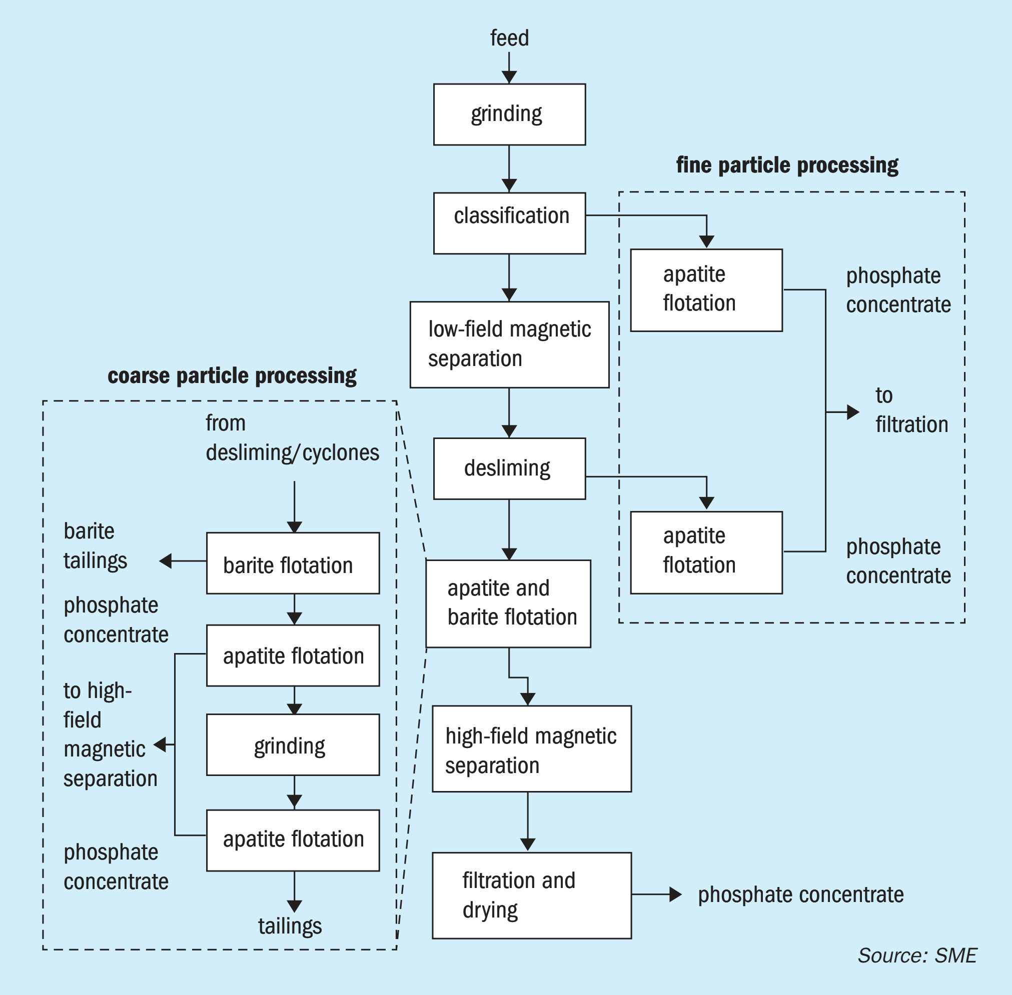
Mining at Cajati produces phosphate from one of the world's lowest grade deposits. The ore contains about 12% apatite (5% P_2O_5) with calcite (54%), dolomite (20%), magnetite (8%), olivine (2%), phlogopite (2%), and sulphides (1%) present as gangue minerals. Apatite occurs in the carbonatite as small parallel veins of elongated rice-like crystals and is concentrated by magnetic separation and rougher-cleaner-scavenger froth flotation. The mine cut-off grade at Cajati is reported to be 3 % P_2O_5 (Table 2).

Table 1: Brazilian rock phosphate production in 2013

Mine	State	Processed product (tonnes)
Vale		
Tapira	Minas Gerais	2,179,000
Araxá	Minas Gerais	1,147,000
Patos de Minas	Minas Gerais	70,000
Catalão	Goiás	1,025,000
Cajati	Sao Paulo	610,000
Anglo American		
Catalão	Goiás	1,300,000
Galvani		
Lagamar	Minas Gerais	220,000
Angico Dias	Bahia	215,000
Irecê	Bahia	115,000
MBAC		
Arraias	Tocantins	330,000

Source: ANDA/SINPRiFERT

Fig 2: Process flow for Brazilian igneous phosphate containing barite



Source: SME

South African phoscorite and pyroxenite

Significant igneous phosphate resources are present in the Phalaborwa (previously Palabora) carbonatite complex of north east South Africa, located on the edge of the Kruger National Park, 360 km north east of Johannesburg. Hydroxyapatite and fluorapatite deposits occur within pyroxenite and a surrounding serpentine/magnetite/apatite rock known as phoscorite. The pyroxenite contains 15% apatite with pyroxene, phlogopite and vermiculite as its main gangue constituents. Very little carbonate is present and magnetite is also absent. Phoscorite, in contrast, contains a large proportion of both magnetite (35%) and carbonate (30% dolomite) but is relatively apatite-rich (25%).

South African producer Foskor extracts phosphate at Phalaborwa from both these ore types, as well as from apatite-rich mine tailings (15-25% apatite) produced by the Palobora Copper Mining Company (PMC), South Africa's leading copper producer.

Apatite is recovered from crushed and milled pyroxenite – 15% above 425 microns (40 mesh) and 20% below 74 microns (200 mesh) – by four-stage flotation (rougher, scavenger, cleaner and re-cleaner) using Wemco flotation cells with the recirculation of middlings. Caustic soda maintains alkalinity at pH10 and tall oil fatty acid is used as the collector. Either a straight-chain petroleum sulphonate or sulphonic acid are added to the pulp as a conditioner. A P_2O_5 concentrate of 39.6% is typically obtained at 70% recovery from pyroxenite ore with a 7% P_2O_5 head grade.

Phoscorite is processed using an identical flotation circuit, although sodium silicate and nonyl phenyl tetraglycol are used as silicate and carbonate depressants, respectively. A P_2O_5 concentrate of

38.5% is usually achievable at 67% recovery from phoscorite ore of 7.5% P_2O_5 head grade.

After extracting copper and magnetite, PMC pumps its slurry tailings to Foskor where they go through two-stage hydrocyclone separation to remove 85-90% of fines below 12 microns. The deslimed product is then treated by the same froth flotation circuit as phoscorite, although a polysaccharide, such as gum arabic or guar gum, is generally used as a depressant.

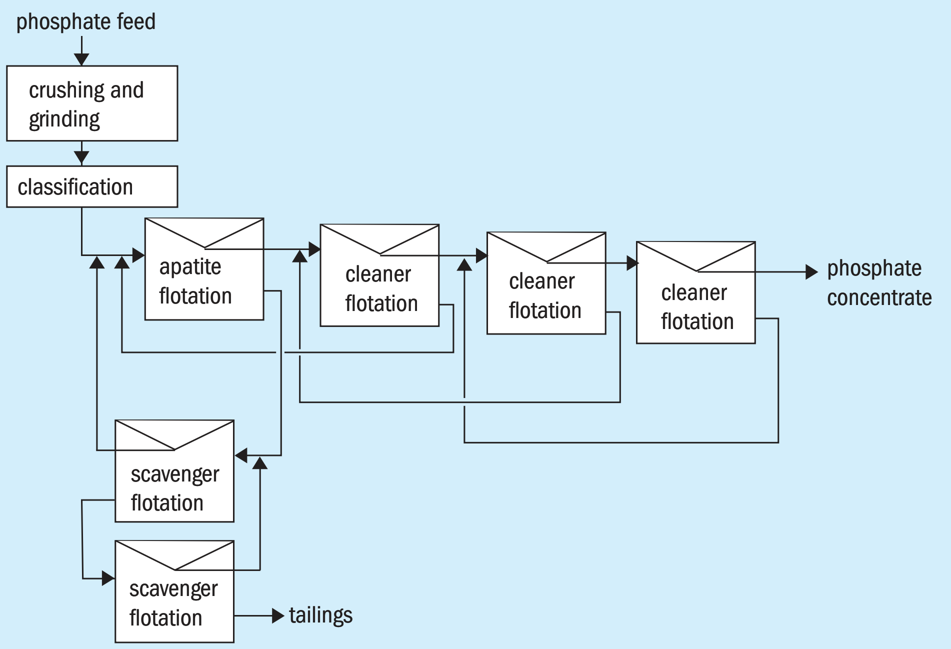
A generalised phosphate processing flowsheet for Phalaborwa ore is shown in Figure 3. Copper and iron are both recovered prior to phosphate processing. Copper is removed first by flotation using a Xanthate collector. Magnetite is then separated with Sala low-intensity magnets after desliming using Multotec cyclones (750-mm and 100-mm).

Table 2: **Selected characteristic of Brazilian igneous phosphates**

Apatite properties	Araxá, Tapira, Catalão ore	Cajati ore
Origin	Mostly weathered/oxidised, some residual and primary	Primary
Crystal morphology	Globular, radial, fibrous aggregates, locally prismatic	Prismatic
P_2O_5 content	Commonly up to 30% or higher	Mostly below 10% with economic deposits as low as 4%
CaO/P_2O_5 ratio	1.3 or less	Above 1.3

Source: Alves 2008

Fig 3: **Process flow for benefication of Phalaborwa igneous phosphate ore**



Source: SME

Western Europe's commercial igneous phosphate deposit

The Siilinjärvi carbonatite complex in east Finland, 20 kilometres north of the city of Kuopio, is the site of Western Europe's only working apatite mine. The deposit typically contains 10% apatite, 22% calcite and dolomite, 65% phlogopite and 3% amphibole. Mineral processing can produce a phosphate concentrate of 36.5% P_2O_5 from the ore at a recovery of 88.5%.

Norwegian producer Yara mines phosphate from the 2.9 km long, 0.75 km wide and 250 metres deep Siilinjärvi open pit. It also extracts ore from a satellite pit at Saarinen which opened in 2012. Total phosphate reserves are estimated to be 218 million tonnes.

Since it began operating in 1979, Yara's Siilinjärvi processing plant has produced 20 million tonnes of apatite concentrate from 200 million tonnes of phosphate ore (4.2% P_2O_5 grade). The plant has a mill feed rate of 1,300 t/h, generates a 1,800 m³/h volume of tailings and has the capacity to produce one million tonnes of apatite concentrate annually, according to Yara. Apatite is processed in six-stages:

- Three-stage crushing
- Homogenisation
- Rod and ball milling, Floatex classification
- Fines flotation
- Flotation, high gradient magnetic separation (HGMS) and low intensity magnetic separation (LIMS)
- Tailings cycloning, fines thickening

The carbonatite ore is initially crushed and ground to 30% less than 74 micron prior to apatite flotation at pH 8-11 in Outokumpu cells using the amphoteric collector N sarcrosine. The rougher concentrate obtained then goes through several flotation cleaner steps and a HGMS and LIMS stage to produce the final phosphate concentrate (Figure 4). A saleable calcite by-product is also generated from rougher tailings using tall oil to float calcite. A mica concentrate can also be derived from the tailings after further processing. The Siilinjärvi plant is capable of producing 1 million tonnes of apatite and 100,000 tonnes of calcite and 12,000 tonnes of mica annually.

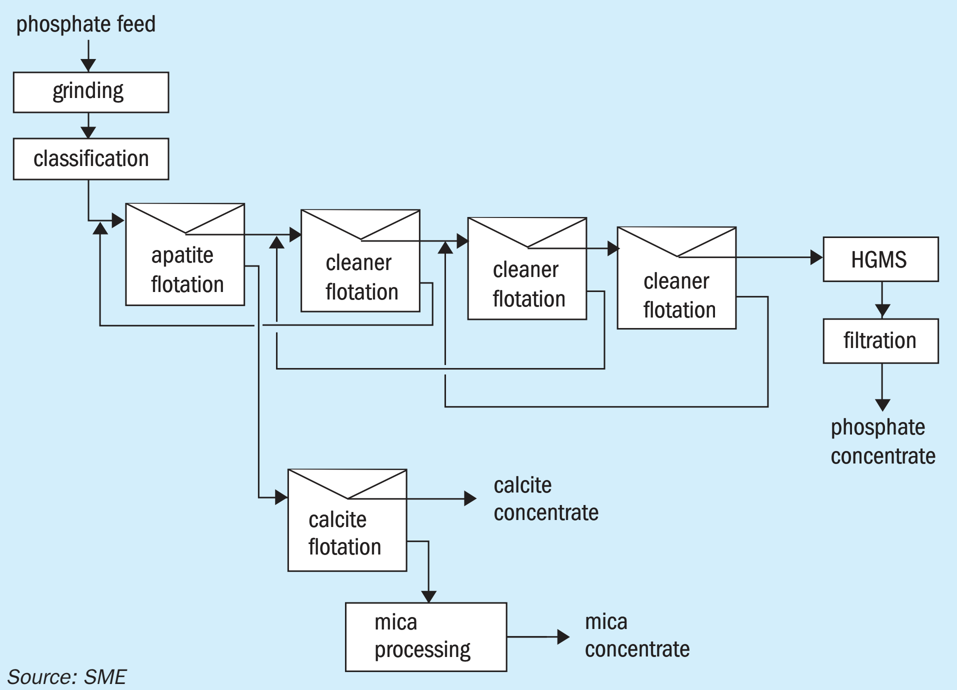
Yara's €300m investment in the Siilinjärvi site since 2007 has included the installation of an automated XRF/XRD system for analysing phosphate concentrates.

Large Russian resources

Russian deposits are currently the world's most important source of igneous phosphate ore. PhosAgro subsidiary Apatit produced 8.127 million tonnes of high-grade (35.7% P_2O_5) concentrate from igneous phosphate in 2010. Apapit extracts ore from the circular, 30km-diameter Khibiny (Khibinsky) nepheline-syenite complex north east of the city of Kirovsk in Russia's Kola peninsular, 200km to the south of Murmansk. This ore mainly consists of apatite, nepheline, aegirine, sphene, feldspar and titanomagnetite. The proved and probable reserves of Apatit's four mines are 771.4 million tonnes (at 14.0% P_2O_5 grade) according to an independent 2010 assessment.

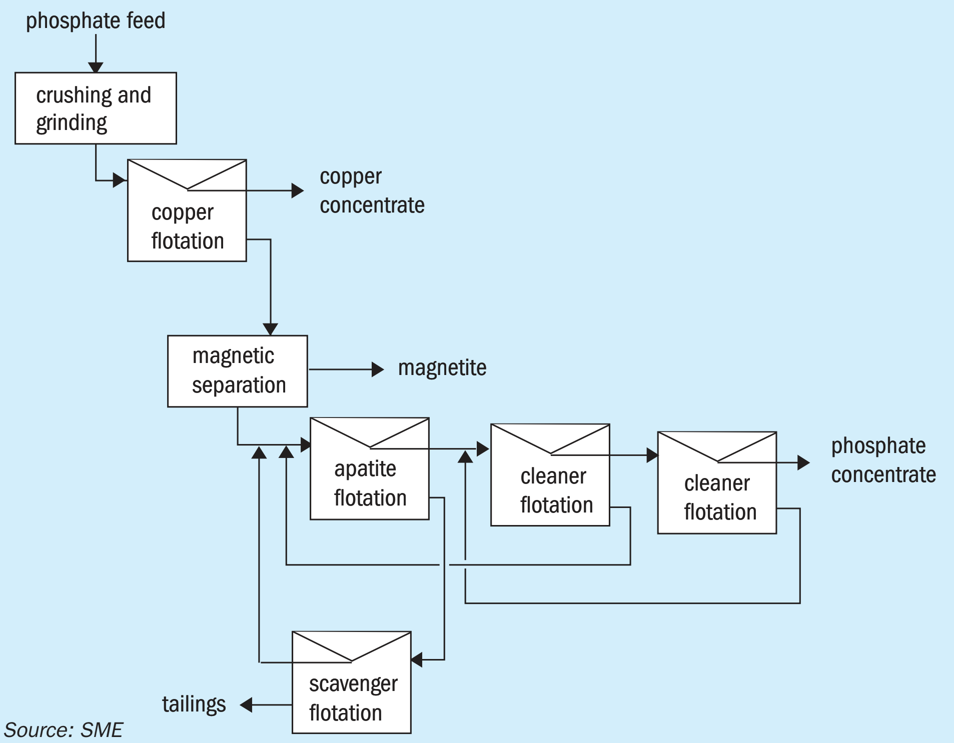
Both opencast (Kirovsky, Central and Vostochny mines) and underground

Fig 4: **Process flow for Siilinjärvi (Finland) phosphate concentrator plant**



Source: SME

Fig 5: **Process flow for benefication of Kola Peninsula (Russia) igneous phosphate**



Source: SME

Table 3: **Mineral processing characteristics of igneous phosphates**

Country	Ore deposit	Ore grade ($\%P_2O_5$)	Concentrate grade ($\%P_2O_5$)	Recovery (%)
Brazil	Barreiro, Cajati	5-15	35	45-78
Finland	Siilinjarvi	10	33.7	85.8
Russia	Khibiny	18	39	94
South Africa	Palabora	7.5	38.5	67

Source: SME (2006)

(Kirovsky and Rasvumchorr mines) mining methods are used to extract the ore. Apatit then produces concentrates at two beneficiation plants, ANBP-2 near the city of Apatity and ANBP-3 near Kirovsk. The mines and beneficiation plants are connected by a 220-km rail network. In 2011, ANBP-2 produced 4.2 million tonnes of concentrate from 14.2 million tonnes of ore. ANBP-3 plant processed slightly less ore that year (13.4 million tonnes) to produce 4.0 million tonnes of concentrate. Two other divisions of PhosAgro, Ammphos and BMF, use beneficiated ore as the starting point for the manufacture of phosphate fertilizers and phosphate feed products.

Beneficiation is relatively straightforward, involving rougher flotation followed by two scavenger and three cleaning stages (Figure 5). Tall oil (110g/t), oxidised petroleum (15g/t), secondary oil gas tar (60g/t) and sodium silicate (45g/t) are all used as process reagents. Caustic soda is also added to ensure a basic pH during flotation. The phosphate ore is generally crushed to less than 20 millimetres and then ground to 55% less than 74 microns prior to processing.

Ultrafine flotation

In recent years, the Eriez Mineral Flotation Group (formerly Canadian Process Technologies Inc.) has developed a flotation column fitted with an advanced air sparging system known as the CPT Cavitation-Tube. The system has been successfully adopted for ultrafine processing of igneous phosphate ore from Araxá, Brazil. Prior to its installation, around 10-15% of the ore's P_2O_5 content, present as fine apatite particles below 25-30 microns in size, was lost during desliming with a hydrocylone.

The introduction of innovative flotation technology at Araxá increased recovery by capturing apatite particles as small as 5-10 microns, compared to the previous cut off of 30 microns. The CPT system captures these ultrafine apatite particles by generating minute 100-400 micron size air-filled cavities. These tiny bubbles also enhance flotation performance by improving the attachment of larger particles on larger size bubbles.

Araxá's ultrafine phosphate floatation stage upgrades P_2O_5 content from 8.1% to 33.5% at 72% recovery – and increases overall plant yield by 3-5%. The ultrafine concentrate obtained is also ideal for producing SSP fertilizer. The concentrate's

1 47 2 48 3 49 4 50 5 51 6 52 7 53 8 54 9 55 10 56 11 57 12 58 13 59 14 60 15 61 16 62 17 63 18 64 19 65 20 66 21 67 22 68 23 69 24 70 25 71 26 72 27 73 28 74 29 75 30 76 31 77 32 78 33 79 34 80 35 36 37 38 39 40 41 42 43 44 45 46

natural fine particle-size has the added benefit of reducing fertilizer plant regrinding costs.

Prospective projects

Innovation in igneous phosphate processing is likely to come from prospective projects such as Arianne Phosphate's Lac à Paul project in Quebec, Canada. This ore body contains apatite, quartz, ilmenite, magnetite, feldspar and pyroxene and is hosted by gabbro and nelsonite. Arianne Phosphate proposes to extract 18.6 million t/a of ore and produce 3 million t/a of beneficiated phosphate concentrate by column flotation.

The potential economic and performance advantage of column flotation over conventional mechanical flotation cells were demonstrated by a pilot-scale test comparison by WorleyParsons (Table 4). Flotation columns produced a 38.6% P_2O_5 grade product from the Lac a Paul ore at an impressive 91.6% phosphate recovery. The potential benefit of using column instead of mechanical cells was estimated to be $10,684 a day adding up to a yearly saving of $35.94 million.

Subsequent validation work published last November confirmed that two cleaner columns combined with a cleaner scavenger column was the most promising mineral processing configuration for producing high-quality apatite concentrates (>38.5% P_2O_5) at high yields (recovery of 90% or better)

Ewan Wingate, principal process engineer at WorleyParsons, presented a paper on processing igneous phosphates by column flotation at last year's Phosphates 2014 conference in Paris, based on the Lac à Paul trial results (*Fertilizer International*, May-June, p51).

"The igneous phosphate being a finer particle size has allowed for the use of column flotation cells (Eriez, Metso and PrepQuip) to dramatically improve metallurgical grade and recovery," says Wingate. "Globally, I believe phosphate projects will be developed to serve their local geographical locations rather become mega projects servicing a global market."

Combining mechanical and column flotation on the same flowsheet may well be the most economic way of beneficiating the Lac à Paul ore. "The project that my 2014 paper was based on has subsequently completed a further tranche of testwork and come up with a hybrid mix of mechanical flotation cells and columns," comments Wingate.

Table 4: Results of pilot plant trial results for Lac à Paul project

Date	Flotation cell type	Recovery		Concentrate grade
		Mass %	P_2O_5 %	P_2O_5 %
June 2012	Mechanical	23.4	78.2	32.4
April 2013	Mechanical	11.7	63.7	37.4
March 2013	Column	17.6	91.6	38.6

Source: WorleyParsons

Uganda Sukulu Hills project

Extensive igneous phosphate resources are present in the Sukulu carbonatite complex, 6 km southwest of Tororo in eastern Uganda, where they occur as a deep blanket of phosphate-rich residual soil to a depth of up to 67m.

These residual deposits contain 20-50% apatite, up to 50% magnetite, hematite and goethite, along with minor amounts of quartz, ilmenite, mica, zircon, pyrochlore and baddeleyite. Aluminium-phosphates such as crandallite are also present. Florida's Bearden Potter Corporation reported the presence of 230.7 million tonnes of phosphate (average grade 12.8% P_2O_5) as part of a SSP plant feasibility study commissioned by the World Bank in the early 1980s.

US consultant John Wing designed the beneficiation and fertilizer process for the Bearden-Potter study.

"Mining is very simple, but beneficiation is very complicated," says Wing. "We masterminded a complex, 18-step beneficiation process to reduce iron to 1% Fe_2O_3 in the concentrate, leaving an apatite concentrate with over 40% P_2O_5."

Bearden-Potter proposed using a wet tower mill to grind a 55% solids content slurry to 80% less than 44 microns (325 mesh). The processing flowsheet included two stages of magnetic separation and rougher and cleaner flotation. The plant was designed to produce granular SSP or partly acidulated phosphate rock (PAPR), with a capacity of either 31 t/h for SSP or 24.4 t/h for PAPR.

Interest in the Uganda's igneous phosphate resources was reignited in 2013 with the signing of memorandum of understanding between India's Gujarat State Fertilizers and Chemicals Limited (GSFC) and Nilefos minerals. GSFC promised to sink $200m into the developing a phosphate mine at Sukulu Hills as part of this agreement. ■

Beneficiation basics

Typical specifications for phosphate used in phosphoric acid production include a P_2O_5 content greater than 30%, a CaO/P_2O_5 ratio below 1.6, and a MgO content less than 1 %.

Igneous phosphates can be upgraded and concentrated by a factor of between five and six due to their highly-favourable crystalline nature. Concentrates of between 87-97% apatite (38-42% P_2O_5) at recoveries as high as 80-90% are perfectly achievable by froth flotation.

Igneous phosphate is typically ground to 100% less than 250 micron prior to froth flotation to liberate apatite from the ore. Hydrocyclones are often used to discard slimes (particles below 10-20 microns in size) prior to flotation as they affect apatite selectivity and recovery and also adsorb collector and cause a stiff froth. Undesirable iron minerals such are magnetite also need to be removed beforehand by magnetic separation otherwise they will float and be recovered with apatite.

The flotation feed is generally conditioned using a depressant at a high pulp content –around 70% solids is usual – for about three minutes. Sodium silicate is typically used as a depressant for silicates and caustic starch for carbonates. The pulp's pH is next adjusted to pH 10-10.5 by adding sodium carbonate and diluted down to 20-30% solids content.

A collector for apatite is then added (most plants use a fatty acid) and conditioned for a further 2 minutes before flotation commences. Plant froth flotation circuits usually consist of a rougher, scavenger and one or more cleaner stages.

The right solution for potash

Solution mining potentially confers a number of cost and technological advantages in comparison to conventional methods of potash extraction

Drilling at K+S's Legacy project, Saskatchewan.

After some recent successes, this year looks like being the start of a make-or-break period for greenfield potash development in general, and potash solution mining in particular. A crowded field of junior mining companies are vying for investor interest at a time when their viability is looking increasingly precarious due to faltering potash prices and the risk of market oversupply.

There are positives, though. Last year saw the completion of Intrepid Potash's HB solar solution mine in New Mexico. The $4.1 billion Legacy project, the largest capital enterprise in the Canadian mining industry, is also due to enter commissioning next summer. K+S's plan to ramp up production at Legacy, Saskatchewan's first new solution mine in 40 years, to two million tonnes production by the end of 2017. ICL's purchase of the pioneering Allana Potash project in Ethiopia's remote Danakil Depression for around $110 million is another vote of confidence in solution mining (p12). In contrast, the April cancellation of Karnalyte Resources' junior mining project in Saskatchewan – considered a relatively strong prospect – may be the first of a spate of cancellations and mark the start of a wider curtailment.

Born of necessity

Potash solution mining was not initially an obvious choice as a potash extraction method and was partly adopted out of technical necessity. The pioneering development of the Moab potash solution mine in the early 1970s is a case in point.

"No one originally intended that Cane Creek's potash be mined with water. Texasgulf started it as a conventional mine in 1964, but was plagued with problems from the start. The mine was gassy, the temperature was high and, instead of being level and flat, the ore layer was distorted into undulating sections," reported the *Four Corners Geological Society*.

PotashCorp's Patience Lake mine in Saskatchewan, although originally a conventional underground operation, was also converted to a solution mine in 1988 due to flooding.

Geological conditions still influence the selection of solution mining as a potash extraction method. It becomes the sole option for potash mining at depths below 1,200m – the lower limit for conventional mining. Proponents of solution mining also point to a number of advantages over conventional mining methods, including:

- Potential for significantly lower costs and faster payback on investment
- Less complex technical, engineering and mine design requirements
- More straightforward with no development shafts, underground mining equipment or de-watering necessary
- Fast project lead in times of around 3-4 years typically compared to 6-7 years for a conventional mine

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47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

An economic solution?

Canada's Gensource Potash Corp, developer of the Lazlo project, offers some interesting insights into the economics of potash solution mining. The Canadian mining junior estimates that average capital expenditure (capex) of US$1,000/t is required for a potash solution mine compared to US$1,400/t capex for a conventional underground mine – a capex saving of close to 30%.

Western Potash, developer of the Saskatchewan Milestone project, agrees that 25-30% saving in infrastructure costs is achievable: "It is more cost-effective to drill a series of production wells to extract potash solution than to construct conventional mining shafts, conduct underground development work and install mining machinery." Analysts CRU ranked the Milestone project favourably on economics, placing it in the second quartile of potash operations worldwide, although this assessment dates from 2010.

Solution mining operational expenditure (opex), in contrast, is typically 20%-30% higher than conventional mining, according to Gensource. Higher energy costs are the main reason for this. Gensource reports that Saskatchewan solution mines consume around 1,300 kWh/t of energy on average – more than three times the 400 kWh/t average for conventional mining.

The North American potash industry is mainly reliant on the supply of natural gas to meet its energy demand. "Because solution-extraction mines use heated brine to extract potash, high prices for natural gas could make this process more expensive over the longer-term than conventional potash mining," notes Western Potash. However, the firm believes low natural gas prices will be sustained, making solution mining "very cost competitive" for the foreseeable future.

Solution mines are likely to reside on the "higher end of the cost curve" for potash production, says PotashCorp, especially when energy costs are high. PotashCorp also cautions that the "limited scalability of solution mines compared to conventional mines is an important consideration in capital investment decisions".

Capex of $1,048/t and opex of $125/t are typical for potash solution mining in Saskatchewan, estimates Gensource (Table 1).

Comparing apples and oranges

Making like-for-like capex/opex comparisons for solution mining versus conventional mining is a risky business due to project-specific variables such as location, geology, scale of production and differences in the price assumptions used. Whilst it is true that the capex costs for many prospective junior solution mining projects (Table 2) are around $1,000/t or less, as Glensource suggests, there is little definitive evidence of a clear, general capex cost advantage over conventional mining. For example, the average capex for a conventional greenfield potash mine appears to be in the vicinity of $800/t currently, based on five projects under construction in Russia and Turkmenistan.

Industry sources confirm that, although largely true for Saskatchewan, the statement that solution mining projects are always cheaper to develop than conventional potash mines does not generally hold true elsewhere.

"The main difference between solution and conventional potash mining is, of course, that a solution mine takes much less time to bring into production – but I wouldn't say it is less costly to build looking at some of the figures in Integer's Outlook for Potash, as we have Capex per tonne quite high," comments Lisa Smith, potash analyst at Integer Research. "Although once operational it has lower manpower demands, generally it will be more expensive energy-wise too."

This just confirms that generalisations about the relative costs of solution mining versus conventional extraction are of limited value when capex and opex costs are largely project-specific.

Investment boost for Allana

Allana Potash Corp has gone further than most in providing potential investors with a breakdown of the capital investment

Table 1: **Typical Saskatchewan solution potash mining economics**

Cost breakdown	(CDN$/t)
Capex	
Primary Mining	881
Secondary Mining	167
Total	**1,048**
Operating costs	
Process Plant	56
Solution mining, typical	11
Sub-total, mine mouth	67
SG&A expenses	13
Transportation costs (f.o.b. Vancouver)	45
Total	**125**

Source: Gensource Potash Corp

Table 2: **Opex and capex costs comparison for selected potash solution mining projects**

Company	Country	Project	Capex ($/t)	Opex ($/t)	Source
K+S	Saskatchewan, Canada	Legacy	894.61	111.79	Feasibility study
Karnalyte Resources	Saskatchewan, Canada	Wynard	948.8	129.12	Bankable Feasibility Study
Encanto Potash	Saskatchewan, Canada	Muskowekwan	829.9	87.44	Pre-Feasibility Study
Western Potash	Saskatchewan, Canada	Milestone	960.7	50.89*	Feasibility Study
Allana Potash**	Ethiopia	Allana	787	130	Feasibility Study
Magindustries	Republic of Congo	Mengo	1,000	76	NI 43-101
Elemental Minerals Ltd	Republic of Congo	Dougou Carnallite	1,075	68	Scoping study

** Excludes tax, royalties, transportation and ship loading*
*** SOP production*

1 47 2 48 3 49 4 50 5 51 6 52 7 53 8 54 9 55 10 56 11 57 12 58 13 59 14 60 15 61 16 62 17 63 18 64 19 65 20 66 21 67 22 68 23 69 24 70 25 71 26 72 27 73 28 74 29 75 30 76 31 77 32 78 33 79 34 80 35 36 37 38 39 40 41 42 43 44 45 46

and operational costs required for its one million t/a project in Ethiopia's Danakil Depression (Table 3). Production on this scale would require capex of $642 million ($642/t) and opex of $125/t, based on a 2013 feasibility study.

Geological factors and the local climate made solution mining the obvious option for Allana Potash. Conventional mining was rejected early on after the previous operator had issues with water infiltration, explains Richard Kelertas, the firm's senior vice president, corporate development.

"Conventional mining and open pit mining were both rejected for the project," says Kelertas. "Solution mining is a well known technology and produces a potash-rich brine that allows the project to benefit from its unique climate and take advantage of solar evaporation as part of the processing design."

The project also benefits from other favourable characteristics in his view.

"The shallow depth lowers the capex compared to other solution mining operations as does the absence of thermal evaporators as part of the processing," comments Kelertas. "Shorter lead times [relative to conventional mining] do help the economics of the project."

Neither is the project reliant on unproven technology, adds Kelertas: "There are no real process innovations. The process is similar to that used by Intrepid Potash in Utah [Moab] and, aside from the solution mining, is similar to ICL's Dead Sea operations and SQM's operations in Chile, *vis à vis* solar evaporation."

Strenuous efforts are being taken to limit environmental impacts of solution mining and sustain the livelihoods of local people.

"Subsidence will not be a factor as large pillars are planned. Waste NaCl will be used to build roads and the drill station with the excess directed to the salt plain – essentially just adding salt on top of salt. The immediate project area is uninhabited but Allana has active CSR programs in the nearby villages."

Table 3: **Allana potash project costs**
1 million t/a production of MOP

Capex	**$/t**
Brine field	85
Evaporation	93
Plant & storage	148
Utilities	102
Truck loading	5
Transportation	18
Port	24
EPCM	47
Owners cost, contingency & other	120
Total Capex	**642**
Opex	**$/t**
Production	65
Transportation & port	6
SG&A, contingency	8
Sustaining capex	26
Total opex	**125**

Source: Allana Potash/Ercosplan

Harsh headwinds for junior miners

Prospects for junior mining projects suffered a setback in April after Karnalyte Resources decided to write off its Wynard project in Saskatchewan. The project's collapse is disappointing and will have repercussions for several reasons. Firstly, the project was at an advanced stage, having completed a bankable feasibility study (BFS) in 2012 and had secured investor interest from the Gujarat State Fertilizers & Chemicals (GSFC), who bought a 20% stake in the company for $45m in 2013. Secondly, the project was truly innovative having filed patents in North America covering directional drilling for potash extraction and an improved extraction and recovery process.

But what will most worry other juniors is the fact that Karnalyte blamed the shelving of the project on the "significant deterioration" in global potash prices since 2012. The company said that in the current price environment for potash: "It is not possible to finance and profitably construct and operate a potash production facility at the Wynyard Project."

Karnalyte's original 2012 feasibility study assumed a potash price of CAD480 ($392/t). Its decision to withdraw suggests that other greenfield projects may also struggle to prove they are a worthwhile investments, given that North American potash is currently trading 20% below this level at around $300/t (Vancouver f.o.b).

Project viability can be particularly sensitive to potash pricing levels. Karnalyte calculated, for example, that a 10% decrease in potash price from its assumed level would wipe out nearly a third of the Wynard project's investment worth, decreasing net present value (NPV) from CAD1.7 billion to CAD1.2 billion.

Gensource calculates that a potash price of $435/t is necessary for a typical greenfield Saskatchewan potash solution mine to earn a 15% internal rate of return (IRR), in contrast to the $580/t price required by a conventional mine to achieve the same IRR. The firm also maintains that the break-even potash price for a solution mine ($200/t) is lower than for a conventional operation ($235/t).

Gensource hopes to keep its capital outlay to a minimum and secure access to market by pursuing a small-scale, vertically-integrated production model to supply a single market partner. It also intends to rely on brackish groundwater to selectively mine potash. However, analysts CRU concluded in April that "Gensource has a long struggle ahead if it is to achieve the necessary financing to make the proposed mine a reality". Potash juniors face finance difficulties, in CRU's view, due to the number of projects being planned and the likelihood of an oversupplied potash market in future.

Eliminating risk

At current potash price levels, attention will inevitably focus on the cost advantages and sensitivities of various greenfield projects. The fortunes of junior mining companies may also depend on their ability to secure a strategic investor and/or long-term supply agreements.

Western Potash Corp has been fortunate to secure both for its 2.8 million t/a Saskatchewan-based Milestone solution mining project. China BlueChemical Ltd has indirectly invested $26 million (CAD32million) in the project. This provides the Chinese fertilizer company with an option to purchase either 30% of production or one millon t/a of potash, whichever is least, for a 20-year period. CBC (Canada) Holding Corp also took a $26m stake in Western Potash in 2013.

Those projects able to lower their energy consumption by using solar evaporation, as Allan Potash has done, also have obvious attractions. Two potash solution mining prospects in Utah's Paradox Basin, American Potash Corp's Green River potash project and Sennen Potash Corp's Monument project, plan to incorporate solar evaporation technology. Both are in the early stage

The solution mining process

Solution mining involves injecting fluid through a borehole to dissolve soluble, potash-bearing minerals locked within deep underground strata and extracting this as a brine solution through another borehole. The development of directional drilling now enables thinner potash beds to be targeted and extracted commercially. The potential advantages of solution mining compared to conventional extraction are lower up-front capital costs and shorter project ramp-up times. Drilling costs and well productivity will influence the overall profitability of a solution mine. But viability, as with all mine ventures, ultimately depends on geology, ore mineralogy, grade and resource tonnage.

Major North American sedimentary potash deposits occur in the Mid-Devonian-age Prairie Evaporite formation of the Williston Basin. This contains sylvinite ore, a mixture of sylvite (KCl), halite (NaCl) with minor amounts of carnallite ($KMgCl_3.6H_2O$) and insoluble materials such as clay, dolomite, and anhydrite. Sylvinite is typically mined and processed to produce muriate of potassium (MOP), a potassium chloride end-product.

Prairie Evaporite underlies a large area of Saskatchewan and parts of Manitoba, North Dakota, and northeast Montana, and is divided into three strata, the Patience Lake, Belle Plaine and Esterhazy members. Mosaic's Belle Plaine mine, the world's oldest solution mine, extracts potash from the Prairie Evaporite as does PotashCorp's Patience Lake mine and K+S's under construction Legacy project. The formation is also the target of Western Potash Corp's Milestone venture.

K+S's Legacy projects involves two phases of solution mining. In the primary phase, hot water is injected 1,500m below the surface through two boreholes to dissolve potash ore and form two circular caverns approximately 80m apart (Figure 1). Each of the three horizontal potash beds – Esterhazy, Belle Plaine and Patience Lake – are solution mined in a step-by-step process. A thin oil barrier is used to control vertical dissolution. In the secondary phase, injection of sodium chloride brine expands the caverns by selectively dissolving KCl from their walls and roofs (Figure 2). Secondary mining uses water more efficiently and also consumes less energy. Amec Foster Wheeler is currently overseeing a massive engineering project to construct six well pads at the Legacy site, each linked to nine underground caverns. Western Potash plans to use a similar two-phase solution mining process at its Milestone venture.

The potash deposits of the Paradox Salt formation which extends northwest-southeast across the Utah/Colorado border, mostly at depths below 1,200 m. These are currently exploited by Intrepid Potash's Cane Creek Moab and HB solution mines and are also the target of a number of junior miners currently.

Fig 1: Primary mining

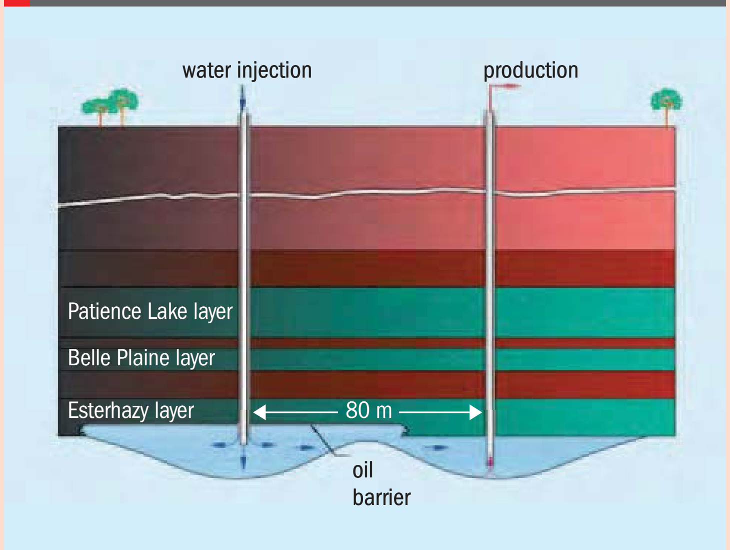
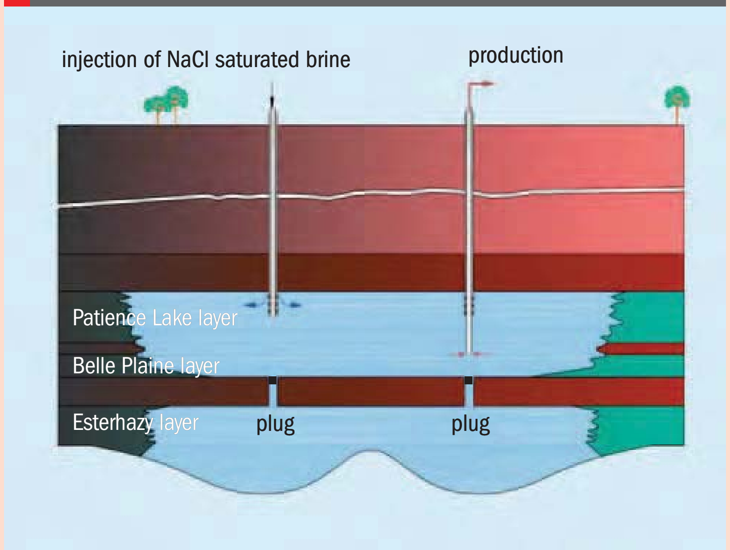


Fig 2: Secondary mining



of development but follow the relatively low capex/opex example of Intrepid Potash's HB solar solution mine in New Mexico. This 150,000-200,000 t/a mine required around $240 million to develop and operates at a cost of $90-100/t.

The underground temperature of the potash ore formation also influences operational costs, as it determines the amount of energy needed to heat injected fluids. Western Potash claims that elevated formation temperature at its Milestone project (65°C) has the potential to reduce production costs by 8.5% and increase KCl concentration in brine by 9%. This is in comparison to an equivalent potash project with a 10°C degree lower formation temperature.

"The higher temperature increases the concentration of KCl in the saturated brine being brought to the surface, which in turn reduces the energy required for evaporation and for brine circulation," reports Western Potash.

Sennen Potash claims to benefit from an even higher formation temperature (68°C) for its Utah project.

There is little that a developer can do to fundamentally change costs, as the boundaries for most solution mining projects are set, according to industry sources. What is clear, though, is that any project targeting a thick, high-grade ore body of high formation temperature, with access to cheap natural gas, and suited to solar evaporation will be most attractive to investors. ■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