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FERTILIZER INTERNATIONAL
ISSUE 468
SEPTEMBER-OCTOBER 2015

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INTERNATIONAL
Fertilizer

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NUMBER 468 SEPTEMBER | OCTOBER 2015

Cover: *Autumn leaves in a Boston public garden.*
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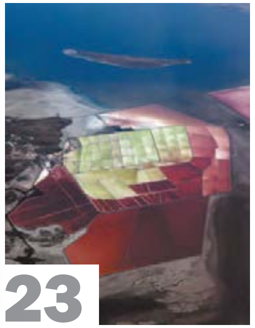
14 Sulphur supply



23 Brine potash

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Published by: BCInsight

CONTENTS

PHOSPHATES AND POTASH INSIGHT

REGULARS

CONTENTS
What's in issue 468

COVER FEATURE 1
TFI World Fertilizer Conference, Boston

COVER FEATURE 2
Sulphur supply sea change

COVER FEATURE 3
The elemental value of phosphorus

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Editorial

A circular argument

The carbon emissions from European ammonia production are regulated by the EU Emissions Trading Scheme (ETS) as part of the world's largest carbon market. Regarded as pioneering by some, and misbegotten and unloved by others, the 10 year old ETS 'cap and trade' system remains a central pillar of European climate policy. Reaction to ETS reforms tabled by the European Commission over the summer has, however, been swift and condemnatory. In July, Fertilizers Europe warned that the commission's proposals would transform the ETS from an incentive for cutting carbon into "a straightforward unavoidable tax" instead.

But, from a fertilizer industry perspective, what potentially undermines a system like the ETS is that it places an environmental straitjacket on just one single part of the food supply chain. The 'unfairness' of this was illustrated very starkly by a paper on EU food waste published in August's *Environmental Research Letters* by scientists at the European Commission's Institute for Environment and Sustainability. This supplied fresh evidence about the staggering amounts of food binned by Europe's households – and also revealed one particularly jaw-dropping fact. The researchers calculated that the nitrogen footprint of avoidable EU food waste is 1.34 million t/a (1.34 Tg yr^{-1}), equivalent to the entire mineral fertiliser use of the UK and Germany combined. (This claim doesn't quite ring true, however, as other statistics show that the UK and Germany actually applied 1.0 million tonnes and 1.6 million tonnes of nitrogen in 2013.)

> **"Over a million tonnes of fertilizer applied to crops is ultimately squandered.**

It does seems particularly pointless, or even tragic, that over a million tonnes of the fertilizer output of Europe's productive and efficient nitrogen industry is sold and diligently applied to crops only to be ultimately squandered in the way. Food is wasted all the way along the supply chain from farm to fork, and has its own serious climate impacts. The average carbon footprint of one tonne of supermarket food waste, for example, is around 1.62 tonnes carbon dioxide equivalent. So why, if the EU is forcing fertilizer producers to take responsibility for their carbon emissions, is it doing so little to prevent the massive carbon and nutrient losses resulting from food waste?

In fact, food waste reduction was included as part of a package of circular economy policies championed by the outgoing EU environment commissioner, Janez Potočnik, in 2014. Unfortunately, the incoming European Commission jettisoned Potočnik's proposals last autumn, only to re-emerge with another, second set of circular economy policies this summer.

Currently, our 'take, make, dispose' economy is largely linear with about 80% of mined and harvested materials made into products which are thrown away within a couple years. The idea behind the circular economy is simple: it is about capturing and keeping materials in economic circulation rather than sending them to landfill. In a circular economy, products are designed to be made again through repeated cycles of disassembly, refurbishment and remanufacture.

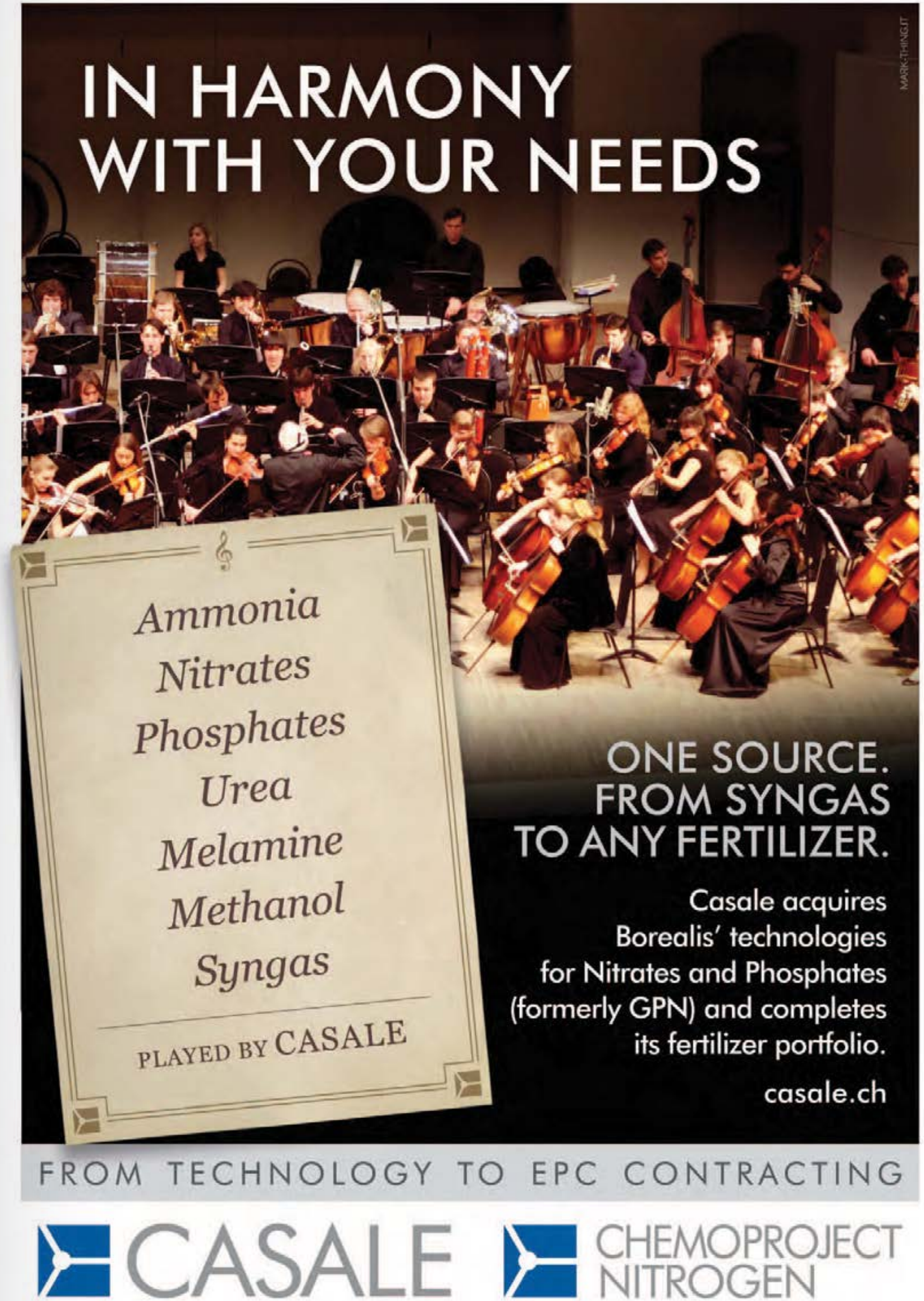
Business leaders are beginning to embrace the circular economy. The phrase is in vogue at the World Economic Forum, for instance. This has been helped by its endorsement by McKinsey who, in tandem with the Ellen MacArthur Foundation, have tirelessly promoted the circular economy.

Important voices in the fertilizer sector are also starting to speak out on the circular economy. Trade body Fertilizers Europe is one organisation showing leadership. It wants to change the sector's pattern of resource use, with a shift to waste reduction and more nutrient capture and recycling.

Fertilizers Europe takes these ideas seriously and organised an event at Expo Milano on 10 September to launch 'Infinite Fertilizers' – a new initiative to promote the efficient use of nutrients and cut the environmental footprint of food production. Jacob Hansen, Fertilizer Europe's director general, used the occasion to specifically link the Infinite Fertilizers concept with the circular economy.

Contributions to an EU consultation on the circular economy held over the summer should help ensure that fertilizer industry views are represented in any final policy prescription. The European Sustainable Phosphorus Platform has submitted its own wish list. It wants to see fertiliser regulations changed to allow the production and use of fertilizers made from wastes such incineration ashes. It also wants the EU to fund research into recovered mineral fertilizer products such as struvite.

Whether the EU ultimately legislates on the circular economy depends on the commission, the European Parliament and member states finding common agreement. Unfortunately, that proved impossible last year. Rejecting a second package of circular economy policies, though, would damage everyone's credibility and be in the interest of none. ■



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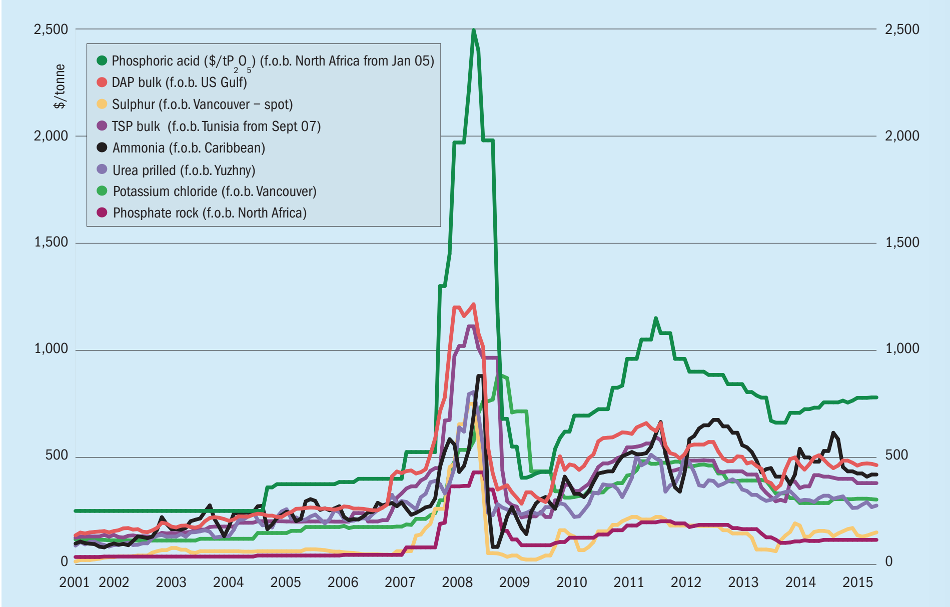
Market outlook

Historical price trends $/tonne



Source: BCInsight

Market insight courtesy of Integer Research

AMMONIA

Plant outages and shutdowns reduced supply substantially on the global ammonia market, with reduced availability from the Black Sea region due to maintenance intervals, gas curtailments in Trinidad and outages in both North Africa and the Arab Gulf in July and August. Demand has been subdued, particularly during Ramadan in July when no deals were concluded in the Arab Gulf region, counteracting upward pressure on prices resulting from low availability. Prices fell slightly, and have been hovering around their floor level between $377-385/t f.o.b. Black Sea during July and late August.

UREA

Urea markets remained comparatively quiet in July and August, with sluggish demand and few deals concluded. Prices fell throughout July, reaching $263/t f.o.b. Black Sea in late July, but edged up again in August on the back of expectations that an Indian tender could be issued imminently. However, the market is staying cautious amidst great uncertainty caused by China's re-introduction of 13% VAT on domestic fertilizer sales and imports from September, as well as the devaluation of the Chinese currency in August.

PHOSPHATES

The phosphates market was expected to tighten as summer progressed, especially as the start of monsoon season and firmer guidance on subsidies in India removed the uncertainty that had previously clouded the market. Indeed, a number of suppliers were sold out for July as a consequence of India, the largest DAP importer, buying nearly 4 million tonnes from April to July. However, the monsoon season has thus far proved disappointing, and due to the tonnages sold earlier this summer, buyers are adequately supplied and not in a hurry to replenish stocks. Indian buying is therefore now expected to slow, until clarity on the economic outlook and price ideas emerges. Prices have since edged downwards and Chinese DAP has been sold at $458-459/t f.o.b. into India.

Currency devaluation in August increased buyers' hopes of lower prices from China, the world's largest DAP supplier. But the Chinese government also moved to reinstate 13% VAT on fertilizer imports from September. China's producers are not under immediate pressure, as many are currently sold out until mid-September.

POTASH

Global potash prices have continued to soften during the third quarter. Significantly, the usual premium for granular grade MOP enjoyed in the US market has severely eroded. The NOLA barge price, a key US pricing indicator for imports, has been falling steadily throughout 2015 and is now at $305 per short ton, reflecting higher inventories, a weak crop price environment and competitive pressures.

There have been attempts to shore up prices. Canpotex announced new MOP pricing of $335/t cfr standard and $350/t cfr granular for Southeast Asian markets in

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early July, but currency volatility is making importers nervous. The window for raising prices of granular MOP during the peak application season in Brazil to $340/t cfr has also now passed. Prices today are around $320-325/t cfr with buying ideas heard closer to $300/t cfr. The June/July period is being viewed as the slowest for Brazilian potash demand in several years, as the country has grappled with currency weakness, a lack of farm credit and a higher starting inventory. In January-June 2015, Brazil's MOP imports fell by 21% year-on-year, down 0.9 million tonnes to 3.2 million tonnes.

SULPHUR

Following three months of rising sulphur prices out of the Middle East, there are the first signs of softening, after Aramco Trading set its September sulphur price at $150/t f.o.b. Jubail, a small $2/t reduction on August's $152/t price. The global market has been supported by buyers in China, the world's number one importer of sulphur. But, in the midst of currency devaluation and stock market losses, trading started to slow towards the end of August. At the same time, lacklustre downstream demand from China's phosphates producers over the summer has seen sulphur inventories at ports start to rise again – moving above the one million tonne mark and reducing the pressure to buy. There has been limited activity elsewhere in the market – third quarter contracts were settled in northwest Europe, Mediterranean demand has been poor and there have been no new spot tenders in the last month out of Latin America.

Market price summary $/tonne – Early-September 2015

Nitrogen	Ammonia	Urea	Ammonium Sulphate	Phosphates	DAP	TSP	Phosphoric Acid
f.o.b. Caribbean	405	n.m.	f.o.b. E. Europe 113-116	f.o.b. US Gulf	463-465	n.m	n.m
f.o.b. Yuzhny	370-390	262-267	-	f.o.b. N. Africa	477-505	380-405	720-840
f.o.b. Middle East	350-410	262-270**	-	cfr India	465-470	-	810*
Potash	KCl Standard	K_2SO_4	**Sulphuric Acid**		**Sulphur**		
f.o.b. Vancouver	290-310	-	cfr US Gulf	65-70	f.o.b. Vancouver	135-150	
f.o.b. Middle East	285-310	-			f.o.b. Arab Gulf	133-150	
f.o.b. Western Europe	-	€480-520			cfr North Africa	145-150	
f.o.b. FSU	272-295				cfr India	150-155+	

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:** Limited availability is expected to continue through September, with a further shutdown in Saudi Arabia in late August and the ongoing maintenance shutdown at OPZ putting pressure on the supply situation for weeks to come. Traders and producers have been forced to repeatedly reject requests from spot buyers, such is the severity of the situation. Prices are therefore likely to start rebounding in September as a result.
- **Urea outlook:** All eyes will be on the impact of Chinese policy changes going forward, as China's excessive supply of urea is the main price driver in global urea markets currently. The VAT increase could be added onto ex-works prices for urea, raising export offers. Yet uncertainties remain over whether VAT on input prices will be offset against VAT on sales, and exactly how the tax will be imposed along the supply chain. Government policy changes could in any case be cancelled out by China's recent currency devaluation.
- **Phosphates outlook:** Some suppliers from regions outside of China are trying to place product in the export market promptly. This attempt to take advantage of the time left before new VAT rules come into force is increasing pressure on the domestic market. Imposition of VAT will increase DAP/MAP producer costs by 3-5% going forward, so producers will likely raise domestic prices by around CNY50-100/t starting from September. Elsewhere, weaker overall demand has affected the Americas. Increased US corn production forecast by the WASDE report in August is likely to have a negative impact on prices going forward. There is also downward pressure on MAP prices in Brazil, as continuing currency falls against the dollar compound credit availability issues. Brazilian market prices are likely to remain under pressure in the short term – unless or until weaker exchange rates stimulate agricultural exports.
- **Potash outlook:** Although Chinese demand has been strong so far, the recent currency devaluation could well slow down imports, with impacts on large Canadian, Russian and Israeli suppliers. The uptick in soybean prices may not be enough to turn things around in Brazil. But suppliers do expect a healthier second half for US potash demand, as farmers address depleted soil nutrient levels. Russian output continues to run at lower rates. A capacity expansion of 0.8 million t/a, to counteract the partial loss of production at Uralkali, will only take effect from 2016, although North American majors can compensate. Agrium's Vanscoy mine is reaching new daily output targets following its expansion. The ramp-up of PotashCorp's brand new mine in New Brunswick is also progressing as planned.
- **Sulphur outlook:** The market is bearish as very little spot activity is taking place and downstream phosphate demand is limited. Sulphur prices seem unlikely to hold at the high prices seen so far in 2015, especially given the current widespread uncertainty in the commodity markets. In a sign of sulphur price weakening, OCP has been able to push for a decrease from FSU suppliers. This is on expectations that UAE capacity will bring more product to market from the third quarter, as the Shah gas project adds new supply from Ruwais. Mosaic's sulphur remelter in Florida, USA, and the Wasit project in Saudi Arabia are also due in 2015, although other projects such as at the Cartagena refinery in Colombia and Carabobo in Venezuela have been delayed.

Fertilizer Industry News

UNITED STATES

CF and OCI merger creates world's largest nitrogen company

CF Industries' Port Neal Nitrogen Complex.

CF Industries is to merge with OCI's $8 billion European and North American operations and worldwide distribution business. The massive merger was announced on 6 August and is the most significant nitrogen market M&A deal in years. The newly-created company will become the world's largest publicly-traded nitrogen business with a production capacity in the region of 12 million short tons. CF also took full control of UK producer GrowHow recently (*Fertilizer International*, 467 p10).

The merger, which won unanimous approval from the board of directors of both companies, brings with it OCI's nitrogen production facilities at Geleen in the Netherlands, and the nearly-completed Wever greenfield nitrogen project in Iowa. Importantly, it also includes two Texan methanol plants, namely OCI's share in the Natgasoline methanol project and its interest in the Beaumont ammonia and methanol complex. The opportunity to expand its portfolio into the fast-growing methanol market is an obvious attraction for CF Industries. The inclusion of OCI's Dubai-based global distribution business will also extend its product reach.

OCI will, however, retain control of significant nitrogen-producing assets, including operations in Egypt and Algeria, with a combined production capacity of 4.8 million t/a.

The deal is expected to deliver annual savings of around $500 million after-tax and should be completed by mid-2016, subject to shareholder and regulatory approval. Under the terms agreed, CF industries will become a subsidiary of a new UK-based holding company led by its existing management and operating under the name CF. OCI will own a 25.6% slice of the new corporation and also be rewarded with $700 million in cash or shares, payable at CF's discretion– although the assumption is that $550 million of this amount will be in shares. CF will keep its executive offices in Deerfield, Illinois, and be New York Stock Exchange listed.

Tony Will, CF's president and CEO, welcomed the deal as a "terrific opportunity for the shareholders of both companies", adding: "This is also a great outcome for US farmers as we have another supply point that will ensure our critical products are delivered reliably and in-time to meet our customers' needs." Nassef Sawiris, OCI's CEO, said "As significant owners in the combined entity, our shareholders will benefit from the on-going value creation of the business."

Yara and BASF break ground on new Freeport ammonia plant

Construction has started on $600 million ammonia plant being jointly developed by Yara International and BASF at Freeport, Texas. The plant is expected to produce 750,000 t/a of ammonia when it comes on-stream in 2017. Yara is managing construction of the plant, which BASF will then operate once it is completed. Yara is also building a new ammonia tank at BASF's existing terminal as part of the project, whilst BASF is upgrading the terminal to allow the export of ammonia from the new plant.

Once completed, Yara and BASF will take a share of the ammonia off-take from the plant in direct proportion to their ownership stakes of 68% and 32%, respectively. Yara plans to sell its off-take to industrial and agricultural users across North America. BASF, in contrast, will produce caprolactam for nylon manufacture.

KBR are EPC contractors for the project. Ammonia will be produced at Freeport using a hydrogen-based process, significantly reducing capital expenditure and maintenance costs compared to traditional plants consuming natural gas feedstocks. Praxair, the largest industrial gases company in North America, will supply the plant with nitrogen and hydrogen as part of a long-term supply agreement.

Speaking at the ground breaking ceremony, Torgeir Kvidal, Yara's president and CEO said: "The building of the Freeport Ammonia plant is a firm demonstration of how we deliver on our growth strategy." Wayne Smith, chairman and CEO of BASF Corporation and an executive director of BASF SE, added: "Through the joint investment with Yara, we can take advantage of world-scale production economics and the attractive raw material costs in the United States; strengthening our operations in Freeport and the competitiveness of our customer value chain in the region."

Rentech Nitrogen purchased by CVR Partners

In a second market merger, Nitrogen producer CVR Partners announced the purchase of Rentech Nitrogen Partners for $533 million on 10 August. The merger creates North America's fifth-largest nitrogen producer. Rentech Nitrogen will own a 35.6% share of the combined company.

The deal will add a second nitrogen plant at East Dubuque, Illinois, to CVR's assets, but apparently excludes Rentech's Pasadena plant. CVR will refinance Rentech's net debt of about $307 million as part of the deal. The merger will be finalised before May 2016, and most likely by the end of this year, according to both companies.

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K+S secures exclusive US offtake agreement for Legacy

The North American subsidiary of K+S has signed an exclusive supply agreement with the trading arm of Kansas-headquartered Koch Fertilizer LLC. This grants Koch exclusive rights to supply a half a million short tons (453,000 metric tonnes) of potash annually to its US customers. The potash will be sourced from K+S's Legacy mine in Saskatchewan. The CAD 1.7 billion mining project is on track to enter production next year and is set to reach around two million t/a of potash capacity by the end of 2017.

"This is an exciting opportunity for Koch Fertilizer to grow our portfolio of fertilizer products to US retailers," said Scott McGinn, president of Koch Fertilizer. "We are proud to enter an agreement with K+S [which] allows Koch Fertilizer to provide additional high quality products produced in North America." K+S board member Andreas Radmacher also welcomed the deal. "Koch Fertilizer is a distinguished partner with excellent experience marketing a robust portfolio of fertilizer products," he said, adding: "We are seeing enormous interest in potash from our Legacy mine both from existing and new customers."

CHINA

China imposes VAT on fertilizers and devalues currency

China reintroduced value added tax (VAT) on fertilizer sales at the start of September, stoking anxiety about the wider health of its economy and future growth prospects. The new sales tax is being levied at a rate of 13% and encompasses urea, potash and phosphate products. The policy change was announced at short notice by the Ministry of Finance on 10 August, triggering a rush to offload stock from inventories before the 1 September deadline. Reinstatement of VAT – first introduced in 1994 but later dropped – was needed to keep prices and supplies stable, the ministry said in a statement.

To complicate matters, VAT imposition was immediately followed by a devaluation of the yuan by the Chinese central bank between 11-13 August. The combined effect of the sales tax hike and currency falls is likely to be mixed. Integer Research predicts that devaluation will improve the cost position and competitiveness of Chinese producers and boost their export prospects. But any export gains are likely to be partially offset by the additional costs of VAT on domestic sales and imports, in Integer's view. Commodity prices falls triggered by the yuan's devaluation, notably for crude oil, is a further complicating factor, and may lead to continuing weakness in nitrogen feedstock prices. The recent plunge in copper prices could also act as further brake on the sulphuric acid market.

Analysts CRU estimate the new VAT rules will raise Chinese prices by roughly \$3.50/t for urea, \$15/t for phosphates and \$25-41/t for potash, although these are ballpark estimates and may not be passed on in full. The impact of the sales tax will also vary because some Chinese producers are able to partly offset prices rises by deducting VAT payable on inputs. Supply chain arrangements are also an important factor. Non-integrated producers, for example, are likely to pay 17% VAT on ammonia purchases, if these are from outside plants or supplied by a subsidiary.

The degree to which VAT rises are passed on depends on both the currency devaluation and prevailing conditions in the phosphate and urea markets. However, China's overseas suppliers are likely to come under pressure to cut their prices when import contract negotiations begin towards the end of the year, suggests CRU. Although they remain unchanged for the present, VAT imposition may eventually trigger a review of Chinese export tariffs on fertilizers, especially as some producers regard VAT as a second tax on exports and are pushing for compensation.

NETHERLANDS

Stamicarbon to build new urea granulator for Yara

Stamicarbon has secured the €125 million engineering, procurement and construction (EPC) contract for Yara International's new granulation plant at its Sluiskil site near Antwerp. The new plant will produce 660,000 t/a of sulphur-enriched urea using Yara's proprietary technology. The new plant will replace an existing 400,000 t/a urea prilling unit at the site.

The 25 months project involves a joint team of Yara and Stamicarbon specialists and is due to be competed in 2017. Sluiskil's UAN output will be reduced by 230,000 t/a as part of work at the site, although CAN production will be ramped-up by an extra 130,000 t/a instead.

Maire Tecnimont's CEO, Pierroberto Folgiero, said the firm was honoured to be working with Yara again on such a prestigious project: "This contract consolidates a fruitful long-term industrial cooperation with a prominent global player, developed through decades of technology supply carried out by our subsidiary Stamicarbon. [It] offers sound evidence of the group's leadership in the fertilizer sector, one of the strategic pillars of our core business."

FINLAND

Outotec wins Siilinjärvi mine tailings plant contract

Outotec has secured a contract with Yara Suomi Oy to design and deliver a new high density tailings disposal system for its Siilinjärvi phosphate mine. The €40 million EPC contract also includes commissioning and the provision of spare parts and servicing. The new 'paste plant' is expected to become operational in the first half of 2017.

The production of one million t/a of apatite concentrate at Siilinjärvi generates about 10 million t/a of tailings as a sand and water slurry. The new high density tailings and disposal system dewaters this slurry, converting it into easier to dispose paste, and reclaims water for mineral processing. "Yara is our long-term partner with whom we have developed and pilot-tested an optimal thickened tailings solution based on Outotec's paste thickener technology," commented Outotec's minerals processing business head, Kalle Härkki. He said that extending the life of Yara's existing tailings facilities and efficient water use at the site were also environmentally beneficial.

INDIA

Tata fertilizer sell-off rumoured

Tata Chemicals Ltd is reportedly seeking buyers for its fertilizer business. The move is part of major restructuring planned by Tata Group chairman, Cyrus Mistry, according to India's *Economic Times*. Fertilizers accounted for almost two fifths (38%) of Tata Chemicals' revenues last financial year. However, divestment would allow Tata to cut debt and focus on its higher-growth consumer and industrial chemicals businesses.

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According to Indian business sources, The Kotak Mahindra Bank Ltd has been sounding out buyers for Tata's fertilizer arm, said to be valued at close to $1 billion. A range of domestic and foreign producers including Coromandel, Deepak Fertilisers, Aditya Birla Nuvo and Morocco's OCP are believed to have been approached – although this has not been verified by Tata or the firm's named.

Tata Chemicals owns a urea plant in Babrala, Uttar Pradesh, one of the most energy-efficient in the country, and a DAP plant at Haldia, West Bengal. It also owns a one third stake in the IMACID phosphoric acid plant in Morocco which supplies Haldia. However, Tata pulled out of a fertilizer project in Gabon last year. It also abandoned a planned urea expansion at Babrala in 2014, blaming the rising price of natural gas feedstock. The Indian government owed Tata's fertilizer operations 19.7 billion rupees ($310 million) in subsidy arrears at the end of March this year.

Tata has not commented directly on the sell-off but filed a statement in July saying: "We routinely assess the performance of our businesses and the relevant market conditions, including evaluating growth and restructuring opportunities."

Mitsubishi and IFFCO form joint venture

Mitsubishi Corporation is setting up a new agrochemicals sales and distribution venture in India with the Indian Farmers Fertiliser Cooperative (IFFCO), the country's largest producer and distributor of fertilizers. The new company, IFFCO-MC Crop Science Private Limited, will be 49% owned by Mitsubishi and 51% owned by IFFCO. Mitsubishi said it will capitalise on IFFCO's brand and its extensive sales network to supply agrochemicals to the Indian market, mainly herbicides, insecticides and fungicides, starting this October. It said the joint venture was "the product of years doing business together".

UZBEKISTAN

Mitsubishi to build Navoiy ammonia and urea plant

Chemical production company Navoiyazat JSC has selected Mitsubishi Heavy Industries and Mitsubishi Corporation to build a large-scale ammonia and urea plant at the city of Navoiy in central Uzbekistan. Mitsubishi announced in July that an EPCC contract for the project "will soon take effect". The new fertilizer plant will benefit from access to Uzbekistan's abundant natural gas resources and use "world-leading" licensors to produce 2,000 t/d of ammonia and 1,750 t/d of granulated urea. Navoiyazat currently produces around 60 products, including fertilisers, chemicals, polymers and acids. Its parent company, Uzkimyosanoat JSC, also manufactures N, P and K fertilizers.

TURKMENISTAN

Production commences at Garlyk potash mine

The Garlyk potash mine in the Lebap region of Turkmenistan entered production over the summer. The 1.4 million tonne MOP mine and processing plant is expected to be fully commissioned early in 2017. With maximum domestic demand estimated at 700,000 tonnes, at least half of the mine's output is likely to be exported. India is a key target market and the country's Prime Minister, Narendra Modi, discussed future fertilizer supply during a visit to Turkmenistan in June. The project is being implemented by Belarusian firm Belgorkhimprom under an agreement with the Turkmen government dating from 2010. A future link-up with the Belarusian Potash Company over export handling is thought possible, due to the close level of cooperation between the two countries.

RUSSIA

ThyssenKrupp wins phosphate mining contract

ThyssenKrupp Industrial Solutions has secured a €30 million mining equipment contract with PhosAgro subsidiary Apatit. The engineering and construction firm will install a 31 million t/a capacity in-pit crushing and conveying (IPCC) system for an apatite-nepheline ore mine near the city of Kirovsk on Russia's Kola Peninsula.

ThyssenKrupp will supply Apatit with a semi-mobile crusher, three belt conveyors and a spreader system needed to remove overburden and expose phosphate seams. The contract also includes engineering, procurement, construction and full commissioning. The new system will take 24 months to deliver and is expected to significantly reduce mine operating costs and carbon emissions once installed.

PhosAgro separately announced the commissioning of a new shaft (main shaft no.2) at Apatit's Kirov Mine near Murmansk. The 350 metre-deep shaft has a nameplate capacity of 8 million t/a. The investment of over RUB 13 billion ($192 million) in the new shaft should boost the mine's ore capacity from 13 million t/a to 16.5 million t/a.

EuroChem's Kingisepp project underway

Construction has started on EuroChem's €900 million, one million t/a capacity Kingisepp ammonia plant in Russia, and is expected to last three years. Maire Tecnimont secured the €600 million EPC contract to build the plant earlier this year (*Fertilizer International*, 467 p 12).

"We are pleased to have launched the construction of our new ammonia production facility in Kingisepp, which is expected to be brought online in 2018," commented EuroChem's CEO Dmitry Strezhnev. "This project is part of EuroChem's broader strategy to improve our level of self-sufficiency through greater control over our own raw materials base."

Plans for EuroChem and Maire Tecnimont to collaborate on building five ammonia plants across the globe emerged in a memorandum of understanding agreed between the two in April (*Fertilizer International*, 466 p14) The Kingisepp project is the first of these to move to construction.

MALAYSIA

Koreans invest in Sarawak nitrogen complex

South Korea's Hu-Chems Fine Chemicals is to invest $1 billion constructing a nitrogen complex in Sarawak, Malaysia. This will have the capacity to produce 600,000 t/a ammonia, 400,000 t/a nitric acid and 200,000 t/a of ammonium nitrate and is due to be completed by 2019. Increasing ammonia capacity to one million t/a is a possible future option. Further investment in downstream production of fertilizers and chemicals is also planned. Production at the site is backed by a long-term gas supply contract signed with the Malaysian government last December.

On the Malaysian mainland, CCM Fertilizers has announced the closure of its 240,000 t/a Shah Alam ammonium nitrate (AN) plant, blaming prolonged negative market conditions and falling demand for AN fertilizers. The worsening crude palm oil price and high palm oil inventory levels meant that its major customers, oil palm plantations, were "trending down to cheaper fertilizers", CCM said in a statement. The company is to continue 260,000 t/a production of urea-based fertilizers from two plants at Lahad Datu, Sabah, and Bintulu, Sarawak.

SPAIN

European banks back Muga potash project

Highfield Resources has secured a long-term €222 million finance mandate from four major European banks for its Muga potash project in Spain. The quartet, BNP Paribas, ING Bank, Societe Generale and Santander, are offering finance over an eight-year term at a debt-to-equity ratio of up to 65%. Full approval is expected in October once the banks complete due diligence.

Highfield plans to start construction on the Muga project in the fourth quarter of this year, having raised $80 million on the Australian Stock Exchange in May (*Fertilizer International*, 467 p13). Muga should enter production in the first half of 2017, if all goes to plan. "The mandate with the four European commercial banks provides a high level of confidence that the funding process will be completed prior to the commencement of construction at our flagship Muga mine," commented Anthony Hall, Highfield's managing director.

AUSTRALIA

Orica cuts nitrates output

Orica is to scale-back ammonium nitrate (AN) production at its Yarwun plant in Queensland from 320,000 t/a to 280,000 t/a, blaming challenging market conditions and short-term oversupply. The Yarwun plant has been operating at well below its 530,000 t/a capacity for some time, and around 20-40 jobs will be lost as a result of the latest cut in production.

Yarwun General Manager, Dave Buick, said: "While we remain confident in the long term outlook for ammonium nitrate, there is a near term oversupply in the market." Explosives for the quarrying and mine industry, rather than fertilizers, are the primary market for AN in Australia. Orica launched a business review in August following its decision.

TUNISIA

CPG resumes phosphate mining

State-owned Compagnie des Phosphates de Gafsa (CPG) has started mining and moving phosphates from its Kef Eddour mines in Tunisia after a four-year hiatus. Phosphates are again being transported by rail and road from the mines in Gafsa province to processing facilities over 200 km away in the provinces of Sfax and Skhira. The resumption of mining activities will be a boost to Tunisia's phosphate industry which has languished and operated only sporadically since 2011 due to fallout from the 'Arab Spring'.

Tunisian phosphate ore production fell from an average of almost 8 million t/a during 2000-2010 to 2.2 million tonnes in 2012. Output did rebound to around 4 million tonnes in 2014 mainly by using stored inventories of ore. The Kef Eddour mines have produced a third of Tunisia's phosphate ore in the past and should add 3 million t/a of extra output if operation at normal rates resumes.

FERTILIZER INTERNATIONAL
ISSUE 468
SEPTEMBER-OCTOBER 2015

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People

Newly formed CF appoints two new board members

Two new board members are to join CF Industries following its merger with OCI (see our lead news story). Although the newly created firm, named CF, will be led by the existing management of CF Industries, the existing eight-member board will expand to 10 people. Current OCI board member Greg Heckman, the former CEO of Gavilon, will join CF's new board. Alan Heuberger, senior portfolio manager for Bill & Melinda Gates Investments, is the other new appointee. CF Industries' current headquarters in Deerfield, Illinois, will be kept as a corporate base for the new firm.

Ken Seitz is new Canpotex CEO

Ken Seitz is to take over as CEO of Canpotex Ltd on the 1 November. Canpotex, the export arm of PotashCorp, Mosaic and Agrium, announced he will succeed Steve Dechka, the outgoing CEO, on 4 August. Seitz stepped down from his previous position as the chief commercial officer of uranium producer Cameco Corp in mid-August.

Yvonne Harz-Pitre joins IFA

Yvonne Harz-Pitre is to join the International Fertilizer Industry Association (IFA) as its new director for communications and public affairs in September. Ms Harz-Pitre, a German national, has lived in France for many years and speaks excellent English. She was previously head of global communications for the AgroFresh Division of Dow Agro Sciences in Paris.

Clariant announces untimely death of Dominik Koechlin

Dominik Koechlin, a non-executive member of Clariant's board of directors, unfortunately died, suddenly and unexpectedly, on 12 July. He was president of Clariant's compensation committee and a member of its audit committee. Koechlin joined Clariant's board in 2008 and held a PhD in law.

"All members of the Clariant board of directors as well as the executive committee, the employees and executives of Clariant, are deeply shocked to hear about Dominik Koechlin's death", said Rudolf Wehrli, chairman of Clariant's board of directors. "We mourn the loss of an adorable colleague and a passionate entrepreneur that Clariant has a lot to thank for."

Yvonne Harz-Pitre

Dominik Koechlin

New crop research prize for young scientists

The International Fertiliser Society (IFS) has unveiled a new global prize scheme for young crop scientists. Known as the Brian Chambers International Award for Young Researchers in Crop Nutrition, it provides prizes worth a total of £2,000 to researchers working at MSc- or PhD-level at any academic institution across the world. The IFS will award a cash prize of £1,000 for the winner, plus £500 each for two runners-up. Researchers will, however, need to demonstrate that their work has practical benefits for crop nutrition. Participation in the award is open to the following people:

- Anyone aged under 26 studying for an MSc or PhD or equivalent qualification at an academic institution
- Researching the nutrition of arable crops and grassland, involving any types of plant nutrients
- undertaking research activity that is based on field studies, pot or laboratory studies, or other data analysis.

The winners and two runners up will be announced at the IFS Agronomic Conference in December. Further details are available on the IFS website at http://fertiliser-society.org.

IFS has named the new award in memory of professor Brian Chambers who died earlier this year. Brian was an IFS council member and head of the soils and nutrient group at ADAS in the UK.

Professor Chambers was internationally renowned for his pioneering research on manure management and the minimisation of environmental pollution. He was a visiting professor at Cranfield University, a member of the British Society of Soil Science and also served as President and Fellow of the Institute of Professional Soil Scientists (IPSS). Another initiative, the Brian Chambers Soils Fund, has also been set up in the UK in his memory. The award and the fund both reflect Brian's interest in encouraging young people to take up rewarding science careers.

Steve Langley joins H.J. Baker

Steve Langley is joining H.J. Baker's Crop Performance Division and Animal Health and Nutrition Division. Langley will oversee all of the firm's international sales and marketing activities in his role as director of international sales and exports. He has been recruited to accelerate global growth initiatives and will be based in Kansas City, Missouri.

Langley brings to H.J. Baker more than 30 years of international business expertise in agriculture manufacturing and marketing. For the last five years, he has focused on the swine and poultry equipment industry as vice president of business development for QC Supply Inc and ran the swine management systems for North America for Big Dutchman, Inc, out of Holland, Michigan. Langley also spent more than 14 years as a sales and marketing executive and then chief operating officer of the China Premium Food Corporation in Shanghai, China. During his China tenure, he was also the founder and president of the North American Agri-Business International, a firm which played a significant role in helping US and European companies successfully gain market entry into China. Langley currently serves as chairman and director on several boards of US and Chinese companies.

"Steve's depth of international experience and success in the agriculture industry make him a true asset for H.J. Baker," said executive vice president of sales and marketing Steve Azzarello. "Having Steve join us as Director is only going to help us as we move forward in our efforts to grow internationally. ■

Calendar 2015/16

SEPTEMBER

21-23
IFA Production & International Trade Conference, TAMPA, Florida, USA.
Contact: IFA Conference Service
Tel: +33 1 53 93 05 25
Email: conference@fertilizer.org
Web: www.fertilizer.org

27-29
TFI World Fertilizer Conference, 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

20-22
IFA Crossroads Asia-Pacific, KUALA LUMPUR, Malaysia.
Contact: IFA Conference Service
Tel: +33 1 53 93 05 25
Email: conference@fertilizer.org
Web: www.fertilizer.org

NOVEMBER

9-12
Sulphur 2015, CRU Events, TORONTO, Canada.
Contact: CRU Events
Tel: +44 20 7903 2444
Email: conferences@crugroup.com
Web: www.crugroup.com

JANUARY 2016

27-29
Fertilizer Latino Americano 2016, CARTAGENA, Colombia.
Contact: CRU Events
Tel: +44 20 7903 2444
Email: conferences@crugroup.com
Web: www.crugroup.com

FEBRUARY

2-4
22nd AFA Annual International Fertilizer Forum & Exhibition, CAIRO, Egypt.
Contact: AFA Conference Section
Tel: +20 2 2417 2347
Email: info@afa.com.eg Web: www.afa.com

MARCH

13-15
Phosphates 2016, PARIS, France.
Contact: CRU Events
Tel: +44 20 7903 2444
Email: conferences@crugroup.com Web: www.crugroup.com

FERTILIZER INTERNATIONAL
ISSUE 468
SEPTEMBER-OCTOBER 2015

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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

TFI welcomes you to Boston

The Westin Copley Place and Fairmont Copley Plaza in the vibrant city of Boston are the venues for The Fertilizer Institute's 2015 World Fertilizer Conference this September.

Boston, Massachusetts plays host to this year's World Fertilizer Conference, the leading annual event organised by The Fertilizer Institute (TFI). More than 800 industry delegates from across the globe are expected to congregate in the city for the three-day programme between 27-29 September.

The conference's exceptional guest speakers and the unparalleled opportunities for business networking have attracted delegates in ever larger numbers in recent years. Chris Jahn, TFI president, promised that: "We will continue to build upon our reputation for bringing phenomenal breakfast speakers who will explore thought-provoking global and management topics valuable to your business operations."

The conference will welcome delegates with an evening reception on Sunday 27 September. High calibre keynote speakers will then address the conference at breakfast sessions on the following two days. On Monday 28 September, **Nader Mousavizadeh** will offer some sage insights into the current geopolitical and macroeconomic situation. Nader writes frequently on these topics for *Financial Times*, *The New York Times* and *Reuters*. He also acts as an advisor to some of the world's leading corporations and investors.

In his *Reuters* column, Mousavizadeh analyses developments in what he refers to as an 'archipelago world'. He explains this as follows: "A deeper – and more radical – shift is at work in the politics of the global economy. A fragmentation of power, capital and ideas is creating a new map of the world with lasting implications for investors and policymakers alike."

Mousavizadeh is currently CEO of global analysis and advisory firm Oxford Analytica. Over an extremely diverse and successful career, he has held senior roles in diplomacy, investment banking and business consultancy. Notably, Mousavizadeh served as Special Assistant to United Nations Secretary-General Kofi Annan, and was a UN Political Officer in Bosnia-Herzegovina. He later co-wrote Annan's memoir *Interventions: A Life in War and Peace*.

Elected a 'Global Leader for Tomorrow' by the World Economic Forum, Mousavizadeh is now a member of the Forum's Global Agenda Council on Geopolitical Risk. He also serves on the board of trustees of Farm Africa. A former associate editor of *The New Republic*, his coverage of the war in the former Yugoslavia was later collated as *The Black Book of Bosnia*. Mousavizadeh received his MBA as a Sloan Fellow at MIT. He is also a magna cum laude graduate of Harvard College and received an MA in international relations whilst a Rhodes Scholar at Oxford.

At the second breakfast session on Tuesday 29 September, delegates will have the opportunity to listen to the renowned public speaker **Peter Sheahan**, founder of global consultancy ChangeLabs. Peter is known internationally for innovative business thinking and thought leadership, and writes and speaks extensively about exploiting business trends and new market opportunities.

Sheahan has worked with some of the world's leading brands, including Apple, Goldman Sachs, Microsoft, Hyundai, IBM, Pfizer, Wells Fargo and Cardinal Health. He is the author of six books, including *Flip*, *Generation Y* and *Making it Happen*. He was named one of the 25 Most Influential Speakers by the National Speakers Association. Impressively, he has delivered more than 2,000 presentations to over 300,000 people in 15 different countries.

Peter also knows first-hand about how to grow a business in rapidly-changing times. His behaviour change consultancy, ChangeLabs, advises executives in manufacturing, health care, telecommunications, financial services and IT, and has staff in nine cities across three countries. Its client list features luminaries such as Apple, IBM, the Commonwealth Bank Foundation and Mondelez. ■

FERTILIZER INTERNATIONAL
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SEPTEMBER-OCTOBER 2015

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A disruptive influence

Sirius Minerals is developing the world's thickest and highest-grade polyhalite deposit near Whitby in northern England as part of its flagship York Potash Project. The ambition is to produce 10 million t/a of polyhalite, either as a direct application fertilizer or as a source of potassium in a NPK blend. The firm's CEO, **Chris Fraser**, and marketing head, **J.T. Starzecki**, update us on the project's progress in an exclusive interview.

Fig 1: **Location of York Potash project**

Source: Sirius Minerals

With its plan to sell an unprecedented large volume of polyhalite into the fertilizer market, Sirius Minerals has some very bold ambitions for the York Potash project, as J.T. Starzecki, director of marketing and sales makes clear: "What we've set out to do is really a game changer. This space has been very traditional – traditional players, traditional ways of doing business. We have come in as a bit of market disruptor, both by the size and the magnitude of what we're implementing, and just the fact that it's a new product."

Over the planning hurdle

Sirius Minerals secured planning consent for its York Potash project over the summer (*Fertilizer International*, 467 p9). The £1.7 billion, UK-based project involves the construction of an underground polyhalite mine at a 64-hectare site within the North York Moors National Park, and a 23-mile (37 km) subsurface minerals transport system linking the mine with port facilities at Teesside on England's North Sea coast (Figure 1).

Confidence at Sirius Minerals is high as, having secured planning permission, the York Potash project edges closer to the construction phase. Yet the project will need to cross further critical thresholds over the next six months, most notably the publication of a definitive feasibility study (DFS) in the last quarter of 2015, and the completion of financing for front-end construction in the first quarter of 2016. The DFS is expected to unveil costs for a 10 million t/a capacity polyhalite mine, and will also look at the potential to eventually double production to 20 million t/a.

Whilst proud of what's been achieved to date, Starzecki and others on the management team are very much looking ahead: "We've got through the planning process and started to really advance from a commercial perspective. There were times when industry experts said you won't sell a tonne of this before you're in production, yet we're sitting here with 3.1 million tonnes [sold]. We're about to deliver the definitive feasibility study towards the end of this year, and quickly move towards construction after."

FERTILIZER INTERNATIONAL
ISSUE 468
SEPTEMBER-OCTOBER 2015

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Without compare

What Sirius Minerals is attempting with the York Potash project is a different proposition compared to many current greenfield potash ventures – in terms of its scale, operating environment and product. The project is being developed in a mature developed economy, and neither is its fertilizer output a standard MOP or SOP product. In production volume, York Potash is also more akin to K+S's Legacy project, Canada's largest mining venture.

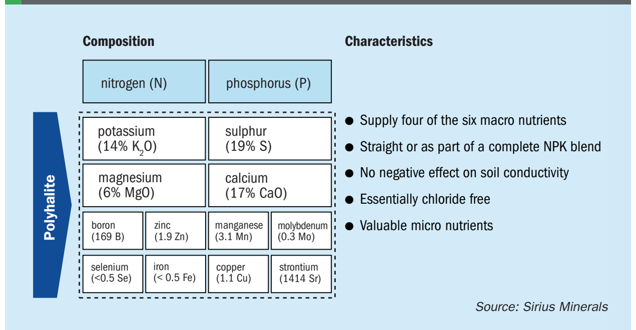
Sirius Minerals' CEO and managing director, Chris Fraser, agrees that finding easy comparisons is difficult: "Where we are with the strategy, finding comparables is quite a challenge now. That largely comes back to what we're actually developing – which is this huge, high-quality resource of polyhalite which hasn't been developed on the scale that we're looking at ever before."

The project's strategy of "large-scale, low-cost and disruptive market entry" involves polyhalite displacing several types of well-established fertilizer currently sold on the market. "What we've got – in terms of our deposit, in terms of scale, the quality and the proximity to the port – means that we have these incredibly compelling competitive advantages," enthuses Fraser.

York Potash also differs from the norm as a mining operation. "In terms of the fertilizer industry there's nothing like this in terms of a straight 'dig-and-deliver' model really," says Fraser. "Everything [else] out there requires processing. Polyhalite is unique in that what you dig up is your product."

York Potash is marketing its 90% grade polyhalite product under the *POLY4* trademark as a "natural single source of K, S, Mg and Ca macronutrients and valuable micro-nutrients" (Figure 2). The product is chloride-free and can be applied straight or as part of an NPK blend with no negative effect on soil conductivity. "These four macronutrients, potassium, sulphur, magnesium and calcium, are bonded together in a way – all of the trials are showing – that release and perform the same as existing sources of nutrients, if not better," explains Fraser. He also thinks the ability to produce "very large volumes at very low operating costs" over a prolonged period will alter fertilizer supply: "Our product is effectively a value-added product in a channel to market where farmers are blending fertilizers. Polyhalite has a right to play in that space globally."

Fig 2: **Polyhalite composition and characteristics**



Source: Sirius Minerals

Exacting environmental standards

Getting over the planning hurdle for a mine within the North York Moors National Park has meant complying with some of the highest environmental standards in Europe. But, in satisfying the UK's planning authorities, has York Potash saddled itself with costs not faced by its competitors – extra costs that could later be a source of regret? So-called 'Section 106' stipulations, for example, will add around £2 million a year to project costs, although these do taper off after 5-10 years.

Fraser is sanguine about such costs, saying they are to be expected for a large industrial enterprise in a modern economy, something he has no problem with. "Of course there's additional cost involved, but they are the costs of doing business. The majority of [Section] 106 funding goes into tree planting around the project in the National Park for off-setting carbon emissions. To put them in context, the total payments end up around 0.12% of annual revenue, so it's a very small relative cost to the business when we're up and running."

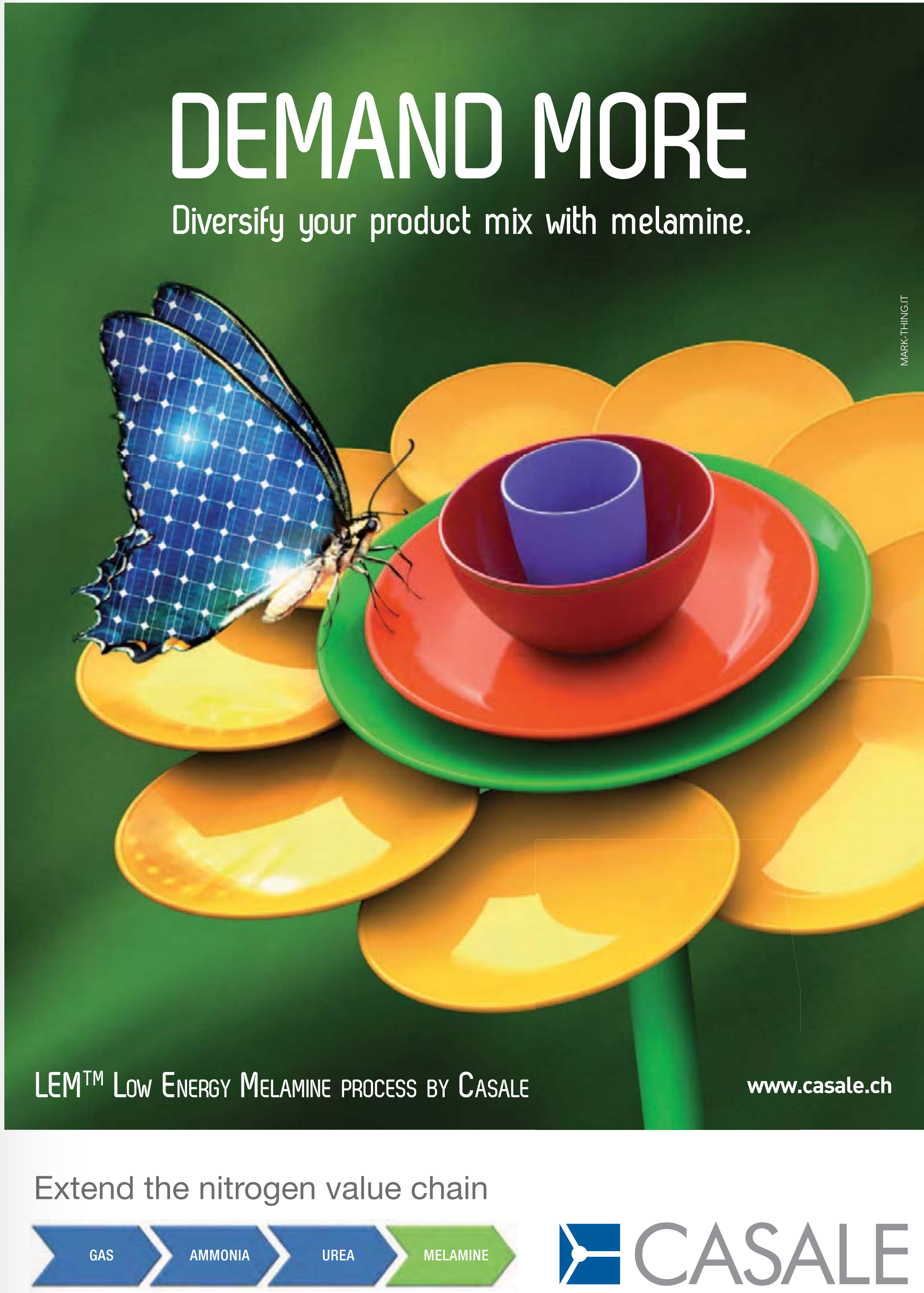
Minimising environmental impacts in the National Park will require the construction of a 37 km underground mineral transport system at an average depth of 250 m (Figure 3). The subsurface transport of polyhalite from the mine to the material handling facility at Teesside will require additional capital expenditure. "Those costs we have to pay during the construction phase are more significant than what you would get in some other places, because of where we are – but it was always factored into our expectations as part of licence to operate," says Fraser. "We don't think these [costs] have saddled us with anything that makes us uncompetitive, and it's nothing that gives us worries in terms of cost structures."

Open investment doors

Sirius expects to conclude initial financing for York Potash in the first quarter of next year. However, the current investment climate, described by some as the worst for mining juniors in 30 years, is far from ideal. Adding to negative sentiment is the state of oversupply in the potash market and recent commodity price falls. So how will York Potash differ from its competitors when it comes to project financing and successfully attracting investors?

Having Fraser as CEO is definitely one major advantage, due to his track record of developing and financing major mining projects for Citigroup, Rothschild and KPMG in the past. "If you are producing generic commodities, just doing the same as the [fertilizer] majors, and you've got no competitive advantage, that's a very tough proposition," comments Fraser. "Because when prices come down, and we really are in a soft commodity cycle now, the robustness of the returns and the business proposition for many greenfield projects right now is poor."

But Fraser takes heart from the fundamental, underlying strengths of York Potash: "We have a five-year construction phase and a mine life of over a 100 years, so we do have to look longer term. Our business also has these competitive advantages, in terms of margin, in terms



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

CONTENTS
What's in issue 468

COVER FEATURE 1
TFI World Fertilizer Conference, Boston

COVER FEATURE 2
Sulphur supply sea change

COVER FEATURE 3
The elemental value of phosphorus

FERTILIZER INTERNATIONAL
ISSUE 468
SEPTEMBER-OCTOBER 2015

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of operating costs, an ability to be strong through a cycle. All of those things mean, when we talk to capital investors and providers around the world, we're finding doors are very open."

Investors are "very interested" in what York Potash is doing, says Fraser, because it operates in a "low risk country" and also benefits from having a "huge resource, huge margins, a huge value curve". Encouragingly, he adds: "The capital markets are always open and available to projects that are genuinely world class – and that's where we would put ourselves."

Although Chinese stock market falls and currency devaluations are affecting market conditions, Fraser remains optimistic: "We're not kidding ourselves that doesn't impact on sentiment. But at all times the cream will always rise to the top. If you've got a very good, solid position – and can show investors you can be strong and resilient in generating returns – capital providers are there and willing to invest in what you are doing."

The struggle by junior miners to raise the large amount of capital needed for construction, and demonstrate sufficient value to justify this, has been called the 'public company trap'. However, the success of York Potash to date has been hugely aided by Sirius Minerals being a public company, says Fraser: "Part of the reason why we are where we are today, with approvals in the bag, is that we did make the tough decision to [become] a public company in 2011 – so we had transparency in the approval process and the mineral rights process. We had to do agreements with 500 farmers [and] go through a National Park planning process which was about transparency and credibility."

Grabbing a slice of the cake

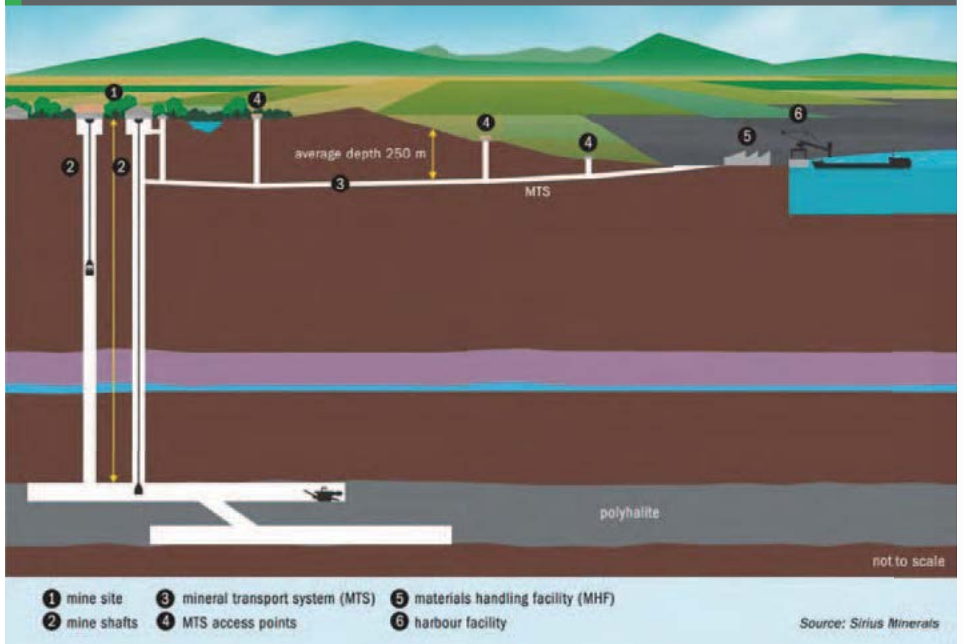
Sirius Minerals has already secured eight million tonnes in annual customer commitments for *POLY4* and, not surprisingly, is bullish about the scale of global demand for polyhalite. "We've got offtake agreements over three million tonnes per annum and then we have other commitments just shy of five million," comments Fraser. "There's more work to be done to support the financing, but the market is very real and the pricing of the product will evolve over time."

Sirius predicts that the price of polyhalite will be in the range of $110-170/t f.o.b., the exact price partly depending on how competitors respond. In a market report last year, analysts CRU concluded that *POLY4*, due to its multi-nutrient composition, is able to compete against potassium fertilizers (MOP, SOP, SOPM), sulphur-based fertilizers (SSP, AS) and magnesium fertilizers (kieserite). Sirius claims the intrinsic value of polyhalite is $198/t, based on the cumulative worth of its individual K_2O, Cl-free, S and Mg components.

Polyhalite's ability to displace a range of different fertilizers is what marks it out as different, says Fraser. "We're going in with a very different proposition to distributors and blenders around the world, saying 'we're willing to give you a very large volume and a very long-term supply agreement so you can make a meaningful change in your supply pattern'. We want them to buy less potassium sulphate or less potassium chloride and displace that with polyhalite."

Fertilizer distributors and blenders are becoming convinced of polyhalite's merits, says Fraser: "We're saying to them,

Fig 1: **York Potash project mine plan**



FERTILIZER INTERNATIONAL
ISSUE 468
SEPTEMBER-OCTOBER 2015

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we want to work with you as a partner, we'll give you discounts that mean your cost structure is better off, you're going to make more money, and your customers are going to be better off in the long-term through our agronomic programme."

But how will major fertilizer producers react to York Potash coming in as a new entrant and taking a multimillion tonne slice of the market? One thing Fraser does make very clear is that York Potash is not just competing with MOP producers. "How will our competitors respond? If you're referring to potassium chloride, a 60 million tonne per annum industry, at 10 million tonnes of polyhalite [production] we would be, on a K_2O displacement basis, a 3-4% market share. So, although we're selling 10 million tonnes of product, what we're actually selling is only several percent of the global potassium market."

> "The cream will always rise to the top. If you've got a very good, solid position capital providers are willing to invest.

This makes an all out price war look particularly unlikely in Fraser's view. "Are they [existing producers] really going to fight us coming in, are they really going to fight with a pricing strategy that it is going to have to be worn across the entire 60 million tonnes of supply, for the sake of 3-4%. I would think the answer is no – but I'm not kidding myself that they're not going to respond competitively."

In any case, effectively combating polyhalite on price would also require a globally co-ordinated market response across three nutrient segments (K, Mg and S), argues Fraser, a prospect he considers unlikely. J.T. Starzecki, takes up the point: "Because our product sits in multiple spaces, you're talking about multiple players having to co-ordinate any response on price." Starzecki doubts whether "the MOP producers, the SOP producers, the magnesium producers, the sulphur producers" would collectively drop their price just "to keep out a product that really only comprises a few percent of the market".

Taking out the risk

Sirius has put a lot of thought into how to de-risk the York Potash project for investors. An extended construction period, in particular, can add to project financing difficulties. "Part of the challenge of financing the project is the duration – how long it takes to go from starting to spend money on construction to when you're actually generating cashflow and paying back dividends," says Fraser. "We have this five-year construction phase – although a year and a half from the end we'll start to have revenue coming out from product."

To help de-risk the York Potash project, financing for the construction phase is split into two parts, one higher risk and one lower risk, as Fraser explains: "When we've sat down and looked at the nature of the [construction phase] risks, the perception of the higher relative risks lay in the subsurface excavation, of digging deep shifts and digging a tunnel. Whereas the back-end of the project – the port in Teesside, shiploaders, conveyors, mechanicals, storage buildings, power supplies – that is all relatively low risk."

The project's financing strategy reflects this split between higher risk front-end subsurface excavation and lower risk back-end fit-out. "We'll finance the perceived higher risk and difficult stuff first, and therefore we'll pay a higher cost for that," says Fraser. "But when we get to the back-end, and we're getting into bigger lumps of money on fit-outs, we will have much lower cost-to-debt." Summing up, Fraser says: "Hopefully, the end result is we that end up with the lowest average cost of funding across the whole project."

Known unknown

York Potash's polyhalite product *POLY4* will be something of an unknown for some distributors and farmers. But the lack of a clearly comparable product is a strength not a weakness, according to J.T. Starzecki: "One of the things we are really happy about is the fact we don't have a standard competitor out there. What that does is allow us to play into many markets. It also allows us to come into the market in a much larger capacity – because we're playing in the potassium space, the chloride-free space, the sulphur space and the magnesium space."

Starzecki says York Potash also hopes to capitalise from unmet demand in the fertilizer market: "Our product [can] come in and be one of two things: a substitute for products that are already in the market today – a more cost effective source of K_2O, sulphur or magnesium – or the product itself can meet a lot of unmet demand."

Part of the unmet demand York Potash hopes to tap into is for potassium magnesium sulphate (SOPM). The latter occurs as the mineral langbeinite and is currently marketed by Mosaic and Intrepid Potash under the *K-Mag* and *Trio* trademarks, for example. These are the types of fertilizer which most closely resembles polyhalite, according to Starzecki: "Even though the fertilizer market is large globally there are preferences that farmers have and, in certain cases, they're not able to get their hands on, take SOPM, *K-Mag*, *Trio*, for example. Those are products which most farmers would, if you took price out of it, get their hands on as much of it as they possibly could – they are supply constrained."

Agreeing with customers

Offtake agreements are a standard way for junior mining projects to secure a route to market. But efforts to sell *POLY4*, prove its agronomic worth and sign-up customers – all in advance of a single tonne of production – are probably without precedent. Offtake contracts include a one million t/a deal with Yunnan TCT Yong-Zhe Co Ltd and a 0.5 million t/a deal with a Fortune 500 listed US agricultural business. Deals have also been agreed with South American (0.3 million t/a) and Central American (0.25 million t/a) fertilizer distributors.

This is all part of a new sales model for the fertilizer industry and a bid to "change the paradigm of how the market operates", says Starzecki: "Offtake agreements are actually not the norm. The market itself is very much a spot market. So what we are doing is not only selling a new product but selling it multiple years in advance."

Starzecki explains more about the customer agreements secured to date. These include legally-binding 'take-or-pay' contracts as well as looser memoranda of understanding, framework sales agreements and letters of intent: "Right now we stand at 3.1 million tonnes of firm offtake agreements where the customers have a firm commitment, length of time, tonnage and price point. We also have another 4.8 million tonnes of MoUs, FSAs and LOIs. It's very standard for a blender to enter into a MoU and to carry through on that commitment."

Customer agreements are there to provide project investors with the certainty that there is a guaranteed market for polyhalite. But is there a risk, with too many offtake agreements, of undervaluing *POLY4* and being left with insufficient volumes for flexible sales at a higher price? In fact, Sirius Minerals does have a maximum limit for firm offtakes of 3-4 million tonnes, although this is an approximate limit because the exact tonnage depends on price. "We are on the lower end of that range already and feeling very, very good where we are commercially," comments Starzecki. "We want to get to a level where the banks are comfortable with our offtake agreements so that we can finance the project, and then spend the rest of the time driving value into the market through our science programme, which will ultimately allow us to drive premium for the product."

Equal or better

Extensive agronomic trials on broad-acre and speciality crops such as corn, rice, potatoes, tomatoes and soy have been a critical part of attracting customers. "How we're starting to showcase the value to potential customers is the product [*POLY4*] happens to be performing equal, in most cases better, than products already out there," says Starzecki.

Sirius Minerals has commissioned agronomic research on a very large-scale. "It's one of the biggest research programmes on a new product going globally," comments Starzecki. "Right now we're testing on somewhere in the neighbourhood of 40 crops in seven different countries." Some results have particularly impressed Starzecki: "If I had to identify one of the standout, eye-opening trials it would be the 73% yield increase in one of our tomato trials."

Starzecki says commercial, large-scale trials of *POLY4* are likely next year as the project edges towards construction. "We'll be doing it on large fields with large amounts of crops and product so that we can see how the product reacts on a big scale. In some cases we'll do it with commercial partners."

Good news for European mining

Once operational, York Potash should benefit Europe's mining industry by showcasing environmentally- and socially-responsible mineral extraction, and illustrate how this can be achieved within EU borders. "We are setting an example of how you can build a very large-scale project like this on a very populated island like the United Kingdom, [with] the added sensitivity of being in a protected landscape," comments Fraser. "I think we've set some very clear benchmarks of how you can do it."

Summing up, Fraser also stresses the economic benefits: "We've got a huge responsibility to do it right. In terms of the impact, we're the largest capital project in [the UK government's] Northern Powerhouse region. In terms of Europe, we'd be the largest mine developed in Europe for an incredibly long time on a scale that means job creation, exports – it is a massive undertaking with massive positive outcomes."

Starzecki goes even further on the merits of York Potash: "It's changing the face of agriculture. That speaks volumes for not only the commitment of the company, but just in general what we're trying to do on a global scale." ■

FERTILIZER INTERNATIONAL
ISSUE 468
SEPTEMBER-OCTOBER 2015

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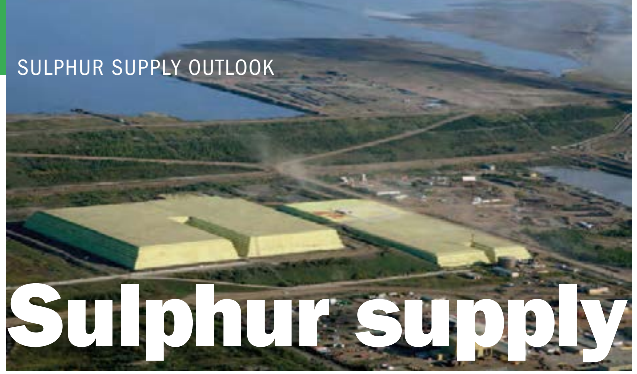


"Producers with sulphur storage capabilities will have a pivotal part to play in balancing the market."

Sulphur supply – from deficit to global glut?

Sulphur is an essential raw material for phosphate fertilizer production and a key manufacturing cost. A supply increase of over a fifth by 2019 looks set to push the market into surplus, driven in large part by the arrival of long-awaited Middle East sour gas projects. We discuss the implications of these developments with analyst **Meena Chauhan** of Integer Research.

Global production of elemental sulphur grew by 1.7% to 55.6 million tonnes in 2014. Almost half of this volume (27.4 million tonnes) was derived from oil refining, with sour gas recovery (24.9 million tonnes) and sourcing from oil sands (2.3 million tonnes) accounting for much of the remainder.

Looking ahead, IFA is currently predicting a 27% increase in production over the next five years to 70.8 million tonnes by 2019[1]. If correct, this will alter the current supply/demand balance and see the global sulphur market finally move into a long-heralded surplus. Shifts in pricing and new market dynamics are likely to accompany this sea change, as the pattern of consumption and production changes in key countries and regions[2].

Middle East takes number one slot

One particularly symbolic shift, as the sulphur market moves from deficit to glut, will be the emergence of the Middle East as the world's prime sulphur producing region, usurping North America, the current occupant of that position (Figure 1). This outcome looks increasing likely, as Meena Chauhan, research manager for sulphur and sulphuric acid at Integer Research, explains: "The current story is, of course, that North America is the number one global producer of elemental sulphur today, and we do see that really shifting. Give it another a couple of years and you might see the Middle East take that top spot."

Of the 55.6 million tonnes of elemental sulphur produced globally in 2014, around 31.0 million tonnes was traded whilst the rest was kept in-country for 'captive' consumption and use. IFA expects global trade to increase by almost a fifth to 36-37 million tonnes by 2019 as new supply capacity becomes available. Critically, unlike much of North American production, the new sulphur supply now emerging in the Middle East is mainly destined for export.

Chauhan explains more: "Within the US, of the eight million tonnes of sulphur produced, the majority of that is consumed within the local market. Yes, there are exports out of the West Coast, also out of the Gulf, but most production is for captive use. In contrast, when we talk about a Gulf producer, like the UAE or Qatar, almost all of their sulphur is being exported. That does create a very competitive environment for sulphur producers overall."

Sour gas dominates new sulphur supply

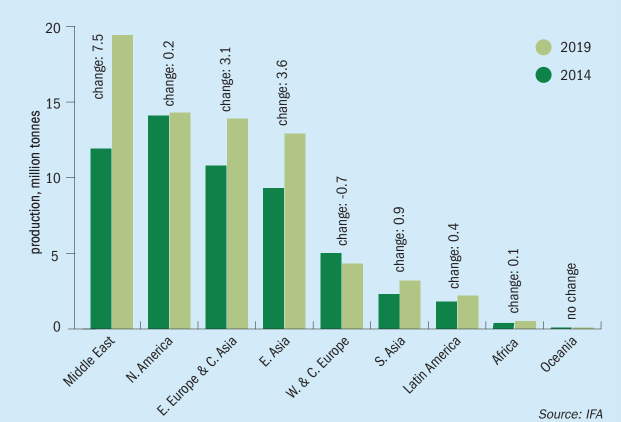
Middle East sulphur supply is expected to grow rapidly as a string of sour gas projects finally come to fruition in the Gulf and Iran (Table 1). IFA expects that, of the 15.2 million tonnes growth in elemental sulphur production between now and 2019, nearly two thirds (9.3 million tonnes) will come from sour gas projects compared to less than a third (4.6 million tonnes) from new oil refining capacity.

"When we look at the next five years for sulphur, we do see the majority of new production coming from the sour gas sector," comments Chauhan. "There are, of course, oil refining capacities being added. However, overall, when we look at supply growth, it is really sour gas which is driving that forwards."

The collapse in the oil price over the last year is unlikely to halt the rise in sour gas capacity. Major new projects still look destined to bring large-scale sulphur production to places where previously there was none.

"The Integer view is that over the next year or so we will be seeing many of these projects come to fruition," says Chauhan. "Examples include the Shah gas project in the UAE, the Wasit gas project in Saudi Arabia – although that's delayed now until the end of the year – and other projects in Iran, Qatar and Turkmenistan."

Fig 1: **Production of elemental sulphur by region**



Source: IFA

Table 1: **Major recent and planned sour gas projects.**

Project	Location	Sulphur capacity (t/a)	On-stream
Middle East			
Shah	Abu Dhabi	3.1	2015
Bab	Abu Dhabi	3.0	2020?
Habshan	Abu Dhabi	1.8	2013
Fadhili	Saudi Arabia	1.0	2018
Wasit	Saudi Arabia	0.8	2015
Karan	Saudi Arabia	0.3	2012
Ras Laffan*	Qatar	0.4	2012-18
Khuff/RHIP	Oman	0.3	2019
South Pars*	Iran	0.3	2012-17
Central Asia			
South Yolotan	Turkmenistan	1.8	2013
Kashagan	Kazakhstan	1.1	2016?
Orenburg*	Russia	0.4	2015
China			
Puguang	Sichuan	3.0	2011
Chuandongbei	Sichuan	1.5	2015
Yuanba	Sichuan	0.3	2014

**Expansion project*

Source: Sulphur, 357 p27

FERTILIZER INTERNATIONAL
ISSUE 468
SEPTEMBER-OCTOBER 2015
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Price benchmarks head east

The continuing rise of Middle East sour gas supply, such is its scale, is starting to affect how the price of sulphur is benchmarked globally. "Historically, Vancouver pricing has been cornerstone of the sulphur market. But in recent years, due to supply developments – largely in sour gas but also in heavy oils – pricing has shifted over to the Middle East as a benchmark," says Chauhan. The underpinning of pricing by substantial import markets in China and India also means Asian prices are receiving greater recognition.

A return to six-month sulphur supply contracts is another possible long-term consequence of the sour gas boom. "We used to see six month contracts as the norm across most of the markets, yet, today in the Middle East, the majority of pricing is on a monthly basis," comments Chauhan. "With the large-scale sour gas projects that are now in the pipeline, and the potential for a global sulphur surplus, we could potentially revert back to historical pricing and six month contracts once again – although that's quite a long way off and we expect monthly pricing to be here to stay in the short- to medium-term."

From deficit to glut

For many years, the big question for the market has been will the supply of sulphur ever reach a global surplus – and, if so, when. IFA now expects elemental sulphur supply growth (27%) to outpace global demand (16%) over the period up to 2019. As a consequence, it expects the supply/demand balance to move from a marginal deficit this year to a three million tonne surplus by 2019 (Table 2).

A growing surplus is not necessarily a cause for immediate alarm, however, argues Chauhan: "All the sour gas projects being developed in the FSU, the Middle East, does it really mean that we will see mountains of sulphur everywhere, is that a realistic and feasible scenario? Well, one caveat is that these projects will take time to reach the customer – so we don't really see this as a huge emergency situation."

If the market does move into surplus over the medium-term, then producers with sulphur storage capabilities, such as those in Western Canada and Russia, will have a pivotal part to play in balancing the market. Alberta currently holds a significant inventory of around eleven million tonnes. Historically, this is comparatively low, as the province used to keep well over 20 million tonnes of sulphur in block form.

"Canada is one of those countries where we see could see huge block inventories," suggests Chauhan. "It's not desirable thing, of course, because producers have the additional cost of remelting sulphur blocks when they're brought back to market – plus there's logistics issues because of the remoteness of where the blocks are located."

In contrast, holding massive inventories is simply not an option for the emerging sulphur-exporting countries, in Chauhan's view. "In the Middle East, where most of the new production capacity is coming online, they're very limited in terms of how much sulphur can be stored at any one time – they simply don't have the storage capabilities the Canadian producers have. Several Middle East producers are looking at ways of storing sulphur, but it certainly wouldn't be on the same of scale as Canada."

Table 2: **Elemental sulphur supply/demand balance** million tonnes

	2015	2016	2017	2018	2019
Demand					
Sulphuric acid	51.3	53.2	55.5	57.1	58.6
Other	8.4	8.7	8.9	9.1	9.2
Total	59.7	61.9	64.4	66.2	67.7
Supply	59.3	63.4	66.0	68.6	70.8
Balance	-0.4	1.5	1.6	2.4	3.1

Source: IFA

Fig 2: **Vancouver sulphur exports** 2014, million tonnes

Source: Integer

Vancouver still a key exporter

Although Integer predicts that Middle East sulphur exports will rise by 11% year-on-year over the next five years, the 2.54 million tonnes of sulphur which left the Port of Vancouver last year shows that North America remains a wide-reaching and key exporter globally (Figure 2). Interestingly, Vancouver exported twice as much sulphur to Australia (0.98 million tonnes) – to meet rising ore leaching demand there – than it did to China (0.47 million tonnes) in 2014, a highly symbolic change in Integer's view. "What is fascinating about this is that, going back two or three years, China was the number one market for Vancouver sulphur, now it's Australia," comments Chauhan. "So there's been a complete reversal in the last couple of years."

The change-around is also illustrative of the strong influence non-fertilizer uses can have on the sulphur market. "The sulphur moving from Vancouver to Australia is not for the fertilizer sector but for metal ore leaching. This impacts not only on sulphur demand but also on trade and certainly on pricing," explains Chauhan.

The US was the world's largest producer (9 million tonnes), second largest consumer (9.4 million tonnes) and third largest importer (2.3 million tonnes) of elemental sulphur in 2014, according to IFA figures. Looking ahead, changes in the US sulphur market, due to the commissioning later this year of Mosaic's new one million t/a sulphur melter at New Wales, Florida, look set to alter the pattern of trade globally.

An increase in US solid sulphur imports through Tampa will be one immediate consequence. "The US market is mostly a molten sulphur market and with Mosaic operating independently it will be able to purchase solid sulphur from pretty much anywhere," comments Chauhan. "Countries like Russia, Kazakhstan, and others within the Middle East also, will be able to supply Mosaic with solid sulphur for remelt for use in phosphate production – that's quite a shift in market dynamics."

Greater potential for exports out of Vancouver are another probable outcome, suggests Chauhan: "Canadian sulphur going down into the US is quite high cost because of rail freight. So we anticipate this could potentially be displaced by the switch to solid imports, meaning Vancouver has more availability to export over the next year."

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Saudi Arabia: pivotal producer and consumer

The Middle East (West Asia) produced 12 million tonnes of sulphur in 2014, around of fifth of global output, and exported the vast majority of this (10 million tonnes). IFA expects sulphur production in the region to grow by an impressive 60% to 19 million tonnes by 2019, the lion's share of this increase coming from Abu Dhabi (3.7 million tonnes), Saudi Arabia (2.3 million tonnes) and Qatar (0.8 million tonnes).

As a result, Middle East sulphur exports are forecast to leap to 15-16 million tonnes annually by 2019. Within the region, Saudi Arabia is seen as a particularly pivotal player, as it strives to balance its role as China's main sulphur supplier with growing captive consumption within the kingdom.

In the immediate future, Saudi Aramco's Wasit plant will process up to 2.6 billion cubic feet of natural gas from the Hasbah and Arabiyah offshore fields when it comes on-stream later this year. Sulphur recovery is also expected to increase as the kingdom continues to ramp up oil production – Saudi oil output hit a record 10.3 million barrels per day in April. But Saudi Arabian captive consumption will also rise in 2017, as Ma'aden is expected to commission three sulphur burners with a total capacity of 1.5 million tonnes at its Umm Wu'al phosphate complex.

China relies on Saudi Arabia for almost a fifth of its sulphur imports (18%). Juggling rising domestic consumption with export demand could prove to be a difficult balancing act for the Saudis, according to Chauhan: "The huge growth in consumption we've seen in Saudi Arabia since 2009 has had no real impact on world sulphur trade to date, as they have their own captive production at Saudi Aramco facilities. Saudi Arabia is, however, the number one supplier for China. That does beg the question of whether growth in consumption within Saudi Arabia will eventually impact China in future – as the Umm Wu'al project expands into phase two."

Stalling imports in China

China is the world's largest sulphur market and, together with Saudi Arabia and Morocco, has led the growth in consumption seen globally over the last five years. The East Asian giant imported 10.5 million tonnes of elemental sulphur last year, equivalent to a third of global trade, and topped this up with around 6 million tonnes of domestic production to meet a 16-17 million tonne level of domestic demand.

"China is an interesting one because they take more than a third of sulphur produced today," observes Chauhan. "What we're interested in is whether that will still be the case in another three, five or 10 years – and, if not, what will this mean for other sulphur consumers, and how will it impact on producer prices in the Middle East."

Although IFA expects Chinese sulphur imports to remain stable at around 10 million tonnes between now and 2019, there are signs that imports have begun to falter. Integer observed a 3% drop in imports last year, for example, linked to inventory management and a reduction in phosphate production. "If you go back 10 years ago, we used to see China holding large volumes of sulphur stocks at their major ports with two million tonnes as a rough level of inventory," says Chauhan. "Today, stocks are roughly one million tonnes – so it's halved – and that was part of the reason why we saw this drop in sulphur imports."

> **"We're anticipating a drop in Chinese imports – and that could have serious ramifications for the market in terms of pricing and trade.**

In the past, low Chinese port inventories have usually triggered a rise in the sulphur price. But simple supply and demand controls on pricing appear to have broken down at present, mainly because Chinese traders are reluctant to hold on to a high-cost product. "Previously, when sulphur pricing fell and inventories also dropped, Chinese speculative traders would enter the market to stimulate trade and that would drive the price up – but we don't see that happening today," observes Chauhan. "Features within Chinese market dynamics can have a huge impact on pricing in the rest of the world."

Whilst East Asian demand will remain important, the rate of growth from China in the last 10 year may not be replicated over the coming decade. "We at Integer don't feel that imports of roughly 10 million tonnes are sustainable over the next five years, should domestic sulphur production continue to grow," comments Chauhan. "Instead, we're anticipating a drop in Chinese imports – and that could have serious ramifications for the market in terms of pricing and trade." Some analysts are even predicting that Chinese exports will eventually drop by over a fifth to around 8 million t/a by the mid 2020s.

Processed phosphates sector crucial

Future increases in sulphur consumption are inextricably linked to developments in the phosphate fertilizer sector, particularly phosphoric acid capacity additions in China, the Middle East and North Africa. In Morocco, for example, a total of eight phosphoric acid plants are scheduled for completion between 2015 and 2019 as part of integrated phosphate fertilizer units being built by OCP at the Jorf Lasfar phosphate hub (*Fertilizer International*, 466 p62). This rapid expansion in phosphate production could drive the country's sulphur imports above seven million t/a by 2019 due to the commissioning of nine million tonnes of new sulphuric acid capacity at Jorf Lasfar.

The ever-expanding phosphates output of Middle Eastern and North African producers such as OCP and Ma'aden will strongly influence future demand for sulphur. Integer, for example, expects the Middle East's share of global sulphur consumption to rise from 26% to 28% over the next five years and the US market share to slide from 16% to 14% over the same period. Both changes are linked to an inexorable long-term shift in global phosphate production. "This is a consequence of rationalisation across the phosphate industry in the US, and the rise of the Middle East and North Africa as significant DAP and phosphoric acid producers and exporters," concludes Chauhan. ■

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Ammonia production on a lower carbon path

The widespread adoption of the best available technology (BAT) by ammonia producers globally provides scope for cutting the industry's carbon emissions by a quarter. Action by China's giant, energy-intensive ammonia sector will be particularly critical. Take-up of cost-effective energy efficiency measures there could potentially cut CO_2 emissions by 27 million t/a, more than the total emissions of European ammonia producers.

The fertilizer industry is responsible for around 1.2% of world energy consumption and about the same percentage share of global greenhouse gas (GHG) emissions. Ammonia production, as a major segment of the chemicals industry globally, has come under close scrutiny, particularly because it consumes more than 90% of the overall energy used in fertilizer manufacturing – with a correspondingly high carbon footprint[1].

The debate over the climate impacts of fertilizer production is likely to intensify during the reminder of this year, particularly in Europe. The issue is rising up the agenda thanks to reforms to Europe's 'cap and trade' system, the Emissions Trading Scheme (ETS), tabled by the European Commission over the summer. Efforts to reach a legally-binding global agreement on climate change will also reach a moment of decision at the COP21/CMP11 conference in Paris in December.

Both of these developments are sparking renewed interest in carbon-saving measures and energy efficiency improvements in the fertilizer industry, and in ammonia production in particular.

Table 1: **Main energy efficiency options for existing ammonia plants**

Retrofit measure	Average improvement	Cost	Applicability		
	(GJ/t)	(€/t/a)	EU (%)	US (%)	India (%)
Reforming, large improvements	4.0	24	10	15	10
Reforming, moderate improvements	1.4	5	20	25	20
Improved CO_2 removal	0.9	15	30	30	30
Low pressure ammonia synthesis	0.5	6	90	90	90
Hydrogen recovery	0.8	2	0	10	10
Improved process control	0.72	6	30	50	30
Process integration	3.0	3	10	25	20

Source: Banerjee et al. (2012), Rafiqul et al. (2005)

Energy use and carbon emissions

Ammonia production is responsible for nearly a fifth (17%) of the energy consumed in the chemical and petrochemical sector, itself the largest industrial consumer of energy. Global ammonia manufacture consumed 5.6 exajoules (EJ) of fossil fuel energy in 2004. Some 2.7 EJ of this was due to plant power usage with the remaining 2.9 EJ contained in the natural gas, oil or coal feedstock devoured during production. Although energy use per tonne of ammonia has decreased by nearly a third (30%) over the last three decades, there is scope to cut energy use by up to a quarter and at the same time slash greenhouse gas emissions by 30% through the adoption of best available technology (BAT) worldwide[2].

These energy- and carbon-saving estimates are largely based on a global benchmarking study by IFA dating from 2008. This reported average ammonia plant energy usage of 36.6 GJ/t NH_3 based on 93 ammonia plants. Of these, the top quartile 'best performers' achieved energy usages in the range 28-33 GJ/t NH_3[2].

The type of feedstock used in ammonia plants varies widely globally and is a primary factor determining their carbon emissions intensity. The use of natural gas generates emissions of 2.1 tCO_2/tNH_3 on average, rising to 3.3 tCO_2/tNH_3 for fuel oil, and more than doubling to 4.6 tCO_2/tNH_3 for coal feedstocks.

For plants producing ammonia from natural gas using BAT, generally the most energy efficient in the sector, IFA figures show that energy use falls to 28 GJ/t NH_3 and carbon emissions drop to 1.6 tCO_2/tNH_3. The European Commission has published its own estimate of 27.6-31.8 GJ/t NH_3 for BAT production from natural gas[3].

Low carbon limits

A summary of the six principal energy saving measures for natural gas steam reforming plants (see box), their cost and applicability is provided in Table 1. These measures formed part of a future 'roadmap' for the European ammonia industry published by CEFIC, the European Chemical Industry Council, in 2013[4]. This set out a pathway to better energy efficiency and lower carbon emissions by 2050 using BAT[3] and other approaches.

FERTILIZER INTERNATIONAL
ISSUE 468
SEPTEMBER-OCTOBER 2015

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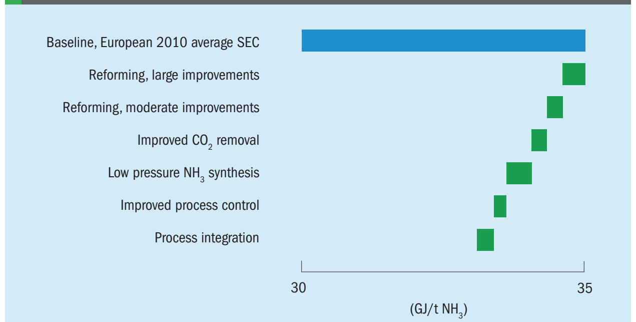
Fig 1: **Carbon reduction pathway for natural gas ammonia plants**



Source: Ecofys (2013)

CEFIC concluded that implementation of such measures could collectively cut the specific energy consumption (SEC) of the current stock of European ammonia plants from the current average of 35 GJ/t (corresponding to 2 tCO_2/t NH_3 emissions) to 32 GJ/t NH_3, a reduction of close to 10% (Figure 1). CEFIC also states that new ammonia plants are capable of operating at an SEC of 28 GJ/t NH_3 and reducing their emissions to 1.3 tCO_2/t NH_3. This can be achieved through better process integration, a low-pressure ammonia synthesis loop and optimising the steam reforming process – by shifting the reforming duty from the primary to the secondary reformer, for example.

Greater integration of ammonia production with other industrial processes or innovative heat recovery systems could see the energy use of greenfield ammonia plants ultimately drop to 26 GJ/t NH_3 by 2050, forecasts CEFIC. This amounts to an energy efficiency improvement of about 7% overall or 0.2% a year. A fall in energy consumption to this level would bring ammonia production ever closer to the lowest practical limit of around 23 GJ/t NH_3 for the steam reforming process.

Only limited carbon and energy savings in EU ammonia production are possible in future, argues Fertilizers Europe, because the continent's plants are already comparatively efficient by global standards. Fertilizers Europe also points out that efficiency gains all come from the power used to run plants which, in Europe's case, represents just a third of total energy consumption. Natural gas used as feedstock accounts for the other two thirds of plant energy consumption – a proportion that could only be practically reduced were carbon capture and storage (CCS) to become viable. Although ammonia production is one of the most attractive industrial options for CCS, current investment costs are somewhere in the region of €180/t CO_2[4].

Much to gain in China

In any case, carbon emissions from ammonia production in Western European (23 million t/a CO_2) represent just 5% of the global industry total[2]. China, in contrast, is responsible for around a third of world ammonia production, but generates almost half of global emissions (220 million t/a CO_2) (Table 2). This is unsurprising given that around four fifths of Chinese ammonia production was based on coal feedstocks (*Fertilizer International*, 466 p20). Less efficient, small- and medium-size plants are also the mainstay of China's ammonia industry currently. The average energy intensity of Chinese coal plants (53 GJ/t NH_3) is nearly a third higher than IFA's global average (36.6 GJ/t NH_3).

The partial oxidation process used to produce ammonia from coal and heavy fuel oil differs significantly from the steam reforming process. In the partial oxidation process, for example, syngas is produced by feedstock gasification with air. Less process heat is also generated in partial oxidation compared to steam reforming, reducing the scope for heat integration

Table 2: **Regional production, energy consumption and carbon emissions for the ammonia industry**

Region	Ammonia emissions (million t/a)	Average plant production (GJ/t NH_3)	Total energy use (TJ/a)	Carbon energy use (million t/a CO_2)
Western Europe	11.0	35.8	393	23.0
North America	14.7	37.9	557	31.3
CIS	21.0	39.9	838	47.0
Central Europe	5.2	43.5	226	12.9
China	49.7	49.1	2,440	220.1
India	14.0	37.7	528	31.9
Other Asia	10.9	37.0	403	22.6
Latin America	9.9	36.0	356	20.0
Africa	6.3	36.0	227	12.7
Middle East	12.7	36.0	457	25.6
Oceania	1.9	36.0	68	3.8
World	157.3	41.3	6,495	451

Source: IETD, IEA. Based on 2010 production

Table 4: **Cost-effective energy efficiency measures for China's ammonia industry**

Ranking*	Measure	Process stage	Energy saving	Carbon saving
	Fuel efficiency		**(PJ)**	**(million tonnes CO_2)**
1	Heat from secondary reformer gases used in primary reformer (heat exchanger reformer)	Reformer	6.3	0.5
2	Carbon dioxide removal system using MDEA	Gas purification	14.2	1.2
3	Unpowered purge gas ammonia recovery technology	Ammonia synthesis	29.4	2.5
4	Recovery of waste heat from reformer flue gas	Reformer	1.8	0.2
5	Three-waste fluidised-mix combustion furnace	Gas generation	41.2	3.5
6	Medium-low-low temperature conversion technology	Shift conversion	24.9	2.1
7	Large-scale axial-radial flow reactors	Ammonia synthesis & shift conversion	96.3	8.0
8	Syngas molecular sieve adsorber/drier for make-up gas feed to synthesis reactor	Ammonia synthesis	9.2	0.8
9	Methanolisation-hydrocarbylation purification technology	Gas purification	33.2	2.7
10	Combined cycle technology	General measure	14.8	1.2
Total			271.5	22.5
	Electricity efficiency		**(GWh)**	**(million tonnes CO_2)**
1	Evaporative condenser cooling technology	General measure	516	0.4
2	Recovery of waste heat from reformer flue gas	Reformer	197	0.15
3	Adiabatic pre-reformer	Gas generation	1,822	1.41
4	High-efficiency rotor technology	General measure	11	0.01
5	High-pressure coal gasification technology	Gas generation	935	0.72
6	Ammonia synthesis tower heat-exchange technology and multi-stage adiabatic system	Ammonia synthesis	1,961	1.52
Total				4.21

**In order of cost-efficiency*

Source: Ma et al. (2015)

CONTENTS
What's in issue 468
COVER FEATURE 1
TFI World Fertilizer Conference, Boston
COVER FEATURE 2
Sulphur supply sea change
COVER FEATURE 3
The elemental value of phosphorus
FERTILIZER INTERNATIONAL
ISSUE 468
SEPTEMBER-OCTOBER 2015

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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

Conventional steam reforming

Almost three quarters of ammonia production globally is by the steam reforming process using natural gas. Ammonia synthesis from natural gas feedstock conventionally involves four key steps: steam reforming (primary and secondary); shift conversion; gas refining (CO_2 removal and methanation) and ammonia synthesis (Figure 2).

Reforming the natural gas feedstock produces a mixture of carbon monoxide and hydrogen (syngas). The carbon monoxide is then reacted with steam in the shift converter to produce carbon dioxide and hydrogen by the water-gas reaction. The resulting carbon dioxide is then recovered in a refining step. This is usually used as a feedstock in urea production, exported as a co-product or vented to the atmosphere. In the final synthesis loop, hydrogen reacts with nitrogen to form ammonia.

Primary and secondary reforming, shift conversion and ammonia synthesis all generate surplus high-level heat. Most of this waste heat is recovered and used to produce high-pressure steam to power turbines which in turn drives syngas compressors, pumps and fans. Modern steam reforming plants are energy self-sufficient, and often export surplus energy in the form of steam or electricity to other industrial consumers.

Total energy consumed in a conventional steam reforming plant is in the range 28.1-35.5 GJ/t NH_3. This is divided between the natural gas feedstock (20-22 GJ/t), energy consumed to power the primary reformer (7.2-9.0 GJ/t), and the auxiliary boiler and other parts of the plant (0.5-4.2 GJ/t)[2]. Two thirds of carbon emissions are associated with feedstock whereas just a third comes from powering ammonia plants, according to trade body Fertilizers Europe (Table 3).

Reforming improvements to existing plants can deliver typical energy savings of 3-5 GJ/t NH_3, at an approximate annual investment cost of €65/GJ, using measures such as[5]:

- Installation of a pre-reformer (1.4 GJ/t)
- Lowering steam/carbon ratio (0.8 GJ/t)
- Avoiding heat loss by insulating the reformer furnace
- Increasing operating pressure
- Increasing preheat temperatures for feed, steam and air
- Reduction of flue gas temperature
- Recovery of flue waste heat (0.4 GJ/t)
- Gas turbine installation (3.5 GJ/t)

Energy savings from reformer improvements of 5.0–13.4 GJ/t are achievable for plants installed before 1980 and about 3.3–4.2 GJ/t for plants dating from 1981-1990[5]. Plants installed after this date are thought to more highly energy efficient with less scope for energy efficiency improvement.

State-of-the art ammonia production is based on two main plant design concepts, **reduced primary reforming** and **heat exchange reforming**. Both concepts deliver additional energy savings and are an important part of current BAT. In reduced primary reforming, the reformer duty is shifted from the primary to secondary reformer using excess air or oxygen-enriched air. This reduces the size, cost and energy consumption of the primary reformer, and increases the life and efficiency of the catalysts and reformer tubes. In heat exchange reforming, outlet gases exiting the secondary reformer, or in some cases an auto-thermal reformer (ATR), are used to supply reforming heat. Examples of heat exchange reformers, also known as gas heated reformers (GHR), include KBR's *KRES* and Haldor Topsoe's *HTER* system, both widely used in plant revamps (*Fertilizer International*, 466 p 44).

Elsewhere in an ammonia plant, **more efficient CO_2 removal** from syngas, using advanced solvents, pressure swing absorption (PSA) or membranes, are associated with energy savings of 1.0-1.1 GJ/t NH_3. Manufacturers also claim that **low pressure ammonia synthesis** can deliver savings of 1–2 GJ/t NH_3 at an investment cost of €25/GJ. **Hydrogen recovery** from the purge gas of the ammonia synthesis loop, using cryogenic separation, membrane technology or pressure swing adsorption (PSA), also conserves energy.

Improved process control and automation of ammonia plants is reported to yield energy savings of around 0.6-0.7 GJ/t NH_3. Finally, better overall **process integration** of heat exchange reformers and combined heat and power generation could save 3–4 GJ/t NH_3 at a cost of €10/GJ per year.

Fig 2: **NH_3 production by conventional steam reforming**

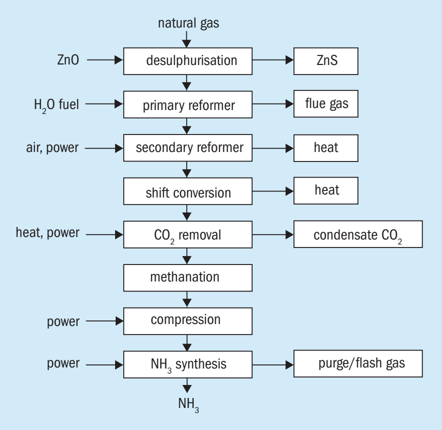

Table 3: **Energy consumption and carbon emissions in European ammonia plants**

	Energy consumption (GJ/t NH_3)	Carbon emissions (tCO_2/tNH_3)
Feedstock energy (natural gas)	18.6	1.04
Theoretical minimum total energy use	22.7	1.27
Best performing plant	28	1.57
Average European plant	35	1.96
EU ETS benchmark	28.9	1.62
EU BAT for existing plants	31.8	1.78

Source: Fertilizers Europe

between different processes. Because of this, auxiliary boilers are generally needed to provide extra steam to drive mechanical equipment and generate electricity. Power for plant compressors is also usually purchased from the electricity grid[2].

Adoption of cost-effective measures by China's coal-dominated ammonia producers could deliver massive carbon and energy savings, according to a study by researchers at the California's Berkeley National Laboratory published in June[6]. They identified 271.5 petajoules (PJ) of fuel efficiency improvements, equivalent almost a sixth (14%) of the total fuel use of China's ammonia industry. The measures could also cut carbon emissions from Chinese producers by over 10% (22.5 million t/a) (Table 4). Uptake of additional electricity-saving measures could deliver a further 4.2 million t/a of carbon savings on top of this.

Interestingly, although some of measures are feedstock-specific, such as high-pressure coal gasification technology, many of the improvements come from process modifications to the reformer, shift conversion and ammonia synthesis stages. Some of these measures closely resemble BAT recommendations for natural gas feedstock plants.

Sound economic sense

As well as saving carbon, it often makes sound economic sense to improve the energy efficiency and capacity of existing ammonia plants. Technology licensors and contractors, notably Casale, KBR and Haldor Topsoe, have been highly active in the ammonia revamp market for decades. Casale alone has revamped over 200 ammonia plants globally since 1985, while KBR has an impressive 80 ammonia plant revamps under its belt (*Fertilizer International*, 466 p 44).

However, actual improvements in ammonia energy efficiency have in some regions been modest. Between 2004 and 2011, CEFIC even observed a slight decline of 0.17% per year for a group of 26 European ammonia plants[4]. Energy efficiency improvements will not happen automatically, in its view, but depend on the ability of plant operators to make additional investments and having the right policy incentives.

Fresh impetus and new thinking on carbon reduction is expected to come from European producers in the next few months. Fertilizers Europe are finalising a 2050 roadmap for the fertilizer industry and are also expected to publish new benchmarking results by the year's end. Both developments will be covered by *Fertilizer International* in future issues. ■

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FERTILIZER INTERNATIONAL
ISSUE 468
SEPTEMBER-OCTOBER 2015
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Introducing a new multi-nutrient fertilizer

ICL Fertilizers is offering new granular and powdered polyhalite products under the trademark *Polysulphate*. Mined in the UK by its subsidiary Cleveland Potash, **Patricia Imas**, ICL's chief agronomist, outlines *Polysulphate's* many applications and agronomic benefits.

Fig 1: **Relative nutrient uptake from *Polysulphate* compared with equivalent standard nutrient sources and an unfertilized control**

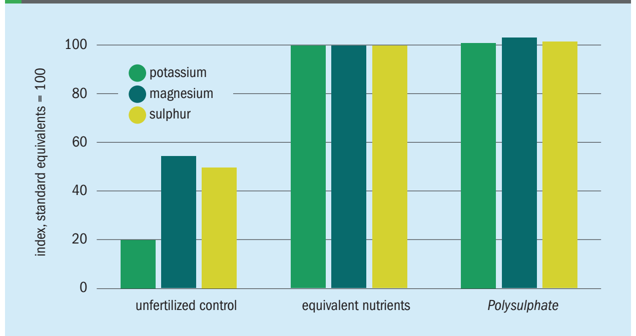
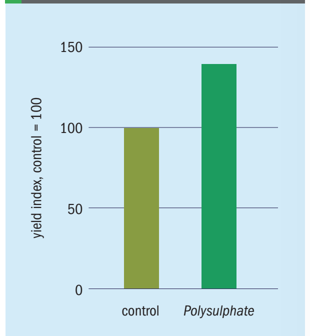


Fig 2: **White cabbage yield response to *Polysulphate***



Polysulphate is a natural, multi-nutrient fertilizer sourced from the mineral polyhalite. Its unique combination of four nutrients, sulphur, magnesium, potassium and calcium, makes it a particularly unusual product. Importantly, *Polysulphate's* solubility means that all these nutrients are readily available for plant uptake.

The new product is mined by ICL subsidiary, Cleveland Potash, at its North Yorkshire Boulby mine in the UK, where it is extracted from a polyhalite layer deep below the North Sea at a depth of more than 1,000 m. This polyhalite layer is found around 150-170 m below Boulby mine's main potash seam and was originally formed 260 million years ago. The first polyhalite samples were brought to the surface by Cleveland Potash in September 2010.

Polysulphate is available as both a granular and powdered mineral fertilizer product. It can be applied to soils as a straight or blended fertilizer and is also suitable for the manufacture of compound fertilizers, according to user requirements.

The 2-4 mm granular product has excellent spreading characteristics and is an ideal fertilizer for applying alongside straight nitrogen. *Polysulphate's* low-chloride characteristics allows it to be applied on all crops, even the most sensitive ones.

Polysulphate is produced in its naturally-occurring state, without processing, and is therefore a low environmental impact product with a small carbon footprint. It is also certified for organic use. Trials show its application provides farmers with dependable, high-value results.

Experimental trials

Polysulphate is suitable as a natural source of nutrients for all crops, especially brassicas, cereals, pulses, field vegetables, clover-rich grassland leys and silage crops. It is particularly well-suited to crops, such as tobacco, grapes and other fruit, which prefer low levels of chloride in the soil, and for potatoes when high dry matter is desired. *Polysulphate* contains:

- 48% SO_3 (19.2% S) as sulphate
- 14% K_2O (12% K) as sulphate of potassium
- 6% MgO (3.6% Mg) as magnesium sulphate
- 17% CaO (12% Ca) as calcium sulphate

Proprietary and independent trials have established how readily available *Polysulphate's* four main nutrients – sulphur, potassium, magnesium and calcium – are to plants. Results generally show that *Polysulphate*, in terms of nutrient uptake, behaves as well as the equivalent fertilizer sources available currently.

In pot trials, crops were either given *Polysulphate* or standard sources of potassium and magnesium sulphate. Uptake of *Polysulphate's* nutrients by the plants was found to be as good, if not better, than the standard fertilizers already used in the field (Figure 1). These results have helped validate *Polysulphate's* effectiveness as a multi-nutrient fertilizer.

Nutrient uptake trials have been repeated many times over in the last ten years, both in pots and in the field. In every case, *Polysulphate* has performed equally well or surpassed the performance of the standard alternatives. Results of UK field trials investigating the response of cabbages, for example, show a 40% yield improvement from *Polysulphate* application (Figure 2).

The testing of *Polysulphate* in field trials of major arable crops in France have also demonstrated the product's agronomic efficiency. For winter wheat, addition of *Polysulphate* to ammonium nitrate gave a statistically significant crop surplus of 1.8 to 2.1 q/ha at different locations. For potatoes, *Polysulphate* increased the yield by 7.0 t/ha, compared with the current agricultural practice (fertilization with non-limiting levels of P, K and Mg). Other experiments at the Indian Institute of Horticultural Research in Karnataka showed that application of *Polysulphate* results in significantly higher head diameter, head weight and head compactness for cabbage and cauliflower crops (Figure 3).

Further Indian field experiments performed at CSA University in Kanpur showed that the yield of mustard increased significantly with 50%, 75% and 100% sulphur applications using *Polysulphate*. Maximum grain yield was recorded for the 100% sulphur treatment using *Polysulphate*, significantly better than for gypsum. For this treatment, a yield increase of 52.7% was obtained compared with the N and P control treatment.

Spreadability trials with granular 2-4mm *Polysulphate* have also been carried out in Denmark and Germany. An excellent overlapped spread pattern was obtained at a 24-metre bout width, with a coefficient of variation of 4.3, and good spreadability up to 36 m (Figure 4).

Fig 3: **Indian Cauliflower trial results for *Polysulphate***

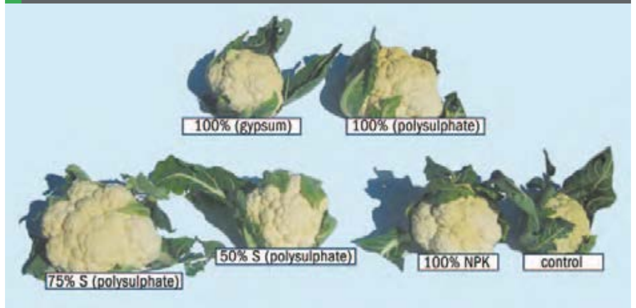
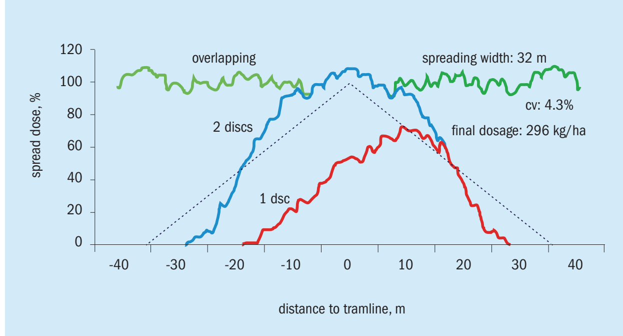


Fig 4: **Spreading straight *Polysulphate***



Benefits of sulphur, potassium, magnesium and calcium

Sulphur is part of every living cell and is needed for the synthesis of certain amino acids (cysteine and methionine) and proteins. Plants require S for photosynthesis, and nitrogen fixation in leguminous plants, and mainly absorb this nutrient in the form of sulphate. Sulphur is also important for ensuring winter hardiness in crops.

Crops such as corn with high dry matter production generally require S in the greatest amounts. Sulphur is also required in large amounts by potatoes, cotton, sunflower, canola (rape seed), brassicas (cabbage, broccoli, cauliflower) and many other vegetables.

Balancing sulphur with nitrogen nutrition is important to both plant and animal health. Sulphur deficiency allows high levels of nitrogen to accumulate in plants in the form of nitrates, for example. This poses a significant potential health threat to grazing ruminants or animals consuming hay. Seed formation can also be inhibited in crops such as canola when nitrates accumulate in the plant.

Soils in some regions have become depleted in S because this nutrient is no longer being replenished from anthropogenic sources, due to falling SO_2 emissions from the burning of fossil fuels, particularly coal, over the last 20 years. *Polysulphate* has great potential to combat the problem of widespread sulphur depletion due its ability to counter S deficiency in crops and grasslands.

As an added bonus, *Polysulphate* also contains valuable levels of potassium, magnesium and calcium. These nutrients confer a range of extra crop benefits, as described below.

Potassium, along with nitrogen and phosphorus, is one of the three essential plant macronutrients, and is taken up by crops from soils in relatively large amounts. Potassium increases the yield and quality of agricultural produce. It also helps plants resist disease, insect attack and the stress of adverse conditions such as cold and drought. Potassium aids the development of strong and healthy root systems, and allows plants to uptake and use N and other nutrients more efficiently. Potassium, as well as being important to plant health, also plays a vital role in livestock nutrition. The K content of *Polysulphate* is therefore a useful complement to routine K-fertilizer applications.

Magnesium is an essential component of chlorophyll, acts as a P carrier in plants and is also necessary for cell division and protein formation. The uptake of P and Mg are entwined and mutually dependent. This makes Mg essential for photosynthesis,

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ISSUE 468
SEPTEMBER-OCTOBER 2015

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phosphate metabolism, plant respiration and the activation of several enzyme systems. Magnesium is removed in significant quantities at harvest for all crops, and an application from *Polysulphate* therefore provides a useful input of this frequently overlooked nutrient.

All of *Polysulphate's* main constituents function as important nutrients. **Calcium**, the fourth nutrient present, is no exception and is responsible for proper cell division and for strengthening cell walls in plants. Calcium improves the root absorption of other nutrients and aids their translocation within the plant. It also activates the enzyme systems which regulate plant growth, converts nitrate into other forms of nitrogen suitable for protein synthesis, and contributes to improved disease resistance. *Polysulphate* is effective at maintaining essential reserves of Ca in soils, and provides a particularly vital source of Ca in highly-deficient tropical, acidic soils. *Polysulphate*, by supplying Ca, can also alleviate the symptoms of aluminium toxicity common in regions where tropical soils occur.

Polysulphate production

Polysulphate is produced from the potassium-bearing evaporite mineral polyhalite [$K_2Ca_2Mg(SO_4)_4 \bullet 2(H_2O)$]. Polyhalite is a single crystalline substance, not a mixture of salts, with two water of crystallisation molecules in its structure. *Polysulphate* is a natural, high-grade product with low levels of impurities. The non-polyhalite content is almost entirely sodium chloride (5% maximum).

Polysulphate is produced from a high grade polyhalite seam by Cleveland Potash Ltd in the United Kingdom from the first operational polyhalite mine in the world. Polyhalite is found below an existing KCl-bearing sylvite seam mined for muriate of potash (MOP) production. Material is extracted and brought to the surface from twin shafts sunk into the polyhalite seam from the overlying potash level of the mine. Unlike blended or compound fertilizers, *Polysulphate* is supplied in its natural state without chemical separation or industrial processing. It is simply mined, crushed, screened and bagged.

UK-sourced and provided in its natural form, *Polysulphate* is a low environmental impact fertilizer that delivers dependable, high-value results for farmers. Because of its low carbon footprint, the application of *Polysulphate* will help growers achieve carbon targets demanded by some retailers and food processors.

Getting the best from *Polysulphate*

Polysulphate has a number of characteristics and key benefits which make it a suitable choice for farmers as a sulphate fertilizer for a range of crops. The product is:

- Readily available – sulphur is already in soluble sulphate form for rapid uptake
- Essentially a straight form of sulphur – with the flexibility to tailor applications to field requirements
- Concentrated – so has a low storage requirement and is quick to spread
- A source of potassium, magnesium and calcium – an added bonus
- Low in chloride – so suitable for chloride-sensitive crops
- Environmentally benign as it used in its natural state – no processing or waste product – and is non-acidifying
- UK-sourced for a secure supply with a low carbon footprint

Advice for crops

Polysulphate can be applied in one dressing at the beginning of spring growth. The aim is to match the sulphur requirements to crop nitrogen needs. Where nitrogen rates are varied, such as in precision farming systems, the *Polysulphate* dressing can be independently tailored to best match overall nitrogen applications.

For Cereals and oilseeds:

- Apply as a straight fertilizer at the start of spring growth
- Being readily available, the crop will take it up with the nitrogen over the spring growing period
- Apply to oilseed rape to optimize yield, protein and oil synthesis
- Apply to bread-making wheats for yield and to ensure grain protein quality
- Apply to malting barley for yield and quality

For Peas:

- Apply in the seedbed or soon after emergence
- Acts as a zero-N fertilizer, bringing readily available sulphur to the crop
- Used by the plant at an early stage to feed nitrogen-fixation process occurring within the root nodules and for protein synthesis in the plant
- Brassica crops have been shown to be particularly responsive to *Polysulphate*. It should be applied as a base dressing, especially on high-risk, light soils.

Advice for livestock farmers

Applications of manure and slurry, although they maintain soil reserves, cannot be relied upon as the sole source of available sulphate. *Polysulphate* should therefore be applied in line with nitrogen requirements to achieve the correct N:S ratio for optimum grass growth throughout the season.

For conserved leys:

- Apply after each cut of silage to complement nitrogen uptake and maintain N:S ratio.
- On lighter soils, an application at the start of spring may also be required

For grazed leys:

- In rotational systems, apply after stock is moved on
- If set-stocked, apply early at the start of spring, especially on lighter soils

For clover leys:

- Provides an excellent sulphur boost for later-growing clover
- Apply as spring growth gets underway – as earlier growing ryegrass will have taken up soil sulphur reserves

FERTILIZER INTERNATIONAL
ISSUE 468
SEPTEMBER-OCTOBER 2015

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Clearwater's granulation masterclass

This year's 39th Annual Clearwater Convention held by AIChE on Florida's Gulf coast on 5-6 June, featured a granulation technology workshop. This well-attended, thought-provoking and occasionally humorous session proved to be a convention highlight.

For four decades now, industry engineers have gathered at Florida's idyllic Clearwater Beach for the AIChE's two-day annual convention on sulphuric acid, phosphoric acid and phosphate fertilizer production. The convention, which always runs on a Friday and Saturday, is renowned for its relaxed atmosphere and ability to combine business with friendship, food and family.

Neil Greenwood chaired the newly-introduced granulation technology workshop on Friday afternoon. The slightly tongue-in-cheek programme promised a panel of four industry experts "who will draw on their vast knowledge and experience to amaze and impress the audience with their expertise". To their credit, the panel managed to surpass expectations by delivering a masterclass on granulation over the course of a single afternoon.

All about solubility

Jacobs Engineering's **David Ivell** kicked things off by going back-to-basics and starting with a fundamental question: "Why do things granulate? In a word, the answer is solubility. In order to make something granulate you need in the order of 15-20% liquid phase." Ivell singled-out four critical determinants of solubility which, in turn, control the granulation process: "What determines that solubility is of course the raw materials, the water content in the granulator, the temperature of the granulation mixture and, in particular, ammonia:phosphate mole ratio."

The granulation of ammonium phosphates is particularly temperature sensitive. "Depending on the raw material, the effect of temperature can be great or not so great," said Ivell. "If you look at ammonium phosphate, it changes tremendously with temperature, particularly at a mole ratio of 1:4." This mole ratio was significant because: "[For] ammonium phosphates, no matter what the temperature, there is a peak in solubility at between 1.4 and 1.5 mole ratio."

Ivell went on to explain the concept of granulation curves, and how optimum granulation occurs within a distinct band when plotted on a graph of moisture versus temperature. For phosphates, such curves are a useful way of looking at how process variables such as pH (ammoniation) and recycle ratio influence granulation. A critical process parameter, recycle ratio measures the proportion of recycled material to final product. It indicates how much granulated material is falling outside of the required size range and being re-run through the granulator to provide fresh nuclei for the process. As Ivell explained, when recycle ratio increases: "What happens is the temperature will decrease because the recycle is less hot than the slurry and the moisture content will decrease because you've increased the dry stuff."

Ivell concluded his presentation by turning to granulator conditions and design: "One thing we perhaps don't pay enough attention to is, first of all, the distribution of the slurry within the granulator but, more importantly, the distribution of ammonia."

In a conventional sparger, ammonia is added at one end and the far end is blanked off. But Ivell had another idea for a sparger, one that would "play all kinds of tunes" by varying mole ratio along its length: "What I'm suggesting is that you add ammonia in both ends and put the blank in the middle… so you can choose how much [ammonia] you can feed where, and by doing that you give yourself a lot better chance of being able to control granulation in a way that you'd like and make it as good as it possibly can be."

Scrubbing ammonia and fluorine

The principles and practice of emissions scrubbing were covered comprehensively by the next speaker, **Marten Walters** of KEMWorks. His presentation encompassed the use of venturi/cyclonic scrubbers, dual mole scrubbing, tail gas scrubbers and ammonia vaporisers/scrubbers in phosphoric acid and phosphate fertilizer plants.

Conventional scrubbing involves a compromise and a trade-off between ammonia loss and fluorine loss: "The problem we've got in scrubbing is that we're trying to do two things – we're trying to scrub fluorine and we're trying to scrub ammonia," said Walters. "But the fluorine emissions go down as pH decreases and the ammonia emissions go up, so normally… we have to find a middle point."

Dual mole ratio scrubbing, in which a primary or pre-scrubber is introduced, is one solution to this, as Walters explained: "The first scrubber, the pre-scrubber, works at a high mole ratio [1.5] this limits the amount of fluorine coming through and captures about three-quarters of the ammonia – not great but good enough – and the second scrubber operates at a low mole ratio [0.70] to capture most of the rest of the ammonia, and, because less fluorine is coming to it, it hasn't got such a difficult job to do on fluorine."

Walters then went on to provide a number of examples of cross-flow scrubbers used for defluorination at US phosphoric acid plants. His presentation ended with a comparison of the relative costs and performance of different types of primary, secondary and tail gas scrubbers.

FERTILIZER INTERNATIONAL
ISSUE 468
SEPTEMBER-OCTOBER 2015

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Machinery people

The final part of the granulation workshop was dedicated to plant equipment and its design and operation. In his presentation, **Shane LeCapitaine** of FEECO International gave examples of the different types of rotary dryer on the market, and described their key features and importance in a granulation plant.

There is a very good reason why granulation plant control rooms are usually located next to the discharge chute, as LeCapitaine explained: "The hot mix that comes out the granulator feeds directly into a rotary dryer. This is typically the most important part of any granulation plant, the discharge chute from the granulator into the rotary dryer, because this [is] very wet and sticky [material] – and if you don't have that controlled properly you'll get plugging no matter what."

In a thorough, authoritative presentation, J & H Equipment's **Cliff Hollyfield** shared his extensive knowledge and experience of how material is crushed, transported, classified and separated in a granulation plant. Proper monitoring and adjustment of recycle ratio and the amount of returns is critical for granulation plant optimisation in Hollyfield's view.

He suggested that smooth operational running requires computer control of recycle returns to the granulator, a calculation of the total quantity of returns, and making sure no particles larger than 3 mm return to the granulator (100% crusher efficiency). These three measures will automatically reduce crusher surges and increase crusher efficiency in granulation plants, and were part of "the big thing we can do as machinery people", according to Hollyfield. He concluded by proposing four key points to running a better plant:

- Adjust recycle from the screen to optimise granulation with a constant quantity of liquids fed to the granulator
- Adjust the recycle solids feed to the granulator gradually as this will yield less fines and oversize
- Aid plant running by returning only smaller particles and not material that is going to make oversize
- Production rates increase when plants can be run without having to reserve extra mechanical capacity for high recycle returns ('sine wave' surges)

Having fully shared his knowledge and expertise, Hollyfield ended the granulation workshop with a suitably deadpan remark: "Other than that, I don't know anything else!"

Day 2: phosphoric acid session

The phosphate industry, as a large consumer of water, needs to adopt a new holistic approach to water conservation that considers water use in its entirety, argued **Ronald Tebbetts**, global technical consultant for Nalco. He pointed out that – although no one considers it valuable until a problem occurs – phosphoric acid plants are unable to operate without water, so making proper water management more and more critical to the bottom line.

"Heavy industry by its very nature uses a lot of water. The phosphate industry and phosphoric acid processes are no exception to this. We use a lot of water in a variety of applications, be it steam generation, power generation, vacuum creation, cooling, washing. So water is an integral part of the process and I hope we all agree it's a critical component to your success and needs to be considered very, very seriously and much more than it has historically," said Tebbetts.

Referring to the recent drought on the US West Coast, Tebbetts added: "If you talk to people in California you can easily understand that water is a very scarce commodity and there's nothing like scarcity to put value on something."

Unfortunately, conventional approaches to water conservation in the heavy industries, if based on a simple hydraulic model using a spreadsheet, can have disruptive and unforeseen consequences. This is largely because they typically focus on water reuse from just a single process, such as cooling tower or a boiler, instead of the whole plant. Other factors such as the distance between a plant's assets, the age of these assets and a lack of knowledge over their condition can also act as major barriers to on-site water conservation and reuse.

An advanced software model for water audits developed by Nalco, *AMS Water*, overcomes some of these problems due to its ability to look at the water system of the whole plant and model both water chemistry (quality) and hydraulics (quantity). The model provides users with a range of water reuse options, as well as the capital costs associated with each of these, and has been used as part of comprehensive water audits at nearly 100 industrial plants since its development began in 2001.

However, extra water savings are likely to come at price in future, warned Tebbetts, once the 'easy' water has been conserved. Water conservation projects are generally becoming more capital intensive because a portion of the salts present in the water system (Ca, Mg, Si, SO_4, Cl etc.) will eventually need to be taken out – requiring equipment, investment, engineering services and space.

Leaching high dolomite ore

Results presented by **Curtis Griffin**, process engineering supervisor at PegasusTSI, suggest that acid leaching can be an effective way of removing MgO from phosphate rock. Experimental testing showed that a high-dolomite ore (3.7% MgO) supplied by EuroChem was "rather amenable" to MgO removal by acid leaching, with pH being by far the most critical factor affecting beneficiation performance.

Controlled H_2SO_4/HNO_3 leaching experiments were carried out in a sealed glass reactor to investigate the effect of particle size, pH, temperature and solids concentration. Under optimum conditions (pH 2.8, temperature 70°C, slurry density 3%), nearly 90% of MgO was removed at a P_2O_5 loss of less than 2%, yielding a phosphate rock product containing under 0.4% MgO. However, a shorter two-hour leaching time is likely to be sufficient to meet EuroChem's target product grade of less than 1.5% MgO, at a phosphate loss of less than 3%. Successful results obtained using EuroChem's ore size specification (90% passing 500 microns, 35 mesh) confirmed that leaching work wells on relatively coarse feedstock.

Adding iron to remove iron

Process engineer **Stephen Hilakos** described a process developed by Jacobs Engineering for removing iron from phosphoric acid. Experimental results suggest that iron oxalate ($FeC_2O_4.2H_2O$) can be successfully precipitated without unwanted co-precipitation of P_2O_5. Jacobs now plans to develop a proprietary treatment method from the technique, after finding it was effective at removing iron from the Abu Tartur phosphate deposit in Egypt.

"It [Abu Tartur] is fairly famous in the literature – people have been working on this for roughly 30 years," commented Hilakos. "There have been eight to 10 companies who've tried to fix this problem that we think we've solved."

Conventional approaches to treat Abu Tartur ore have been largely unsuccessful because most of its iron is locked inside apatite particles. Attrition scrubbing, for example, is only partially effective because less than 50% of the iron is attached to the surface of apatite particles.

Jacobs' new iron removal method is a two-stage process that firstly reduces the oxidation state of phosphoric acid solution and then precipitates out iron oxalate by adding oxalic acid. The process has been shown to reduce iron content of Egyptian phosphoric acid from 2.17% to 0.5% Fe_2O_3. This acid was derived from rock concentrate (2.44% Fe_2O_3) obtained from Abu Tartur ore (3.24% Fe_2O_3).

The procedure is unusual in that, paradoxically, it involves "adding iron to remove iron". This was found to be necessary after Jacobs discovered that changing the redox state from Fe^{3+} to Fe^{2+} is a critical step for removing iron efficiently. This redox change can be accomplished by adding elemental iron to phosphoric acid, or by altering the solution's electrical potential to below 100 mV.

Jacobs' iron removal process is at 'proof of concept' stage at the moment and requires further improvements such as recycling of oxalate to reduce costs. One recycling option involves reacting precipitated iron oxalate with calcium chloride solution and then treating the calcium oxalate recovered with hot sulphuric acid to regenerate oxalic acid. Unfortunately, the current market price for calcium chloride makes this approach uneconomic at present. More encouragingly, Jacobs says it has a viable, but as yet undisclosed, alternative recycling process which is able reduce the primary cost of oxalic acid use ($600/t) by around a half. Switching from using elemental iron to an electrolysis method for the redox reduction step would also cut costs by around 30%.

Boosting production with filter aids

The potential benefits and drawbacks of using polymer filter aids during the gypsum filtration of phosphoric acid were set out by Nalco's industrial development manager, **Paul Wiatr**. Better P_2O_5 recovery, increased filter productivity and lower gypsum filter cake moisture content are the main rewards from adding polymer flocculants as filter aids.

"It doesn't work everywhere and it can be difficult to implement – but it is worth considering," commented Wiatr. "There are costs to a filter aid programme but the benefits of increased product recovery… can add a lot of revenue to your operations."

Filter aid trials at an African plant demonstrated a net saving of four t/d of P_2O_5 (equivalent to 4,000 t/a) and a return on investment (ROI) of $6.50 for every dollar spent. A polymer filter aid used during a second European plant trial increased filter production by 20% from 200 m³/h to 240 m³/h. A third trial for a single filter at an Asian plant helped recover an additional 12.74 t/d of P_2O_5, equivalent to around 13,000 t/a extra P_2O_5 when scaled-up for all three of the plant's filters.

Polymer filter aids do have potential drawbacks, however, including the extra consumption of polymer make-up water. This can raise water consumption by 0.5-1.0 million gallons per year and has the knock-on effect of increasing evaporation energy usage. One way of avoiding this is to add the polymer to gypsum slurries as a neat liquid emulsion. But concerns remain about whether neat fed polymers are able to fully invert in time and act as effective flocculants in the slurry.

Making fluoride reduction viable

An innovative process for recovering commercial-grade hydrofluorosilicic acid (FSA, 20-25% concentration) from cooling water was described by **Leif Bouffard**, Hatch's director of phosphates process engineering. This is able to capture fluoride (96%

FERTILIZER INTERNATIONAL
ISSUE 468
SEPTEMBER-OCTOBER 2015

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recovery) and discharge high quality water (89% recovery) suitable for use as cooling tower make up water.

"We've got people who have problems with fluorides in their cooling towers, it's in their cooling ponds," explained Bouffard. "That gave us the impetus to go ahead and try to come up with this technology to add on to our sustainability programme."

Bouffard called the new resource recovery system the "third leg to the stool" because it is designed to be used in combination with two other elements – series filtration technology and a closed loop cooling water system. Plants that adopt this integrated approach to losses management should benefit from extra revenues of up to $120 million over 15 years because of better P_2O_5 recovery. Another $30 million is also saved due to avoided treatment costs from lower cooling pond acidity.

Hatch is developing its FSA recovery method as a proprietary process, but admits further testwork is required. Pilot-plant tests to validate preliminary recovery figures for fluoride and water will be necessary, followed by partial plant-scale demonstration tests to obtain "real world results". Hatch's ultimate aim is to develop a viable and effective fluoride reduction process for cooling water circuits that achieves a much higher water recovery than is currently possible.

Water balancing act

In a joint presentation, **Mohamad Al-Hawaree**, vice president of Ardaman & Associates, and Mosaic's **Brittany Cooley**, a water balance engineer, summarised how water balance models can be used to safely operate and manage phosphogypsum stacks. Such models are calibrated using routine water inventory measurements and are an "extremely powerful" tool for understanding the hydrology of stack systems.

Ideally, the models need to be all-encompassing yet flexible and user-friendly. "Your ideal water balance model needs to be site-specific but adaptable. You need to be able to handle your stack geometry, your cooling ponds, your surge ponds and your chemical plants. It's a very dynamic system and you need to be able to provide a standardised output to compare sites easily, whether you're running into a problem or highlighting a success," said Cooley.

As well as being valuable operationally, water balance models can be used by engineers to design various components of a new phosphogypsum stack systems, such as surge ponds and settling compartments. They are also a useful predictive tool for planning either the expansion of stacks or their eventual closure.

Plan early for success

A successful expansion project at Rock Springs phosphoric acid plant in Wyoming was the subject of a joint presentation from contractors Hatch and the plant's owners JR Simplot. The 15% P_2O_5 capacity expansion project took over half a million man hours to deliver yet was completed on schedule and 10% under budget. Project manager **John O'Toole** and senior project consultant **Andy Nuyianes** spoke about Hatch's efforts in delivering the project. Operations superintendent **Bob Skorcz** and senior engineering project manager **Mike Fossceco** also explained the outcome of the project from Simplot's perspective.

At the heart of the project was the addition of a second parallel reactor, the demolition of Rock Springs' old phosphoric acid cooling tower (PACT) and the construction of new blend tank system. Hatch's new reactor allows Rock Springs to operate without monthly down days and has also eliminated annual turnaround outages of 10-24 days. The new rubber-lined blend tank prevents ice build-up in winter, dampens swings in process temperature and increases wash time by reducing scaling.

The project's successful execution was down to "watching the costs and the scope" according to Simplot's Mike Fossceco. "Plan early, plan early, plan early," he advised. "[Also] innovate and create the safety culture early, as that was another reason for our success. We had good buy-in from the contractors – don't underestimate brownfield project execution as it can trip you up – and create a team that functions, behaves as a team."

Granulation from past to present

The original diammonium phosphate (DAP) granulator was first patented in 1956 by Frank Nielsson of the Tennessee Valley Authority. In his second presentation of the day, **Curtis Griffin** of PegasusTSI traced the evolution of granulation from Nielsson's design to current state-of-the-art equipment and techniques. This was also the subject of a contributed article in our May/June issue (*Fertilizer International* 466, p53).

Good quality granulation requires careful control of particle size (93-95% between 2 mm and 4 mm) and uniformity, explained Griffin. Granulation also needs to happen by a layering rather than an agglomeration process to avoid particle breakage and chipping. Granulator design parameters, such as the location of the ammonia sparger and slurry header, slurry spray nozzle configuration and granulation speed, strongly influence granulation quality.

"Good granulation is a function of the granulation speed, ammoniation, slurry nozzle header design, recycle ratio, making sure that you layer particles," concluded Griffin. "But if you set up everything correctly, there's no problem meeting the requirements today for quality."

Day 2: sulphuric acid session

The parallel sulphuric acid session on day two included the following eight presentations:

- How to buy a vessel. **Kevin Lambrych**, Ashland
- Strategies for reducing start-up emissions from sulphuric acid plants. **Kim Nikolaisen**, **Andres Mahecha-Botero**, **Guy Cooper**, Noram
- From nano-scale studies of the working sulphuric acid catalysts to improved industrial scale sulphuric acid production. **Kurt Christensen**, **Filipo Cavalca**, **Pablo Beato** and **Stig Helveg**, Haldor Topsøe
- Best practices for specifying and purchasing composite piping systems. **Kira Townsend**, RPS Composites, Inc
- Hydrogen incidents: why now – what can we do? **Leonard Friedman**, Acid Engineering & Consulting, Inc.
- Small project optimisation in sulphuric acid plants: achieving the best ROI. **Kirk Bailey**, MECS/DuPont
- Shell & tube strong sulphuric acid coolers. **Frans Kudeda**, OUTOTEC-Edmeston Product Center
- Understanding spray technology to optimise sulphur burning. **Chuck Munro**, Spraying Systems Co

2015 Engineer of the Year

Mosaic's Dave Sabatino was named this year's *Hero of the Industry* and Tino Prado of Prado & Associates was awarded the accolade of *Engineer of the Year* for 2015. Delegates will convene again in Florida for the 40th Annual Clearwater Convention on 10-11 June next year. ■

Potash from brine: the major playas

Last year, over ten million tonnes of potash was produced by harvesting brines using solar evaporation. The limited scope for potash ore mining makes potassium-enriched brines a particularly important source of potash in China. We profile major brine processing operators around the world, and look at the merits and demerits of this production route.

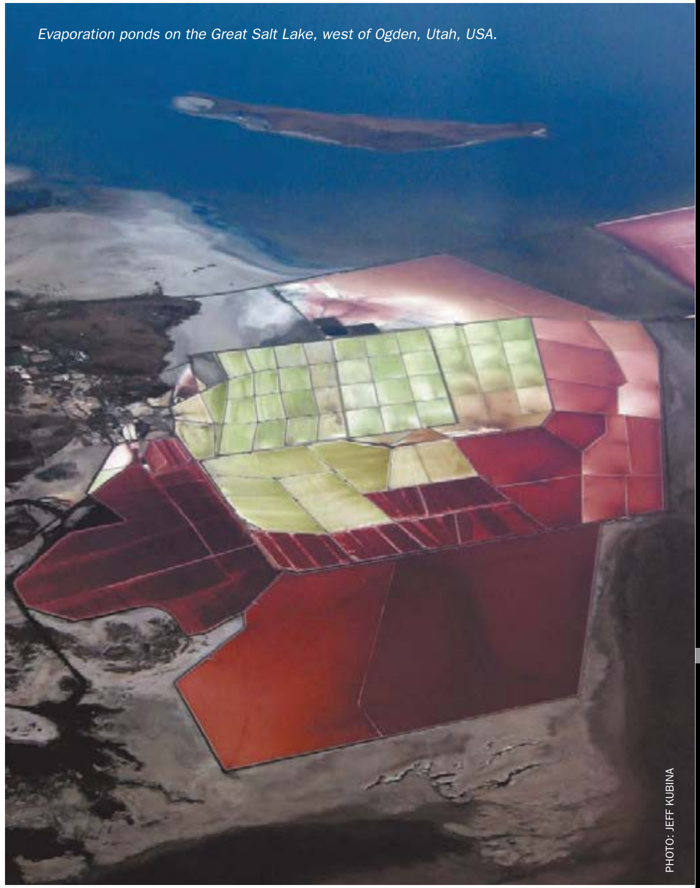
As well as occurring as solid ore, commercially-recoverable quantities of potash are also found across the globe dissolved and enriched in lake brines. These brines may have a potassium chloride concentration of just one or two parts per hundred, but can pool in vast volumes at or near the surface, given suitable geological and climatic conditions. Brines of commercial significance have a particular association with closed drainage systems and the extensive salt flats that occur in arid continental interiors.

China's growing potash brine industry has sprung up in two particularly harsh and remote parts of the planet. The muriate of potash (MOP) operations of the Qinghai Salt Lake Company at Qarhan Salt Lake, in Qinghai Province, several thousand kilometres west of Beijing, are perched at a height of 1,800 m on the fringes of the Tibetan Plateau, where temperatures plummet to below minus 40°C in winter[1].

In another equally inhospitable part in China, the SDIC Xinjiang Luobupo Potash Company produces sulphate of potash (SOP) from brines collected in the world's largest set of salt ponds at Lop Nur in the Xinjiang autonomous region[2]. This location, on the eastern edge of the Taklamakan Desert, is prone to frequent dust storms and is swept by 200 metre-high shifting sand dunes. It is also notorious as the former location of a nuclear weapons test site.

Brine processing

The Qarhan and Lop Nur salt flats in China are part of a select group of large-scale commercial potash brine processing sites operating globally (Table 1, Figure 1). These



Evaporation ponds on the Great Salt Lake, west of Ogden, Utah, USA.

PHOTO: JEFF KUBINA

FERTILIZER INTERNATIONAL
ISSUE 468
SEPTEMBER-OCTOBER 2015

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extract surface or near-surface brines from closed continental basins of Pliocene-to-Quaternary age and concentrate these in ponds using low-cost and energy-efficient solar evaporation. If the estimates in Table 1 are correct, around 10-13 million tonnes of potash was produced from brine last year, almost a fifth of world production (68.9 million tonnes). Many brines are also enriched in economically-valuable lithium, boron and magnesium which can also be exploited as co-products.

The world's two largest MOP brine factories are operated by ICL subsidiary Dead Sea Works and the Arab Potash Company at the southern end of the Dead Sea. In the US, Compass Minerals Group recovers SOP and Intrepid Potash extract MOP commercially from the Great Salt Lake brines in Utah. In Chile, SQM produces both SOP and MOP on a commercial-scale from the salar brines of Chile's Atacama Desert.

Qarhan Salt Lake, Qinghai, China

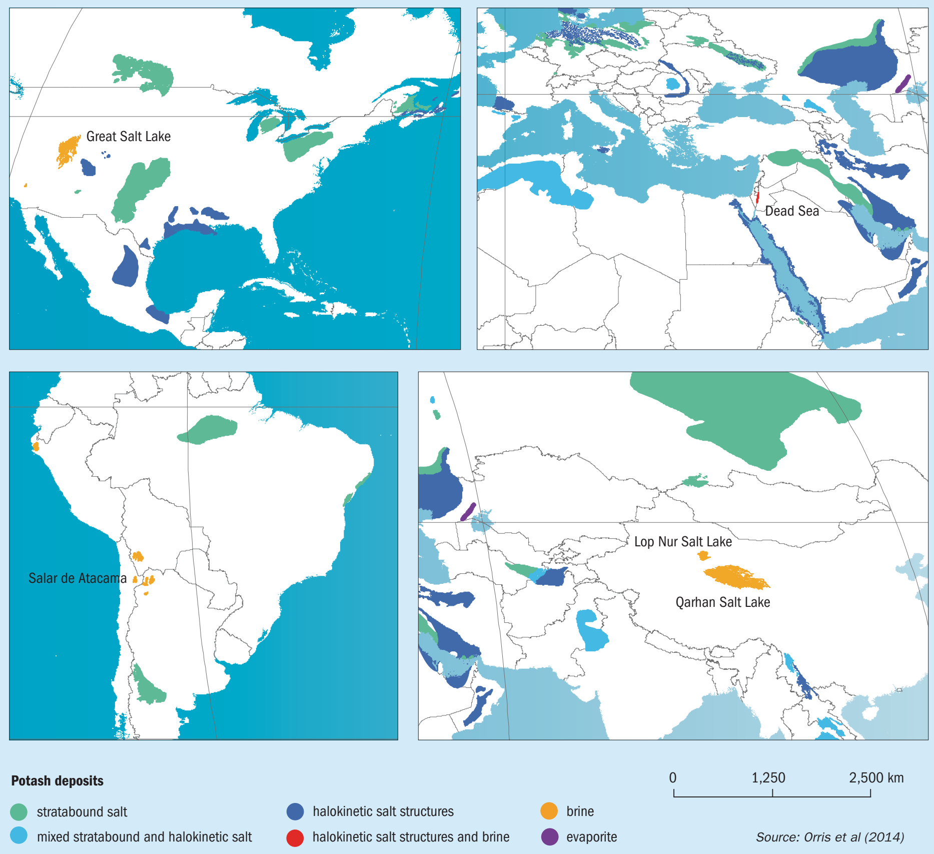
Brine processing dominates the Chinese potash industry and is concentrated in two areas: Qarhan Salt Lake in Qinghai Province and Lop Nur Salt Lake in Xingjiang. Six producers in Qinghai produce around 5 million t/a of MOP, equivalent to about two thirds of total Chinese production, with Qinghai Salt Lake Potash Company, China's largest potash producer, responsible for 2.5 million t/a. Another of the region's producers, Qinghai Avic Resources Co Ltd has an annual production of 0.5 million tonnes.

Qarhan Salt Lake is a closed lake system fed by the Golmud, Qarhan and Urtom rivers and is just one of a number of wet and dry (playa) lakes spread out over a 120,000 km² square area of the Qaidam Basin. Qarhan's potash reserves were recently estimated at 251 million tonnes. Brine from highly saline groundwater lies around 1.3 m beneath a salt pan crust. This is collected in trenches and transported to a solar evaporation pond where halite is firstly precipitated. The remaining brine is then transferred to another evaporation pond where carnallite, still containing 12-25% halite, precipitates and is harvested by dredging. The low summer temperature at Qarhan (9-22°C) means solar evaporation is comparatively slow.

The carnallite-halite mixture harvested at Qarhan is processed by the Qinghai Salt Lake Potash Company in two stages (Figure 2). In the first stage, halite is removed from carnallite by froth flotation followed by a cold decomposition/crystallisation stage to produce an MOP concentrate with a 90-95% grade (KCl). A similar flowsheet is used by Dead Sea brine operators due to compositional similarities.

Prior to froth flotation, the feed is conditioned by adding a collector (dodecyl morpholine) at a dose of 50 g/t to a pulp at 30-35% solids concentration. A reverse flotation process recovers about 90% of halite present. The Qinghai flotation plant was expanded from 0.2 million t/a in the late 1990s to one million t/a capacity in 2014[3].

Fig 1: Global distribution of potash brines versus other potash tyres



Source: Orris et al (2014)

Table 1: Potash production from lake brines

Location	Company	Product	Reserves (million tonnes)	Production (million t/a)
Dead Sea, Israel	ICL	MOP	1,000	3.5
Dead Sea, Jordan	Arab Potash Company	MOP	-	2.1
Lop Nur (Luobupo) Salt Lake, China	SDIC Xinjiang Luobupo Potash Co Ltd	SOP	36	1.3-3
Qarhan Salt Lake, China	Qinghai Salt Lake Potash Company (Sinochem)	MOP	251	1-2.5
Salar de Atacama, Chile	SQM	SOP & MOP	250 (SOP)	1.6
Great Salt Lake Utah	Compass Minerals Group	SOP	-	0.36
Wendover, Bonneville Salt Flats Utah	Intrepid Potash	MOP	-	0.09
Total				**9.95-13.15**

Source: Company information, Warren (2015)

Dead Sea brine factories

Dead Sea Works Ltd (DSW), near Mt Sedom in Israel, and the Arab Potash Company (APC) at Ghor al Safi in Jordan, both produce MOP from the solar evaporation of Dead Sea brine. Both firms use the power of the sun to carefully concentrate and precipitate salts in a series of interlinked, gravity-fed ponds. The harvested salts are purified and converted to MOP in hot leaching or cold crystallisation plants.

In the initial salt pans, half the volume of water is lost to solar evaporation, causing the precipitation of large volumes of halite and minor amounts of gypsum on the pond floor. As it thickens, the brine is allowed to flow into carnallite harvesting ponds where around 0.3-0.4 m of slurry is allowed to accumulate. The slurry, composed of 84% carnallite and 16% halite, is then harvested using floating dredges fitted with powerful pumps. The dredges also crush and filter the slurry and separate off coarser, purer carnallite crystals.

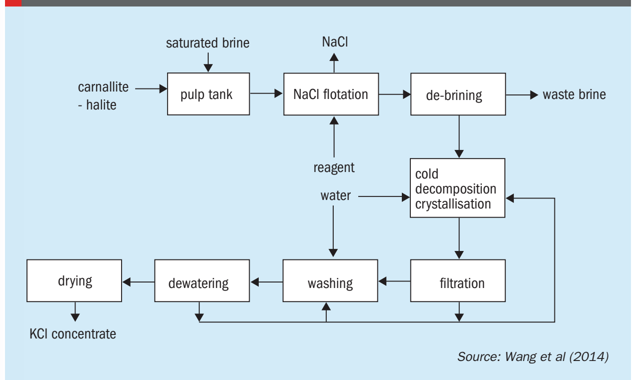
Originally, both DSW and APC converted harvested carnallite-halite slurry into an MOP end-product using a hot leaching/vacuum crystallisation process. But significant volumes of MOP are now produced at a lower cost by processing coarse slurry fractions at ambient temperature in a cold crystallisation plant. This process is less energy intensive and also consumes less water. Reverse froth flotation is also used to remove halite and improve the purity of finer slurry fractions (<1 mm) prior to cold crystallisation[4]. Veolia Water Technologies recently supplied DSW with a high-throughput (153 t/h) cold crystallisation system (*Fertilizer International*, 465 p60).

The brine operations of DSW are an important revenue-earner for its parent company ICL. In 2014, the potash (3.5 million tonnes), salt (259,000 tonnes), bromine (174,000 tonnes), magnesium chloride (136,000 tonnes) and magnesium (26,000 tonnes) produced by DSW accounted for around two fifths of ICL's sales.

DSW's evaporation ponds cover 146 km² and include a group of 35 halite and carnallite precipitation ponds. The largest of these, 'pond 5', covers 80 km² and was built in the 1960s from a large dam sealed by a clay core. DSW transferred 370 million m³ of water from the Dead Sea's Northern Basin into its adjacent evaporation ponds during 2014 using its powerful 100,000 m³/h capacity pumping station.

Arab Potash Company (APC) production reached 2.091 million tonnes in 2014, up by almost a fifth from the 1.744 million tonnes output in 2013, generating revenues of JD 475.1 million. APC

Fig 2: Flowsheet for froth flotation and cold crystallisation of Qarhan Salt Lake brine



Source: Wang et al (2014)

FERTILIZER INTERNATIONAL
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production is set to rise in future years after board-level approval was given last year for a 30-month project to raise production capacity by 65,000 t/a. This is extra to an existing 250,000 t/a expansion project which is due to be completed in 2016.

Bonneville salt flat, Utah

In Utah, Intrepid Potash, Inc. produces both MOP and magnesium chloride from near-surface brines and ponds at Wendover on the Bonneville salt flat, a region of the Great Salt Lake desert located high above sea level at 1,270 m. Brine present in the deep and shallow aquifers at Wendover contains probable reserves of 3.43 million short tons. The Wendover operation produced 97,000 short tons of MOP in 2014, close to the plant's 100,000 ton nameplate capacity.

Solar evaporation is only effective in Utah during June, July, and August, with more than half the evaporation taking place in July. A combination of low rainfall and windy conditions are required during this three-month period to maximise evaporation and mix the brine properly. The sylvite and halite present in the salt harvested at Wendover are separated by reverse froth flotation at the processing plant.

Brines within lake sediments drain into a 160 km network of two metre-deep ditches cut into a 350 km² area of the Bonneville salt flat. The extracted brine is firstly pumped into an 8,000 acre solar evaporation pond. After further concentration in other smaller evaporation ponds, brine is eventually transferred to sylvite harvesting ponds when the density exceeds 1.245 g/cm³. Each year, Intrepid harvests around 18 million m³ of lake brine in this way to produce up to 100,000 tons of MOP at Wendover.

The total harvesting process, from the ditch extraction of brine to the precipitation of sylvite-halite on the pond floor, takes around 180 days. Harvesting ponds have compacted floors and use synthetic rubber liners, both to prevent brine loss and to stop front end-loaders and scrapers from sinking into wet mud as they to remove encrusted salts from the base of ponds. Leftover $MgCl_2$-rich brines are transferred to additional evaporation ponds and allowed to concentrate further. These are then stored to be later sold as a liquid highway de-icer, a dust controller and soil stabilisation agent.

Great Salt Lake, Utah

Compass Minerals dominates North American SOP capacity due to its ownership of brine processing facilities at Ogden in Utah and Big Quill Lake in Wynyard, Saskatchewan. The firm produces both agricultural-grade SOP, marketed under the *Protassium+* name since 2014, and industrial-grade SOP. The firm also sells brine co-products such as magnesium chloride and salt for consumer and industrial de-icing. Compass also markets magnesium chloride for agricultural use under the *Chlori-Mag* brand name.

The plant operated by Compass in Ogden is the largest SOP production site and the largest solar evaporation operation in North America. SOP production capacity at the site (400,000 short tons) is split between 320,000 t/a of brine capacity and 80,000 t/a of MOP conversion capacity. In recent years, Compass has used bought-in MOP to supplement SOP production from brine to "help meet demand when economically feasible". This supplementary method of SOP production, although more expensive due to the cost of MOP, keeps production volumes stable if poor solar evaporation conditions reduce pond harvesting, as happened in 2012. Between 2008 and 2013, SOP production costs for Compass Minerals fluctuated between $287/t and $381/t, according to analysts CRU, depending on the amount of MOP purchased. The Ogden plant also has capacity to produce 1.5 million short tons of salt and 0.75 million short tons of magnesium chloride from brine annually.

The Ogden processing plant sources its brine feedstock from solar evaporation ponds covering more than 45,000 acres. Salts are concentrated and harvested from brine as it moves through a series of solar evaporation ponds over a two- to three-year production period. The Behrens Trench, a 35 km underwater canal on the floor of the Great Salt Lake, links up the two sides of the lake and allows saturated brine to flow from the 17,500 acre solar ponds on the western shore to the Ogden plant on the eastern shore. This has cut transport cost by replacing the trucking of harvested salts around the lake's perimeter. Using ponds on the west side of the Great Salt Lake for solar evaporation is preferable because they receive less than half the average annual rainfall than those on the eastern side.

In recent years, Compass has raised SOP brine capacity from 240,000 to 320,000 t/a by investing in solar evaporation ponds, to improve the annual solar harvest, and through expenditure on the Ogden plant to increase processing capacity and extraction yield. Although capacity has risen by a third, the $160 million investment announced by Compass in 2010 was supposed to boost production to 570,000 t/a by 2015. However, Compass still expects "a meaningful increase" in SOP production once investments in further renovations and upgrades at the Ogden plant are finished in 2016. Compass also plans to extend its solar evaporation area at the Great Salt Lake in future, although no new pond construction is expected this year.

North American SOP production out of Ogden is mainly destined for the domestic market. Compass is concentrating more on US sales because this market "recognises the value of SOP and is closer to our production facilities, which further benefits our net selling price". The firm sold 372,000 short tons, 94% of its agricultural shipments, into the US market in 2014. This was mainly in granular form for bulk blending or for straight application to turf. Key customers for North American SOP include fruit growers in Florida and California and tobacco growers in eastern states.

Salar de Atacama, Chile

Chilean producer SQM extracts brines from beneath the saline crust of the 3,000 km² Salar de Atacama, the third largest salt flat in the world. It has the capacity to harvest over two million tonnes of MOP and SOP from solar evaporation ponds covering a 1,700 hectare area. The 2,250-metre high Andean plateau offers near ideal evaporation conditions, having an average annual rainfall of less than 15 mm and a solar evaporation index of 3,200 mm.

SQM began producing MOP and SOP in the 1990s and operates several processing facilities at Salar de Atacama. Original production of around 80,000 t/a has now increased to 2.3 million t/a as part of a $2 billion investment programme by SQM. Production at the main MOP and SOP plants expanded to 1.05 million t/a and 360,000 t/a, respectively, in 2009. Capacity of the SOP plant, a dual operation able to switch between SOP and MOP production, was subsequently increased to 760,000 t/a. Two smaller plants provide SQM with an additional 265,000 t/a of MOP capacity.

CONTENTS
What's in issue 468
COVER FEATURE 1
TFI World Fertilizer Conference, Boston
COVER FEATURE 2
Sulphur supply sea change
COVER FEATURE 3
The elemental value of phosphorus

FERTILIZER INTERNATIONAL
ISSUE 468
SEPTEMBER-OCTOBER 2015

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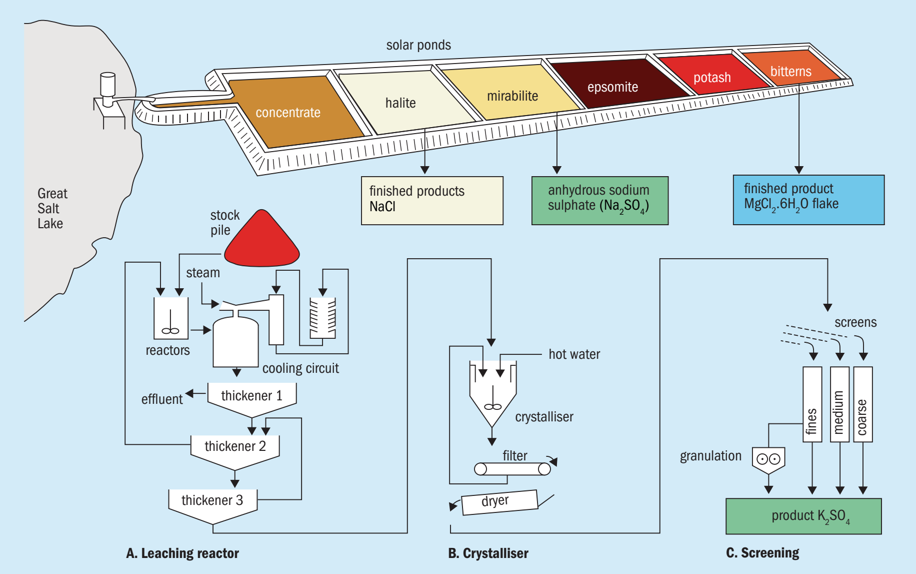
SOP production from brine

Fig 3: Typical flowsheet for SOP production from Great Salt Lake brine



Source: Butts (2007) / Warren (2015)

The solar evaporation of natural sulphate-rich brines provides the most cost-effective production route for the commercial manufacture of SOP. Operators currently capable of producing SOP on a large-scale from brines include SDIC Luobupo, Compass Minerals and SQM. In 2013, brine producers in China (1,680,000 tonnes), the US (150,000 tonnes) and Chile (70,000 tonnes) accounted for nearly 40% of the five million tonne global market for SOP.

A generic flowsheet for SOP production is shown in Figure 3. Unsurprisingly, the process requires brines with high sulphate level (Table 2) and typically involves the concentration and precipitation of kainite ($KCl.MgSO_4.3H_2O$) and schoenite ($K_2SO_4.MgSO_4.6H_2O$). The kainite-schoenite slurry used for potash production is generally harvested last, following the precipitation in sequence of halite (NaCl), mirabilite ($Na_2SO4.10H_2O$) and epsomite ($MgSO_4.7H_2O$).

In the first processing step, harvested salts are completely converted to schoenite by leaching in a reactor, as follows:

Kainite 2($KCl.MgSO_4.3H_2O$) + excess sulphate brine → schoenite ($K_2SO_4.MgSO_4.6H_2O$) + magnesium chloride ($MgCl_2$)

(Low-grade harvested feed can be successfully upgraded prior to this by separating schoenite from halite using froth flotation with an amine collector.)

Table 2: **The chemical composition of commercially-extracted potash brines**

	Concentration (g/l)				
Brine	Na	K	Mg	Cl	SO_4
Dead Sea	35	7	35	190	<1
Great Salt Lake, USA	95	7	10	155	20
Salar de Atacama, Chile	90	22	12	190	23
Qarhan Salt Lake, China	14	22	75	250	5
Lop Nur Salt Lake, China	n.d.	10	17	180	45

Source: Garrett (2012)

After leaching, the schoenite slurry is then thickened and decomposed in a draft baffle tube (DFT) reactor/crystalliser using hot water. Magnesium sulphate enters solution leaving behind SOP as solid crystals:

Schoenite ($K_2SO_4.MgSO_4.6H_2O$) + hot water → SOP (K_2SO_4) + magnesium sulphate ($MgSO_4$) + $6H_2O$

The crystals are finally filtered, dried and screened into fine, medium and coarse granular SOP products.

Although SQM's nameplate capacity for SOP is around 340,000 t/a, according to analysts CRU, the dual plant has mainly been producing MOP in recent years with annual SOP output declining from 189,000 tonnes in 2009 to 90,000 tonnes in 2013.

Combined sales of 1,556,000 tonnes of SOP and MOP generated almost a third ($584.3 million) of SQM's total revenues in 2014. Three quarters of these sales were to North, Central and South America. Brazil is a particularly important market, accounting for 30% of MOP sales alone.

Lop Nur, Xinjiang, China

Since 2008, the extraction and processing of brine from Lop Nor (Luobupo) in the south east of Xinjiang in Western China, has massively increased China's supply of SOP. The SDIC Luobupo Potash Company has rapidly established itself as the country's dominant SOP supplier by extracting brine from a dry lake bed at the eastern end of the Taklamakan Desert, around 780 m above sea level. This is China's largest and driest desert and, with annual evaporation of 2,901 mm and annual rainfall of just 31 mm, solar evaporation conditions at Lop Nor are almost as favourable as those of the Atacama.

Lop Nor acts as a sump for the Tarim Basin, an enclosed groundwater system covering some 530,000 km². SDIC has constructed a pond system larger in scale than that of the southern Dead Sea to extract the 36 million tonnes of recoverable SOP present in subsurface brines at Lop Nor. This has enabled the firm to produce 1.3 million t/a of SOP since 2008, almost exclusively for the domestic market. An additional 300,000 t/a capacity, due to be competed this year, should bring capacity up to 1.6 million t/a. SDIC's ultimate aim is to increase capacity to 3 million t/a.

Importance to China

Sales from potash brine operations in North and South America and China are largely restricted to the domestic and regional markets. Large differences in reported brine production costs, with SDIC Luobupo at one extreme ($167/t) and SQM ($421/t) at the other, are less relevant if producers are not generally competing head-to-head by selling into the same market. It is therefore likely that, of all the current brine-operators, the 5-6 million tonnes of potash produced and exported from the Dead Sea will continue to have the most impact on global trade.

Salar de Atacama is the largest salt flat in Chile.

A recent USGS assessment concluded that potash production from brine is particularly important for China[5]. "A significant finding of this assessment is that there appears to be little to no potential to develop potash mines in either China or India, where large populations create the need for highly productive agricultural land, which in turn requires large amounts of appropriate fertilizers," lead author, Greta Orris, said in March. "High import costs have resulted in lower usage of potash fertilizers than commonly seen in the U.S., and the potential for the land to be less productive."

As the USGS notes, the potash brought into production in China in recent years has been almost exclusively sourced from large brine deposits discovered in the Tarim and Qaidam Basins of West China. The lack of domestic potash ore mining potential suggests China will have little choice but to invest heavily in expanding domestic potash brine production, if it is to satisfy internal demand, as it has done in domestic phosphate and urea production over the past two decades.

That could end the perception of brine processing as the minnow of the global potash industry, at least in the Far East, although the USGS doubts whether brine resources will ultimately be sufficient to meet China's internal needs. This is no doubt part of the explanation for China's keen interest in the development of Africa's potash potential, as discussed elsewhere in this issue (p58).

Uncertain climate bring risks

Using the sun's energy to concentrate and precipitate valuable salts is what keeps potash brine operation costs low. Adding dyes to solar ponds increase energy adsorption, raising brine temperatures and evaporation rates. The downside is that the effectiveness of solar evaporation, and therefore the productivity of brine operations, is highly sensitive to variations in weather and climate. Heavy rainfall in September and October at the Great Salt Lake, for example, reduces Wendover's potash production from brine for that year and possibly the year after. Similarly, lower-than-average temperatures or higher-than-average summer rainfall can also reduce evaporation rates and impact on production.

In the longer term, climate change could well become an issue for brine operators in some regions. "The potential effects of climate change may increase the possibility of adverse weather conditions," comments Intrepid Potash. "If we experience heavy rainfall or low evaporation rates at any of our solar solution mines, we would have less potash available for sale, and our sales and results of operations could be adversely affected."

The impacts of climate change on brine processing may prove to be limited and gradual. But the growing prevalence of brine potash operations in China, by increasing reliance on solar evaporation, will undoubtedly bring with it a greater vulnerability and exposure to climate-related production risks. ■

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CONTENTS
What's in issue 468
COVER FEATURE 1
TFI World Fertilizer Conference, Boston
COVER FEATURE 2
Sulphur supply sea change
COVER FEATURE 3
The elemental value of phosphorus

FERTILIZER INTERNATIONAL
ISSUE 468
SEPTEMBER-OCTOBER 2015

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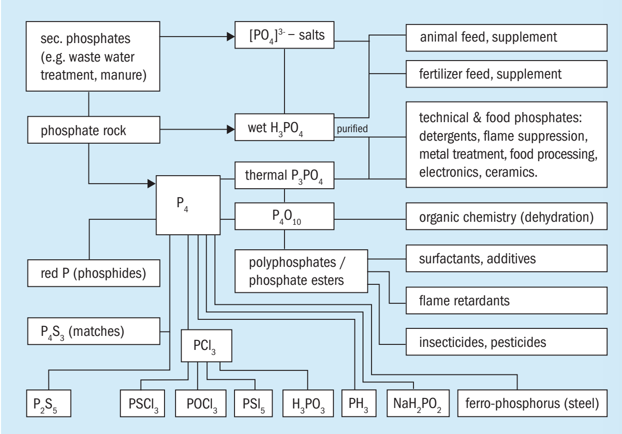
The elemental value of phosphorus

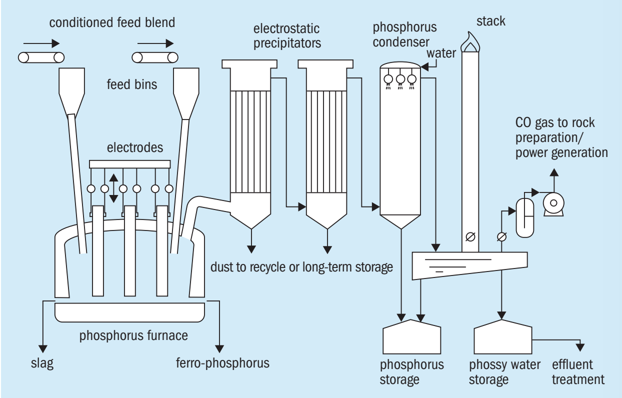
China, Japan, North America and Europe provide large markets for elemental phosphorus (P_4) and its derivatives. High-value speciality chemicals such as glyphosate, lithium-ion battery electrolytes and flame retardants depend on P_4 for their synthesis. Phosphoric acid production in China is also almost exclusively sourced from P_4. We explain the complex dynamics governing the global P_4 market and look at the industry's value chain and future prospects.

Fig 1: Elemental phosphorus and main derivatives



Source: Scholtz et al (2014)

Fig 2: The electric arc process



Source: Gilmour (2013)

The production of elemental phosphorus (P_4) exemplifies how the phosphates industry, by diversifying into non-fertilizer markets, can add value and generate higher revenues. Delegates at this year's SYMPHOS 2015 conference in Marrakech, for example, learnt that phosphate compounds widely-used in lithium-ion batteries have a value of $50/kg (*Fertilizer International*, 467, p45), roughly 100 times the current market price of phosphate fertilizers.

Elemental phosphorus (P_4), also known as yellow phosphorus or white phosphorus, is the starting point for a variety of small volume but highly valuable industrial compounds. The manufacture of a range of important chemicals, often at the far end of a long, labyrinthine value chain, ultimately depend on P_4 and its availability.

Phosphorus trichloride (PCl_3), pentasulphide (P_2S_5), pentoxide (P_2O_5) and sodium hypophosphite (NaH_2PO_2) are all directly synthesised from P_4, and are often termed 'true derivatives' because they can only be made from elemental phosphorus. These sulphide, chloride and oxide compounds, in turn, are used as building blocks in the manufacture of more chemically complex inorganic and organic derivatives further down the value chain[1] (Figure 1). Important end-markets for P_4 include herbicides, flame retardants, lithium-ion batteries, detergents, water treatment chemicals, engine lubricants and nickel plating solutions.

Energy intensive production

Elemental phosphorus is produced in China, the US, Kazakhstan, Vietnam and, until recently, the Netherlands by the traditional electric arc process[2]. Dried and ground phosphate ore is mixed with coke and sand and continuously fed into a carbon-lined furnace, often as briquettes or nodules. Relative proportions of these three components are calculated on the basis of two chemical ratios: a silica/lime (SiO_2/CaO) ratio of 08-1.0 and a phosphate/carbon (P_2O_5/C) ratio of 2.3-2.6 are most desirable[3].

Graphite electrodes within the arc furnace raise the temperature of the furnace and its load to 1,400-1,500°C. The silica sand is strongly acidic at this temperature and reacts with calcium in the ore to form a molten calcium silicate slag. The phosphate ore undergoes a reduction reaction with coke, generating a stream of diphosphorus vapour and carbon monoxide. Elemental phosphorus is captured by passing this vapour stream through a water condenser where it condenses as a liquid and is then stored under water (Figure 2). More sophisticated electric arc furnaces use electrostatic precipitators to remove entrained dust from the vapour prior to condensation.

Around four fifths of the fluoride content of the phosphate ore remains locked within the slag as calcium fluoride. The remaining fifth combines with silica and is volatilised as silicon tetrafluoride (SiF_4) gas, most of which goes into solution in the condenser. Roughly 8% of phosphorus content is lost during the arc furnace process. These losses are partly due to reactions with sulphur, magnesium, aluminium and iron impurities, although some phosphate also remains bound within the calcium silicate slag. Any molten iron phosphide (ferrophosphorus) which forms in the furnace is tapped, recovered and sold to the steel industry.

The electric arc process is energy-intensive and consumes 12.5-14 MWh of electricity for each tonne of elemental phosphorus produced. Energy costs can account for half of total production costs, although power costs can be cut by nearly a fifth by capturing heat from the vapour stream using an indirect heat exchanger.

Stack pollution is an issue for smaller plants which rely solely on the water condenser to remove dust emissions. Flames venting from the main stack are a common sight at such plants, due to the flaring of carbon monoxide and hydrogen, as are white clouds of phosphoric acid created by phosphorus particle emissions. Pollution problems are further compounded by the dispersion of measurably radioactive dust.

Thermal acid

Thermal acid – phosphoric acid manufactured by the thermal route – is produced by burning elemental phosphorus in the presence of air in a combustion chamber at a temperature

FERTILIZER INTERNATIONAL
ISSUE 468
SEPTEMBER-OCTOBER 2015
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of 1,800-2,000°C. The P_2O_5 vapour produced passes to a hydrator at a temperature of 500-1,000°C to form phosphoric acid on contact with water and recycling acid. Both the initial oxidation reaction (-3012 kJ/mol) and subsequent hydration reaction (-188 kJ/mol) are strongly exothermic. Energy recovery enables the capture of at least 60% of the heat of reaction as high-pressure steam.

Co-production of solid P_2O_5 by using dry air in the combustion chamber is another process option. The P_2O_5 vapour passes to a condensing tower where it solidifies and is then transferred by screw conveyor for bagging. The remaining vapour passes to wet scrubbers where phosphoric acid is recovered in an acid tank. The concentration of the acid produced is controlled by adjusting the amount of water vapour in the combustion air or the water added during hydration and scrubbing.

Costs

According to some estimates, thermal acid is almost twice as expensive to produce as purified wet acid (PWA), for the same electricity, water, labour and overhead rates. Some sources quote costs of around \$2,720/t for P_4 production and \$1,295/t P_2O_5 for thermal acid production[3]. In contrast, the cost of the solvent extraction technology used to produce PWA from merchant grade acid (MGA) is relatively low. PWA production costs are dominated by the expense of the MGA feedstock plus maintenance, administration and deprecations costs.

Overall, the lower costs of PWA make it more competitive than thermal acid and its derivatives in those markets where they overlap and directly compete, such as the food phosphates sector. The economic viability of elemental phosphorus and thermal acid production in countries such as China largely depends on access to low-cost, locally-sourced phosphate, coal and electricity.

Value chain

Despite its larger energy consumption and investment cost, P_4 manufacture via the furnace process confers a number of technical advantages, including an ability to consume low-grade phosphate rock and a higher tolerance for impurities such as silica, magnesium, and aluminium. But the main rationale for P_4 production by the thermal route is it allows the synthesis of phosphate compounds, so-called 'true derivatives', that could otherwise not be produced (Figure 3).

> **"Uncertainties make the future of the P_4 market unpredictable.**

Thermal acid is the primary end-use market for elemental phosphorus, accounting for over half (56%) of world P_4 consumption. However, continuing competition between less costly PWA and thermal acid has seen demand for elemental phosphorus contract sharply over the past decade, according to IHS[1]. This decline is also linked to more stringent environmental restrictions on phosphate use, particularly for laundry detergent products such as sodium tripolyphosphate (STPP).

The thermal acid market, however, is holding up in China and remains the largest end-use segment for domestically-produced elemental phosphorus. This is helped by the fact that, in China, almost all downstream industrial products of phosphoric acid, including food phosphates, are still produced from thermal acid due the country's lack of PWA capacity and technology.

Derivative demand buoyant

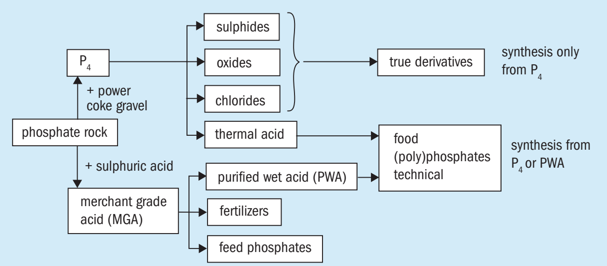
Despite the continuing decline of the thermal acid market, demand for the main derivatives of elemental phosphorus (PCl_3, P_2S_5, P_2O_5 and NaH_2PO_2) has increased over the past five years. Overall, PCl_3 remains the leading P_4 derivative due to its use in the manufacture of the organophosphate herbicide glyphosate, the most popular herbicide sold worldwide. Based on 2011 estimates, around 650,000 tonnes of glyphosate products are sold annually, generating \$6.5 billion in revenues and consuming around two thirds of PCl_3 production[1].

Glyphosate is applied to fields before crop sowing or germination, and is also used as a desiccant to dry out cereals, oilseed rape, maize and sunflowers a few weeks before harvesting. In the European Union, glyphosate is also approved for weed control in vineyards, olive groves and fruit orchards. Monsanto originally patented glyphosate's weed-killing properties in the 1970s. Although this patent is long-expired, the company still accounts for around half of global production. The growing glyphosate market will consume a quarter of million tonnes of phosphorus by 2017, 1% of total global usage, according to some estimates.

Lithium-ion batteries (LIBs) are another growing industrial market for P_4. Cathodes made of LFP ($LiFePO_4$), for example, are used in the LIBs of electric vehicles and hybrid electric vehicles. These are expected to have a 25% share of a \$9 billion market by 2020. Lithium hexafluorophosphate ($LiPF_6$) is also used as an electrolyte in 95% of currently-manufactured LIBs, an end-use which could be worth \$2billion by 2020 (*Fertilizer International*, 467 p45). Importantly, $LiPF_6$ can only manufactured via the elemental phosphorus derivatives PCl_5 and its PCl_3 precursor.

A relatively new and promising growth area is stationary grid storage batteries, according to IHS analyst Samantha Wietlisbach: "Around 90% of the installed grid storage capacity in early 2015 utilised LIBs. LFP cathodes currently lead the market for grid storage, although there is stiff competition from nickel manganese cobalt (NMC) cathodes for future projects." This is a quickly developing market, though, cautions Wietlisbach: "Battery material suppliers must be prepared for the rapid change required by these fast evolving technologies."

Fig 3: The value chain of elemental phosphorus



Source: Schipper (2014)

Table 1: **Global elemental phosphorus production**

Country	Number of plants	Capacity (tonnes)	Production (tonnes)	Domestic consumption (tonnes)	Phosphate ore source	Average labour costs ($/month)	Coal ($/tonne)	Electricity ($/kWh)
China	85+	1,900,000	950,00	750,000	Self-supply	Low 650-750	High 105-115	High 0.08-0.09
US	1	200,000	200,000	200,000	Self-supply	High 4,900-5,100	Medium 70-80	Medium 0.06-0.07
Kazakhstan	1	120,000	120,000	60,000	Self-supply	Medium 1,000-1,100	Low 60-70	Very low 0.01-0.02
Vietnam*	5-7	45,000	38,000	N/A	Self-supply	Very low 200-300	Very low 25-35	Medium 0.06-0.07
Total		**2,265,000**	**1,308,000**					

** Capacity and production possibly too low, as IHS reports exports of 63,000 tonnes from Vietnam.*

Source: Mahajan (2015), Schipper (2014)

The flame game

The non-halogenated flame retardant market is also lucrative. Clariant, for example, markets a range of non-halogenated, organic phosphinate flame retardants under the trade name *Exolit*® from production sites in Knapsack, Germany, Muttenz, Switzerland, and Lufeng, China. Clariant also markets and sells phosphate ester cleaning and metal working products, under the *Hordaphos*® marque, as well as red phosphorus, phosphoric acid, phosphorus pentoxide and other specialist organophosphates compounds.

ICL's \$1.3 billion industrial products division is the world's number one producer of organophosphorus flame retardants. ICL acquired US-based Supresta LLC, the world's largest producer of phosphorus-based flame retardants in 2006 for \$352 million. The buy-out brought with it two Supresta plants, one in the US and one in Germany, and a line of 80 phosphorus-based industrial products. Supresta, set up in 2004, was originally the phosphorus chemicals arm of Akzo Nobel.

The flame retardants *Disflamoll*® and *Levagard*® and *Bayfomox*® are part of Lanxess' portfolio of organophosphorus derivatives. The leading European supplier, originally part of Bayer, also produces a variety of pharmaceutical and water treatment products.

The global flame retardant market is worth around \$5.7 billion, according to IHS analyst, Samantha Wietlisbach: "The volume of organophosphorus flame retardants was estimated at about 340,000 tonnes In 2013, making up 15% of the total world flame retardant consumption, which is forecast grow annually at 1.4% over the next 3 years." The most common type of organophosphorus flame retardant used in Europe currently is the chlorinated phosphate ester TCPP. "This has almost replaced TDCP flame retarding additives in polyurethane foams and engineering resins," comments Wietlisbach.

Reducing wear and tear

Another leading derivative, phosphorus pentasulphide, is primarily used as a lubricating additive in the motor oil market. P_2S_5 is combined with zinc oxide and other ingredients to form zinc dialkyldithiophosphate (ZDDP), an engine wear and corrosion inhibitor. Toronto-based industrial

FERTILIZER INTERNATIONAL
ISSUE 468
SEPTEMBER-OCTOBER 2015

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chemicals firm Chemtrade is one of only two North American producers of P_2S_5, with a 30% share of the domestic market, and obtains its elemental phosphorus from ICL under a long-term supply agreement. ICL, in turn, has started to source P_4 from overseas as well as from its traditional US producer. Product pricing in this market is closely linked to the cost of the two main raw materials, elemental phosphorus and sulphur, according to Chemtrade.

Sodium hypophosphite (NaH_2PO_2) is a critical ingredient for 'electroless' nickel (EN) plating solutions. By acting as a reducing agent, NaH_2PO_2 supplies the electrons needed for plating and also provides the phosphorous for nickel alloy deposition. EN plating is able to deliver a uniform coating on plastics and ceramics as well as on metal objects. Tennessee-based Palm Commodities International, Inc, a subsidiary of Umicore, is the largest producer of liquid sodium hypophosphite concentrate in North America.

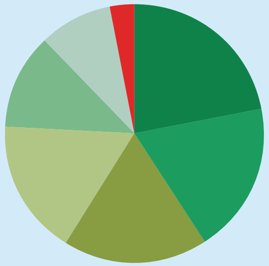
Food market fight

Global production of food-grade phosphates reached 0.4 million tonnes in 2014, supplemented by food-grade phosphoric acid production of 0.2 million tonnes[4]. Although thermal acid has a strong foothold in the Chinese food additives market, this is at increasing risk of competition from lower-cost PWA, as explained previously. The food grade phosphoric acid market is split between beverages (35%), yeast production (24%), edible oil refining (23%), sugar refining (12%) and petfoods (6%). Food phosphates, in contrast, are mostly used in meat, poultry and seafood (70%), bakery products (33%), dairy products (6%), and potato processing (9%). Global demand for food-grade phosphoric acid and phosphates is growing at 3.1% and 4.2% per annum, respectively.

East Asia and South East Asia are expected to witness the strongest overall demand growth for food grade phosphoric acid (7%) and phosphates (9.5%) over the medium term. P_4-derived thermal acid is likely to benefit from this growth, given the near monopoly supply situation in China. North America and Western Europe will, however, remain major regional consumers of food-grade phosphoric acid, particularly in the beverages and yeast segment, and will also continue to consume large volumes of phosphates in bakery goods.

The food additives sector is a strong revenue earner. In 2014, food grade and

Fig 4: Chinese thermal acid production and producers



Source: Mahajan (2015)

technical grade phosphoric acid and phosphates generated nearly three quarters (71%) of the $1.6 billion sales achieved by ICL's performance products division.

Production capacity

There is some uncertainty over total global P_4 capacity and production due to the concentration of a large number of smaller producers in China. World capacity is around 2.27 million t/a, according to a recent estimate[4], with over four fifth of this capacity (1.9 million tonnes) located in China (Table 1). (Other sources, however, put global capacity in the much lower 0.85-1.05 million t/a range[5].)

Analysts do agree that Chinese P_4 production, which has greatly increased over the last decade, is currently operating at less than half capacity. The total output of China's 85 active P_4 producers was only 870,517 tonnes in 2013, from a combined capacity of 2,340,000 t/a, according to a recent market review[6].

Tariffs have curbed Chinese P_4 exports in recent years. Exports of 35,557 tonnes in 2010 fell to 10,170 tonnes in 2012, recovering only slightly to 10,517 tonnes in 2013. The US followed by Japan are the main export destinations, collectively accounting for almost half of Chinese P_4 exports, followed by the Netherlands and then India.

Although the price of P_4 rose in China between 2009 to 2012, it fell back in 2013 and 2014 due to overcapacity and correspondingly weak demand. The national price of P_4 fell 10% year-on-year to CNY 14,200/t in 2014. Oversupply has been a problem for around a decade. Chinese capacity in 2008, for example, was around double global demand at the time (0.8-0.9 million t/a), and China's P_4 industry was operating at about one third capacity during the five year period between 2003-2008.

Major production plants

Chinese P_4 production is responsible for about 15% of the nation's phosphate ore consumption and is concentrated in Yunnan (48%), Sichuan (21%), Guizhou (17%) and Hubei (12%) provinces in the country's south. Major producing companies and their market share are shown in Figure 4. Around 860,000 tonnes of production (99%) was consumed domestically in 2013 due to the high level of internal demand. Around three quarters of Chinese consumption is earmarked for thermal acid and PCl_3 production.

The Soda Springs plant in Caribou County, Idaho, operated by Monsanto subsidiary P_4 Production LLC, is now North America's sole P_4 producer following the closure in 2001 of FMC Idaho, the world's largest elemental phosphorus plant at the time. Soda Springs is an integrated operation and the phosphate ore feed for the three arc furnaces is mined from the Blackfoot Bridge mine 10-20 miles away. Air pollution is controlled by a *Hydrosonic*® air scrubbing system installed in 1987. This was later updated in 2007 to control SO_2 emissions. The P_4 produced at Soda Springs is used to manufacture Monsanto's *Roundup*® glyphosate brand, the world-leading agricultural herbicide.

Kazphosphate's phosphate mining, processing and chemicals operations in Kazakhstan are another integrated operation. The Novodzhambul (NDFZ) 120,000 t/a phosphorus plant, near Taraz in the country's Zhambyl region, produces P_4 from four 80-megawatt electric arc furnaces using phosphate ore mined 200 km away at the Karatau mine and processing plant in Zhanatas.

NDFZ manufactures a range of food and technical grade P_4 derivatives, including thermal phosphoric acid, sodium tripolyphosphate (STPP) and sodium hexametaphosphate. Ferrophosphorus and granulated slag are also produced at the site. The EU is the main market for many products and is accessed through a 250 km private rail system which connects Kazphosphate's operations with the international rail network. The company also uses a fleet of 30 trains and over 900 specialist wagons to transport P_4, thermal phosphoric acid and other products to Europe and other markets.

A plant upgrade in 2011 allowed NDFZ to begin manufacturing food grade STPP and phosphoric acid, and also doubled acid output to meet growing EU demand. Producers in Kazakhstan, Vietnam and China were trading P_4 to the EU, Japan and North America for $3,000-3,500/t in 2014[5].

Outlook

IHS predicts further global growth for the main P_4 derivatives – principally phosphorus trichloride – over the next five years. Market growth will be particularly pronounced for PCl_3 in China, linked to rising downstream demand for glyphosate, plastics additives and surfactants. However, weaker growth in demand for thermal acid – the largest-volume consumer of elemental phosphorus – is expected in all global regions, limiting annual overall growth in the P_4 market to 1%.

The potential for substitution in the glyphosate, flame retardant and lubricant end-markets for P_4 is generally low. This contrasts with a high risk of displacement by PWA in the market for thermal acid and its derivatives, particularly food grade phosphate, food grade phosphoric acid and detergents[5].

Consultancy China Chemicals Market (CCM) predicts that China will continue to restrict P_4 exports, partly to protect ore resources and partly to encourage domestic downstream consumption. Overcapacity is likely to slowly ease, in CCM's view, as China develops an increasingly sophisticated value chain for P_4. Over the long term, the growing PWA industry in China will hit both the thermal acid market and underlying P_4 demand, although CCM agrees this will be offset by rising demand for other derivatives.

Energy prices are already making some P_4 derivatives less attractive in Chinese markets where production alternatives exist. The survival of China's P_4 industry may depend on further consolidation and a shift to large-scale production, helped by stronger environmental regulation of smaller P_4 plants, and the development of other outlets for derivatives[5]. A failure to do so could see Chinese P_4 production eventually follow the same pattern of decline seen in Europe and North America.

Uncertainties abound

Phosphorus market consultant Willem Schipper believes China's switch from thermal acid to PWA is inevitable, but exactly when this will happen is hard to say. "That is partly because developing the technology required is proving harder than expected, and reconfiguring the existing P_4 supply chain will also slow the transition," says Schipper. "The 'how' is also difficult because it's being driven by many factors such as environmental pressures, unpredictable export barriers and Chinese P_4 finding new outlets such as glyphosate."

Many questions about the future of the Asian P_4 market remain unanswered, as Schipper explains: "Will there be a large capacity shutdown or will we again see Chinese phosphorus exports on a large scale, and will P_4 production capacity shift more and more to Vietnam as we've already seen? Vietnamese competitiveness may well become less attractive over the longer term, although that could be remedied by an industry shakeout, process improvements and consolidation."

All these uncertainties make the future of the P_4 market unpredictable, concludes Schipper: "We could even see new capacity come on-stream, if that's secured through strategic partnerships backed by long-term supply contracts." ■

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FERTILIZER INTERNATIONAL
ISSUE 468
SEPTEMBER-OCTOBER 2015

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PHOTO: ROLF COSAR

Africa: the emerging potash continent

Two very different African countries, the Republic of Congo and Ethiopia, are fast becoming greenfield potash hotspots. We weigh up the prospects for six front-running African potash mining projects.

Sulphuric acid pools in Dallol in Ethiopia.

Promising African entrants to the potash market could eventually produce over eight million tonnes of potash annually, more than 10% of current global supply. Below, we review the progress of six of Africa's leading greenfield potash projects. All of these projects are at an advanced stage. Four of the contenders have released definitive feasibility studies with the other two expected to follow suit within the next three to nine months. Ambitiously, many hope to be in a position to begin construction next year and start producing potash as early as 2018. Finding partners prepared to invest in and finance these projects remains a common hurdle though.

The huge potential of Congo potash

The Republic of Congo (ROC) is a relatively small and politically-stable nation by West African standards. The country, also known as Congo Brazzaville, occupies the northern side of the Congo River, immediately to the west of the Democratic Republic of Congo (DRC), its immense, resource-rich but conflict-ridden neighbour.

Oil and gas currently dominate the national economy, accounting for around two thirds of GDP, although international interest in developing gold, iron ore and potash resources is on the increase. The ROC used to produce up to 450,000 t/a of potash from an underground sylvite mine at Holle until its closure in 1977 due to flooding. Around 2.4 million tonnes of Holle potash was produced and exported from the ROC between 1968 and 1977.

The resurrection of Congolese potash production and development of the ROC's massive potash resources could help the former French colony emerge from the shadow of the DRC. A number of companies are looking to exploit the ROC's thick, large-scale potash deposits which, advantageously, occur relatively close to its Atlantic coast (Figure 1).

Chinese investor interest

The Toronto Stock Exchange listed mining junior **MagIndustries Corp** has well advanced plans for a 1.2 million t/a potash solution mine in Kouilou province, some 15 km inland from the port of Point Noire, as part of its ambitious Mengo potash project. MagIndustries employs 400 workers in its existing forestry operations in the ROC and is familiar with both the country and its government.

An exploitation permit granted in 2008 followed the publication of a Bankable Feasibility Study and gives MagIndustries

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ISSUE 468
SEPTEMBER-OCTOBER 2015

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Fig 1: **Potash projects in the Republic of Congo**

the right to mine potash over a 136 km^2 area of Kouilou. The firm is currently concentrating its mining efforts within a much smaller 25km^2 area near the village of Mengo. Proven and probable carnallite reserves of 33.7 million tonnes (KCl) at Mengo are sufficient for 27 years of production, assuming production of 600,000 t/a for the first two years and 1.2 million t/a thereafter.

The ultimate scale of the region's potash resources is much larger though. Three licences for the surrounding areas of Makola, Loango, and Tchizalamou in Kouilou give MagIndustries potash exploration rights over a further 2,056 km^2 of the ROC. The total inferred potash resource for the 1,111 km^2 Makola licence alone is 1.7 billion tonnes, based on a 2010 estimate.

MagIndustries is targeting growing agricultural demand for potash from Asia, South America, South Africa and Europe. It hopes to become a competitive, low-cost producer by adopting solution mining, using local natural gas and accessing major markets via new port facilities at Point Noire on the nearby Atlantic coast market. An agreement with ENI Congo to supply gas to the project from its Djeno treatment plant 25 km southwest of Mengo has helped reduce cost uncertainties.

Project updates filed in 2013 and 2014 reveal that a 1.2 million t/a solution mine at Mengo would require capital expenditure (capex) of $1.27 billion and produce potash for an operational expenditure (opex) of $76/t. The capex covers the building of an evaporation and crystallisation plant, a dedicated ship loading jetty and facilities for product transport, drying, compaction and storage. MagIndustries also calculates that the Mengo project could achieve payback in its eighth year of production, assuming a potash price of $380/t f.o.b.

Developing the project has been expensive and required expenditure of $100 million during the initial exploration and feasibility phase. Chinese investor interest has driven the project forward over the last four years and will be vital for its eventual realisation. China's Evergreen Resources originally acquired a 77% controlling interest in MagIndustries in 2011. Production at Mengo was originally scheduled to begin in 2015, following the award of engineering design contracts totalling $24 million to two Chinese companies in 2012. This timetable has subsequently slipped although Chinese contractors did start laying foundations in 2013. Similar to many junior mining ventures, securing the $1.27 billion investment to deliver the project remains the main hurdle. The China Development Bank provisionally agreed to arrange $740 million of finance for the project two years ago, but this offer has yet to translate into a finalised loan.

MagIndustries is currently in discussion with Chinese potash producer Qinghai Salt Lake (QSL) about a possible investment in the Mengo project. Getting QSL on board would give the project's prospects "a significant boost", according to analysts CRU, although uncertainties remain over Mengo – a venture previously described by CRU as highly speculative. "The company [QSL] is also looking at its options for further expansion outside of the country," commented CRU. "However, with a range of planned supply increases and new players looking to enter the potash market, the Congolese site remains a risky investment and the wait for funding may continue for some time."

Three options for Elemental

Close on MagIndustries' heels, Australian Stock Exchange listed mining junior **Elemental Minerals Ltd** (ELM) is pursuing three projects within its 1,408 km^2 Sintoukola exploration licence on a coastal plain area 90 km north of Pointe Noire. The region's sylvite and carnallite deposits were first discovered during oil exploration in the 1930s and further investigated by a drilling programme in the 1960s.

ELM has been active in in the country since 2009. Its flagship Kola project involves the conventional mining of a high-grade sylvite deposit (33.1% KCl) with measured and indicated resources of 573 million tonnes. Further down the pipeline is low-cost solution mining project to extract potash from the much larger nearby Dougou carnallite deposit (20.6% KCl), which has measured and indicated resources of over one billion tonnes. ELM also began preliminary exploration drilling of the Yangala sylvite prospect immediately to the west of the Dougou deposit in June.

The Kola potash mining project is at the most advanced stage, having been awarded a mining licence in April 2013, although production is still at least four years away. Exploration drilling and seismic surveying in 2010 and 2011 confirmed the presence of two flat-lying, four metre-thick sylvite beds at a depth of 200-300m. A pre-feasibility study (PFS) for Kola, originally published in 2012, was updated last October.

The Kola deposit is located just 36 km from the Atlantic coast. ELM intends to transport Kola ore by conveyor over this distance to a coastal processing plant and purpose-built export jetty at Tchiboula. Investment will be required to get these facilities built, although there is scope for keeping costs down by taking advantage of existing road, port and power infrastructure. During the initial stages of production, for example, exports shipments could be made through the jetty currently under construction at Pointe Indienne, 60 km to the south of the project.

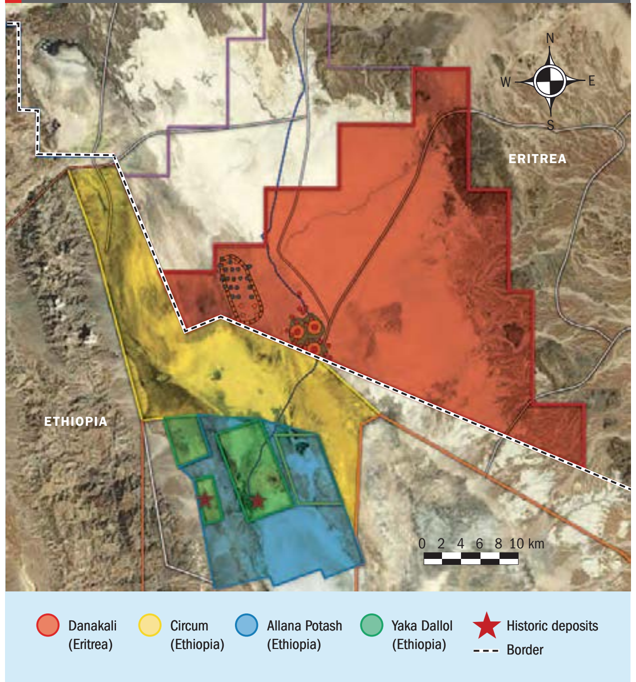
A proposed power line connection with the Mongo-Kamba II substation would also enable the project to source its electricity from the 300 megawatt Centrale électrique du Congo (CEC) gas turbine power station south of Pointe Noire. Offtake from the plant could also supply natural gas for product drying. The 2010 power plant, a joint venture between the government and ENI, is currently supplied by the M'boundi onshore field, although it will switch to the offshore 'Marine XII' concession for its natural gas supply from 2016.

ELM's current plan is for a two-stage implementation of the Kola project starting with one million t/a of potash production (capex $908 million) in 2019 ramping up to two million t/a (capex $683 million) in 2022. ELM calculates that Kola is capable of producing MOP at an opex of $91/t over its 25 year life.

Project progress was delayed for a nine-month period in 2013 and 2014 when ELM came to an operational standstill after receiving the AUD 190 million ($169 million) cash takeover offer from China's Dingyi Group Investment. The offer subsequently lapsed in April last year after Dingyi was unable to gain shareholder approval. However, a definitive feasibility study (DFS) for Kola is currently in preparation and should be published towards the end of next year. Basic engineering and construction have been pencilled-in for a two-year period from the end of 2016.

Although development of the flagship Kola deposit looks set to remain ELM's main priority, the firm is continuing to asses the potential of Dougou as a low capex solution mine. A scoping study published in February suggested that a 400,000 t/a solution mine would require capex of $430 million and produce potash at an opex of $68/t, making Dougou one of the lowest cost producers globally. In the scenario set out in the study, production would commence in 2019, reach 400,000 t/a by 2020 and then ramp-up to 1.2 million t/a over the following eight years.

Fig 2: **Ethiopian and Eritrean Potash concessions**



East African appeal

On the other side of the African continent, Ethiopia has become something of a magnet for greenfield potash projects and junior miners over the last decade (Figure 2). The Ethiopian government has responded by offering favourable incentives such as lower royalty payments and exemptions from both customs duty and mining equipment taxation. The potash export route through Djibouti on the Horn of Africa to fast-growing Asian markets is also attractive to prospective producers. Palm oil production in Indonesia and Malaysia, for example, which accounts for around 70% of their potash consumption, has doubled in the last decade.

Ethiopia's sound underlying economic fundamentals are also appealing. Good relationships with the World Bank, China's Export-Import Bank and the African Development Bank mean the country has continued to attract foreign investment. Ethiopia's economy also grew at 10.9% on average between 2005 and 2013, compared to the regional average of 5.3%.

African agriculture is also on an upwards trajectory. The World Bank predicts Africa's $313 billion food market, about 20% of the continent's GDP, could triple in value by 2030. Were this to happen, Ethiopia, as East Africa's most populous nation and possessing the third largest agricultural industry on the continent, could live up to its promise as Africa's future 'bread basket' – and create a strong domestic market for its abundant potash resources.

Junior mining firms recognise the domestic and regional potash potential and are keen to work with the Ethiopian government and local farmers. The strategy

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ISSUE 468
SEPTEMBER-OCTOBER 2015
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of Allana Potash Corp and its owner ICL, for example, is to develop African potash markets and "create and capture new [potash] demand in Africa in general and East Africa in particular". The Ethiopian government is also keen to reduce the $150 million it spends annually on fertilizer imports. Allana predicts East African potash consumption of around 100,000-400,000 tonnes over the next 5 years, and forecasts potential sales of one million tonnes across the whole continent over the next decade.

> **African entrants to the potash market could eventually produce over eight million tonnes of potash annually, more than 10% of current global supply.**

Big producers invest

Fertilizer giant **Yara International** has invested tens of millions of dollars in a potash mining venture in Ethiopia's Danakil Depression over the last three years. The Norwegian producer first acquired a $50 million majority stake in mining junior Ethiopotash in 2012 as part of its strategy to independently-source potash. Such an investment is affordable, given Yara's earning of $2.2 billion last year, and worthwhile if it ultimately ensures that the firm's NPK operations no longer have to rely on the handful of major suppliers who tightly control the potash market currently.

Yara's Ethiopian potash mining venture, now known as the **Yara Dallol BV**, holds exploration licenses for two concessions, North Musley (18.7 km²) and Crescent (35.3 km²), located around 605 km northeast of the capital Addis Ababa and 388 km northwest of the port of Djibouti. Yara is also in the process of re-applying for an exploration license for the 10.1 km² Musley Block concession in this region.

The Yara Dallol project took a major step forward this February with the release of a DFS put together by Canada's NovoPro Projects Inc. This provides production and investment costs for a sulphate of potash (SOP) solution mine and solar evaporation operation, and demonstrates that Yara's concessions have sufficient reserves (kainite, carnallite and sylvite) for 23 years production at 600,000 t/a.

The plan, as set out in the DFS, involves solution mining the western part of the North Musley area with 40 caverns a year to ultimately recover over 14 million tonnes of SOP. The SOP produced will be trucked 790 km to a purpose built storage and handling terminal on the coast at Tadjoura, a new port that is currently being constructed by the Djibouti Port Authority. Overall, the project will require $740 million capex and produce SOP for an opex of $170/t f.o.b. Djibouti, according to the DFS.

The Ethiopian government is throwing its weight behind the project by agreeing to build a new 130 km power line and road to support mining operations. Yara wants to begin production in the third quarter of 2018 and is currently seeking project investment partners to help realise this.

The Ethiopian Ministry of Mines has approved the environmental and social impact assessment (ESIA) and negotiations are currently underway to reach the final mining agreement. The start of construction is scheduled for the third quarter of 2016, and should take around two years to complete.

Allana Potash sets the pace

Israeli producer ICL's purchase of **Allana Potash Corp** for $110 million in June (*Fertilizer International*, 466 p12) strengthened the credentials of the Danakhil Potash project as one of Africa's front-running greenfield ventures. ICL had previously invested $23 million in Allana in February 2014 and then cemented the partnership with a further $14.4 million of financing last April. Allana's permit covers a 312 km² area of the Danakil Depression. The project to produce muriate of potash (MOP) from sylvite resources in the region was already well-advanced prior to ICL's acquisition.

The publication of a feasibility study (FS) and a reserve estimate of 23.7 million tonnes MOP by Allana in 2013 were closely followed by the granting of mining permit and ESIA approval by the Ethiopian government. These were critical hurdles, as analysts CRU reported at the time: "The required regulatory approvals to complete the development phase of the project and move directly to contracting and construction... establishes it as one of the better-placed junior mining projects, with many analysts believing that Danakhil, unlike others, is a project which might actually get built."

Allana's immediate priority is developing a $642 million solution mine (*Fertilizer International*, 466 p72) able to produce one million t/a of MOP for port delivery at a cost of $99/t. ICL has signed a 'take-or-pay' offtake agreement for 80% of this production, together with a marketing offtake agreement for the remaining fifth, as part of a strategic deal with Allana to de-risk the project to potential investors.

The project began to gear up for the construction phase last year after Allana hired engineering consultancy Amec Foster Wheeler to complete front end engineering and design (FEED) work, and also announced it was reviewing potential engineering, procurement and construction (EPC) contractors. The granting of a water permit by the Ethiopian government in 2014, allowing the extraction of 30 million m³ of water annually, was another positive sign that the project is taking shape.

Fast lane competitor

Circum Minerals has made impressive progress in the two years since it purchased Ethiopian Potash Corp (now AgriMinco Corp), culminating in the publication of a DFS in August. Circum has so far raised $47 million to fast-track the development of its 365 km² exploration license area on the northern edge of Danakil.

Circum, managed by London-based private investment group Plinian Capital Ltd, was recently described as "private equity's big African potash play". The firm has adopted a different business model and plans to move to the production stage using private equity investment alone. Another London-based private equity firm, African Minerals Exploration and Development (AMED), owns a 37% slice of Circum after buying-in to the project last year.

"We don't think in the current environment the public markets would entertain something like this, as they are struggling to finance big projects," Brad Mills, Plinian Capital's managing director, told *Mineweb* in May. "So we would prefer to deal with strategic investors."

Circum's investment approach is specifically designed to avoid the "public company trap" which mining juniors often fall into. Large amounts of capital are needed to build projects, but juniors can struggle to demonstrate sufficient value. Junior mining projects can develop "much more logically and calmly" in a private market setting in Mills' view.

Circum's license area is bordered to the south by its two rival projects, Yara Dallol

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ISSUE 468
SEPTEMBER-OCTOBER 2015

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Table 1: **Six leading African greenfield potash projects**

Project	DFS	Mining licence	Production (million t/a)	Capex ($ milliion)	Opex ($/t)	Reserves* (million t)	Resources** (million t)	NPV ($ million)	IRR (%)
Republic of Congo									
MagIndustries, Mengo	Yes	Yes	1.2 MOP	1,270	76	33.7	241.5	1,303	23.5
Elemental Minerals Ltd, Kola	Q3 2016	Yes	1 MOP 2 MOP	908 1,591	91 91	-	1,048	1,836	24
Ethiopia									
Yara Dallol	Yes	Q4 2015	0.6 SOP	740	170	13.8	1,174	-	22-24
Allana Potash	Yes	Yes	1 MOP	642	99	23.7	117.9	1,320	33
Circum Minerals	Yes	Q4 2015	2 MOP 0.75 SOP	2,580	83.89 MOP 158.95 SOP	107.8	4,900	2,100	22.4
Eritrea									
Danakali	Q3 2015	Q4 2015	0.425 SOP	442	189	1,107	1,289	206	22.3

**Proven & probable, **Measured, indicated & inferred*

Note: Project information may not be directly comparable due to different assumptions used.

and Allana Potash, and flanked to the north by Danakali's project on the other side of the Eritrean border. The sharing of a common orebody means its exploration activities have been able to draw upon the results of Allana's DFS, as Mills explained to *Mining Journal* in February.

"We drilled the obvious extension of the orebody that they [Allana] had identified. The geology changes as you go north… from this relatively thin sylvite deposit to where it suddenly triples… to 5-10 m in thickness. This very, very thick kainite-carnallite sequence sits underneath this, and so in some areas we have a combined column of potash mineralisation that is over 65 m thick."

The DFS published by Circum in August confirmed proven and probable KCl reserves of 107.8 million tonnes, and a measured, indicated and inferred resource of 4.9 billion tonnes (18.1% KCl). In the project's first phase, the plan is to begin solution mining in mid-2018 and then ramp up production to two million t/a of MOP and 0.75 million t/a of sulphate of potash (SOP) over the following three years. A mine life of 26 years is expected for production on this scale.

Circum's ambition is to be "an extremely competitive producer" with operating costs in the lowest quartile and capital costs around half those of existing major Russian and Canadian producers. Delivering the first phase of the project will require capex of $2.58 billion, according to the DFS, and provide potash at an opex (f.ob. Djibouti) of $83.89/t for MOP and $158.95/t for SOP.

Circum expects to receive a mining permit later this year once the Ethiopian government has reviewed the DFS. Other next steps for Circum include finding a "strategic development partner" for the project and carrying out a scoping study on expanding production to five million t/a.

The contender over the border

Just across the border in Eritrea, **Danakali Ltd,** formerly South Boulder Mines, recently announced proven and probable reserves of 1.1 billion tonnes (10% K_2O) for its Colluli mining project. The estimate includes 250 million tonnes of SOP reserves. Plans to construct an open pit SOP mine and 425,000 t/a processing plant were unveiled as part of a PFS for Colluli in March (see project profile in *Fertilizer International*, 463 p39). The project requires capex of $442 million and should be able to produce SOP for opex of $189/t. Under current plans, SOP production at Colluli would eventually ramp up to 850,000 t/a after five years.

Danakali, which together with the Eritrean National Mining Company (ENAMCO) owns a 50% equal share of Colluli, says it is on track to complete a project DFS by the end of the third quarter. Pilot SOP processing trials were also completed in August. Construction could start as soon as next year with production following in 2018, although this is conditional on both DFS approval and the granting of a mining permit by the Eritrean government.

SOP holds the key

The pursuit of projects by Yara, ICL and others in recent years has turned East Africa into what CRU calls "a key potash production opportunity". How many Ethiopian, Eritrean and Congolese potash producers (Table 1) will ultimately enter into an already oversupplied MOP market remains difficult to predict. IFA remain cautious and its latest potash supply outlook does not forecast any new African greenfield capacity over the next four years. However, the tightness of the SOP market, and the price premium for SOP, may provide projects proposing to supply SOP, such as Yara Dallol, Danakli and Circum Minerals, with an edge in terms of viability. Unsurprisingly, Allana Potash is also exploring its options for SOP production and recently commissioned a preliminary economic assessment of the kainite resources within its concession. ■

FERTILIZER INTERNATIONAL
ISSUE 468
SEPTEMBER-OCTOBER 2015

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ISSN: 0015-0304
Design and production:
JOHN CREEK, DANI HART
Mixed Sources FSC
Printed in England by:
Buxton Press Ltd
Palace Road, Buxton, Derbyshire, SK17 6AE

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ISSUE 468
SEPTEMBER-OCTOBER 2015

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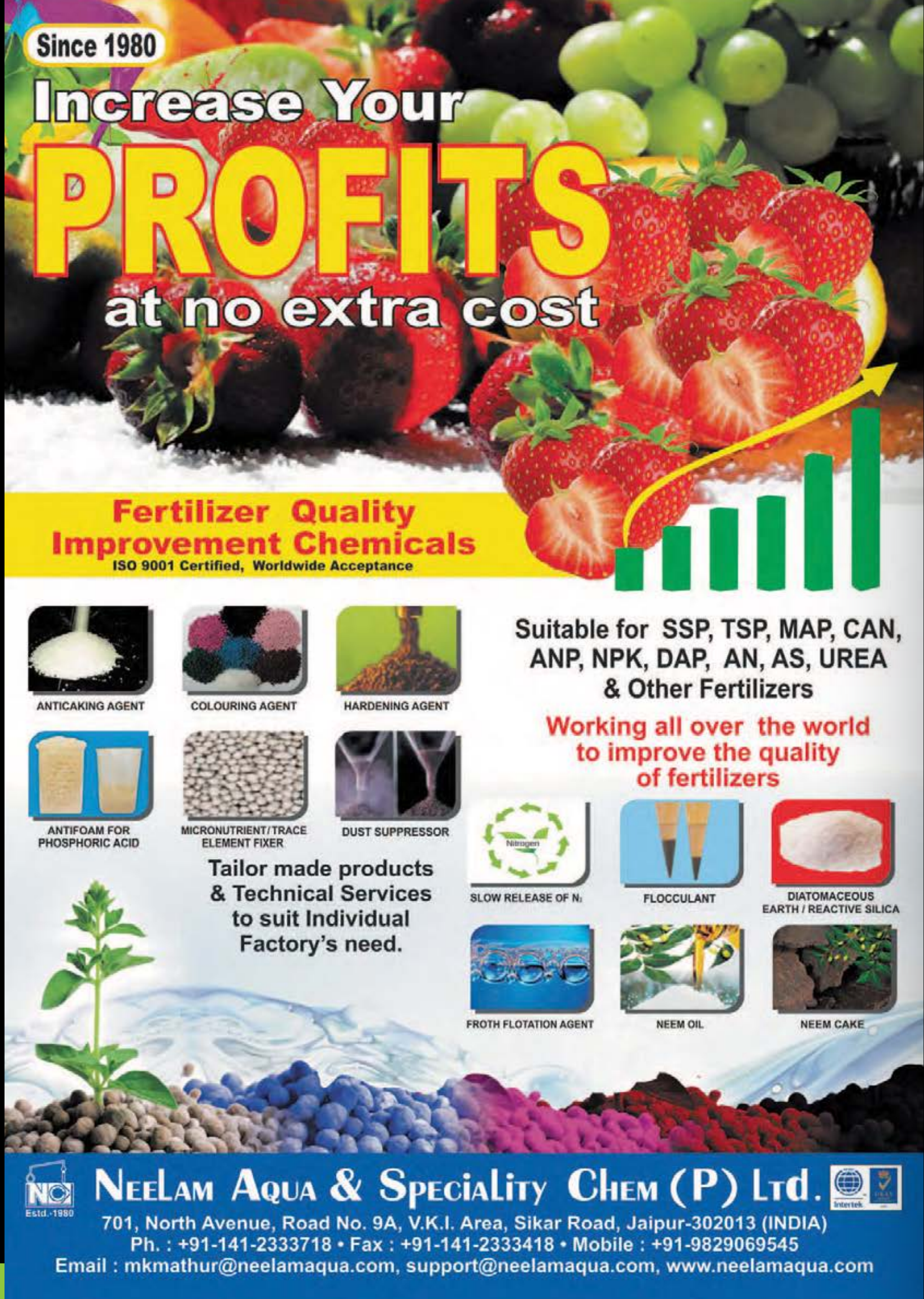

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