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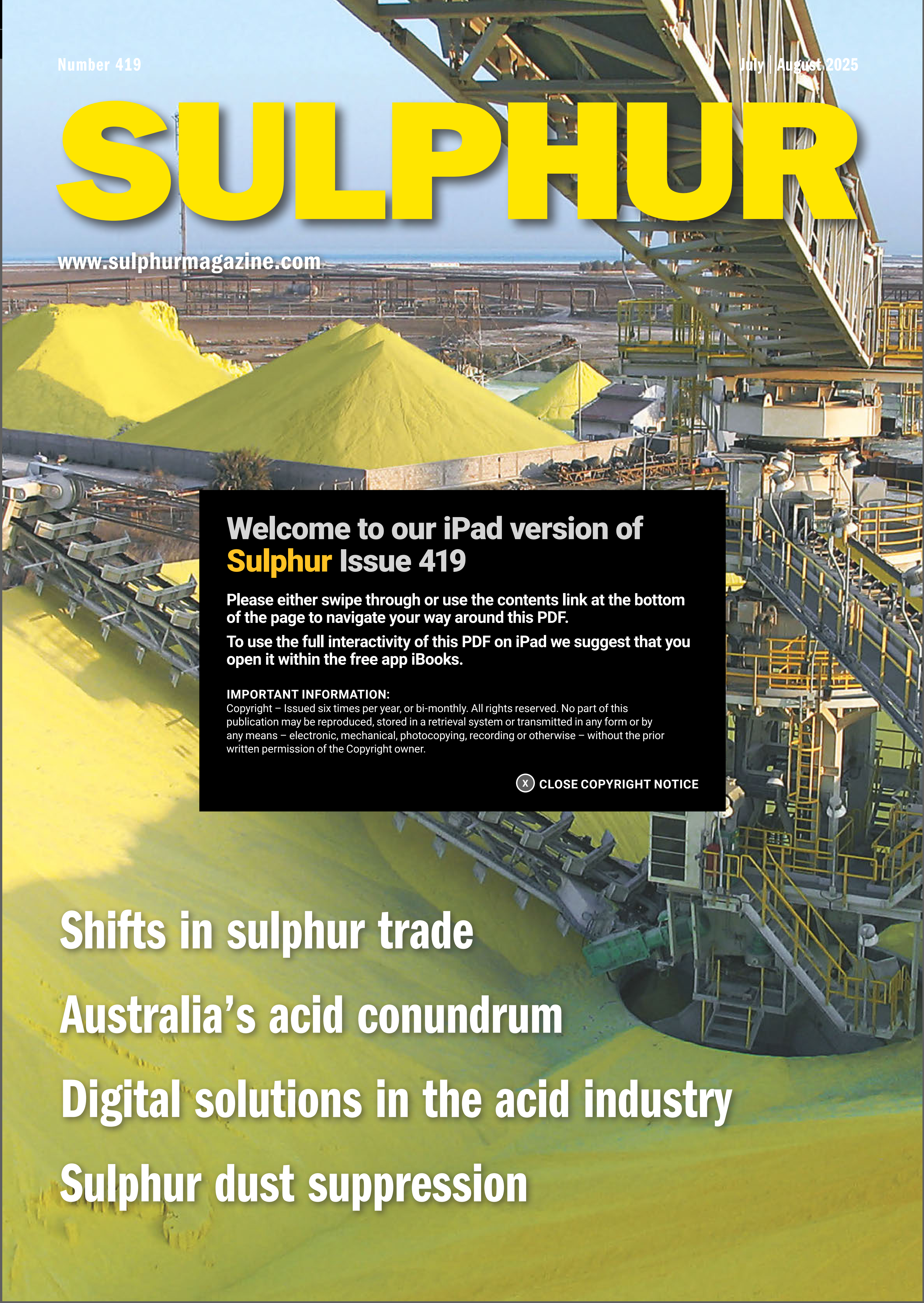

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SULPHUR

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Shifts in sulphur trade

Australia's acid conundrum

Digital solutions in the acid industry

Sulphur dust suppression

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Cover: *Processing of bulk solidified sulphur. Photo: IPCO*

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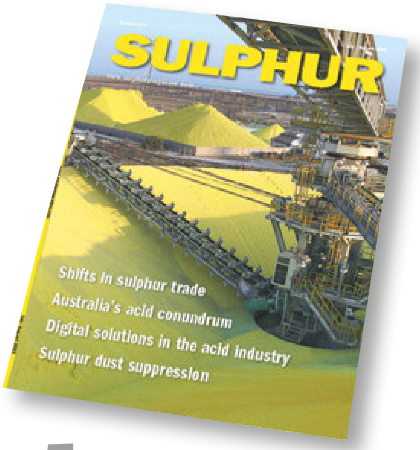
Read this issue online at: www.sulphurmagazine.com

Published by:

CRU

Editorial



How long can phosphate prices stay high?

"There seems to be something of a vicious circle between sulphur and phosphate prices at the moment..."

Phosphate prices have been at high levels for a couple of years now, and talk at the recent International Fertilizer Association (IFA) meeting in Monaco was that it was not only continuing to support higher sulphur prices in spite of oversupply in the sulphur market, but that there seemed to be no prospect of it falling in the short term.

Phosphate markets have been squeezed by Chinese export restrictions which have kept supply tight. This year China has instated even stricter export restrictions, and it is expected to ship only 5.4 million tonnes of DAP, MAP and TSP combined to international consumers in 2025, with restrictions only being lifted from late May to September. The DAP market seems to be tightest of all, and import tariffs in the US have added to the premium being charged. Phosphate fertilizers continue to command a premium well over and above that for nitrogen or potash. The prolonged run of high prices raises concerns about affordability for farmers, and the potential for demand destruction remains as long as phosphates are as expensive as they are. India is particularly sensitive to higher phosphate prices, and farmers may start to forego phosphate applications until prices fall to a more reasonable level.

At the moment, affordability seems to be the only potential check on where phosphate prices go. Indeed there seems to be something of a vicious circle between sulphur and phosphate prices at the moment, whereby high sulphur prices, particularly in China, lead to high domestic phosphate prices, and consequently continuing moves by the Chinese government to reduce domestic phosphate prices by restricting exports, which in turn increases international phosphate prices and hence justifies continuing high sulphur prices. Some easing to this is expected in the third quarter of 2025 as we pass the peak application season for phosphates, but CRU's medium-term forecast is that phosphate prices are unlikely to reduce substantially before 2028, when large new capacity comes on stream.

The good news is that in the longer-term prolonged runs of high prices tend to be a signal to the market for more investment, and will help justify new phosphate capacity, in places such as Egypt, Morocco, China and the Middle East. In the meantime, a correction to sulphur prices is long overdue, but seems to be taking its time in arriving. Once it finally does, though, it may in turn lead to easing of Chinese export restrictions and a slump in phosphate prices.

Richard Hands, Editor

Price Trends

SULPHUR

The end of June saw declines in sulphur prices in many regions amid subdued global demand across regions. Most import markets are sufficiently covered through July at least, resulting in limited activity while supply increases. These conditions have exerted downward pressure on prices as bearish sentiment spread across regions.

Middle East prices were assessed down due to weakening demand in Asia, which has led to improved levels of supply in the Middle East. Prices started on a downward trend towards the start of June, but this was temporarily limited by the escalation of the Iran-Israel conflict. However, following the de-escalation of the conflict, Asia returned to a wait-and-see approach to purchasing, causing Middle East prices to fall further. A QatarEnergy tender was awarded at $282-283/t f.o.b. as the conflict began to subside, with prices falling rapidly as QatarEnergy set its July selling price at $258/t f.o.b., down $28/t, and ADNOC at $265/t f.o.b., down $25/t, with Kuwait at $259/t f.o.b.

Demand for sulphur has been lacking from China particularly. Chinese stocks of sulphur have increased, with domestic prices at around $277/t c.fr, and domestic sentiment bearish and expecting further decreases. Bids and offers between $265-270/t were circulating at the end of June. Total sulphur port inventories in China increased by 120,000 tonnes to 2.3 million tonnes by 2 July. The volume at Yangtze River ports increased by 134,000 tonnes to 1.09 million tonnes, while levels at Dafeng port inventory decreased by 11,000 tonnes to 373,000 tonnes.

Market sentiment has turned positive, driven by expectations of a second round of phosphate quota allocation, rumoured to be 1.5 million t/a of MAP and DAP combined.

Buyers in Indonesia are understood to be covered through July at least, with some covered through August, according to multiple industry sources. As a result, demand has weakened and activity has been limited. No transactions were reported into the country at the end of June, but market indications suggest that the price level has moved to around $275-285/t c.fr, with any future business likely conducted at these lower levels. Indonesia's sulphur imports increased by 120% year on year from January through April, reaching 1.53 million tonnes, according to Global Trade Tracker (GTT).

In the Mediterranean, despite unchanged prices for weeks, bearish sentiment has grown, and it is likely that prices will soon trend downwards as most buyers in the region are understood to be covered in the short term. A Motor Oil tender was expected to send a clearer price signal, but the final price of the award could not be verified at the time of writing. With limited demand and decreasing prices in the Middle East, sulphur prices in the region are experiencing downward pressure.

Prices in the US Gulf were also unchanged, but early indications suggest that the price is likely to move lower soon, according to market participants. Adding to the bearish sentiment is the conclusion of the Tampa Q3 agreements at a $18/t lt decrease from Q2. Seaborne sulphur export prices from Canada were assessed unchanged at $255-265/t f.o.b. and the market remains bearish. Purchases of material by Indonesia and China have been limited following the ceasefire between Iran and Israel, with those markets taking a more cautious stance on purchases and largely adopting a wait-and-see approach to the market.

In Brazil, the latest CMOC tender is understood to have been awarded at $292/t c.fr, according to multiple market sources. As a result, the price was assessed higher, and appeared to be going against the global trend, but these price levels have so far been sustained by prices in the Baltic and the US Gulf, which have not fallen as in regions east of Suez. Still, the market is presently bearish with prices in the US Gulf expected to adjust soon.

Despite subdued demand, India imported 212,800 tonnes of sulphur in June, marking an 87% increase year on year. Oman accounted for 60% of these volumes, followed by Qatar (18%), with the remainder sourced from Yemen, China, and other origins.

Price Indications

Table 1: **Recent sulphur prices, major markets**

Cash equivalent	February	March	April	May	June
Sulphur, bulk ($/t)					
Adnoc monthly contract	174	206	280	290	290
China c.fr spot	223	285	300	305	280
Liquid sulphur ($/t)					
Tampa f.o.b. contract	165	270	270	270	252
NW Europe c.fr	214	214	254	254	254
Sulphuric acid ($/t)					
US Gulf spot	137	125	143	150	155

Source: various

SULPHURIC ACID

In contrast to sulphur markets, sulphuric acid prices registered increases in North Africa, Chile, India and South Korea in June, with the market largely expectant of the latest Tongling tender award in China. Bullish sentiment remains in China despite an unchanged price assessment. The final award price for the latest Tongling tender could not be confirmed at time of writing, but some market participants believe it could reach $100/t f.o.b. Others note that producers have been signalling this price for over three weeks without any confirmed transactions at that level. Still, prices in the domestic market have kept climbing and are now indicating levels above $100/t f.o.b. As a result, any international deal is likely to have to match that price level.

Prices increased for the Japan/South Korea on the latest transaction, which is understood to have taken place at a level of $87-88/t f.o.b. Availability in the region is very tight, and producers are now indicating no material left until the end of September.

The price range for delivered material into India was assessed higher. India's sulphuric acid market is exhibiting a firm upward trend, with offer levels rising to as high as $130-135/t c.fr. The increase in offers is largely attributed to limited availability and firming freight rates, particularly from Far East origins. Trade flow data suggests that some volumes from South Korea and Japan are now being diverted to Latin American markets, tightening availability across the Indian subcontinent. India imported approximately 113,000 tonnes of sulphuric acid in June. Of this, 36% originated from Japan, 35% from South Korea, and 18% from China, with the remainder sourced from domestic suppliers, according to Interocean vessel tracking data.

Prices in Europe were unchanged this, with no transactions taking place at higher levels than currently published. The return of Aurubis' Pirdop plant in mid-July is likely to reflect in increased liquidity in the market and some downward pressure in prices but current prices in Asia could limit the downside of prices in Europe, according to market participants. The plant is scheduled to come back onstream on 15-20 July.

In Chile, prices were assessed higher on the latest transaction into the South American country. Although demand remains mostly muted, the current global price environment sees prices in Chile move beyond $160s/t as they are no longer considered viable. Demand is expected to increase during Q3, but most buyers are understood to be covered in the short term. Chile's imports of sulphuric acid in January-April 2025 decreased by 4% to 1.17 million tonnes, compared to the volumes imported during the same period in 2024, according to Global Trade Tracker (GTT) data.

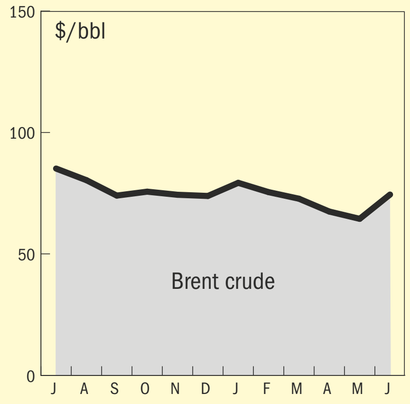
Brazil's imports of sulphuric acid for January-June 2025 were down 12% year on year at 263,302 tonnes, with Spain and Belgium again the main suppliers, though both down on volumes for 2024. Imports from Turkey and Italy increased significantly. Brazil's sulphuric acid imports have held a downward trend after registering record high volumes of 845,000 tonnes in 2022. During 2023, annual imports plunged 33% year on year to 564,000 t/a and in 2024 imports further declined by 1.5% year on year to 556,000 t/a.

Market activity in the US Gulf is limited. The market is in balance, but barely so, according to market participants. Although it is likely that any future business takes place at higher levels than currently published, buyers in the region have been able to extend their purchases of material. As a result, with no transactions having taken place, the price was assessed unchanged.

The US imported 1.3 million tonnes of sulphuric acid during January-May 2025, decreasing by 9% compared to the volumes imported during the same period in 2024, according to data via Global Trade Tracker (GTT). Canada was the main exporter of volumes into the US, totalling 746,408 tonnes, a decrease of 5% on year. This was followed by Mexico, which saw its exports of acid into the US increase by 8% to 319,318 tonnes. Japanese volumes totalled 85,369 tonnes, increasing by 52% year on year, while volumes from Finland were 39,330 tonnes, decreasing by 21%. Poland exported 33,286 tonnes. The US did not import any material from Poland during January-May 2024. Volumes from Spain were 31,000 tonnes, a decrease of 73% year on year. The US imported a total of 3.48 million t/a of sulphuric acid during 2024, an increase of 6% compared to the total imports of 2023. ■

END OF MONTH SPOT PRICES

oil



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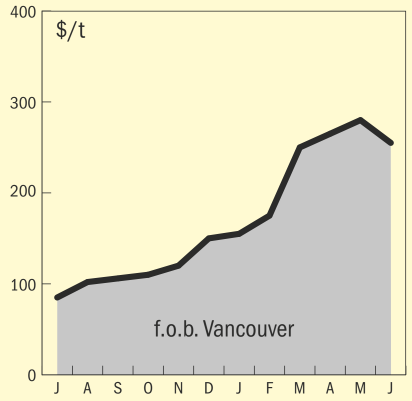

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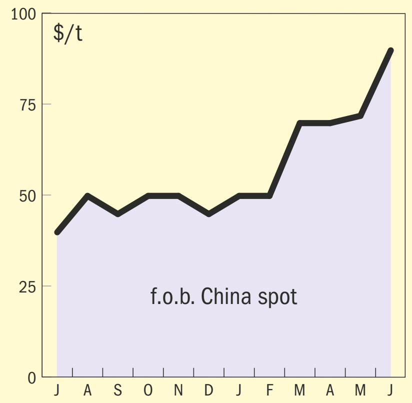

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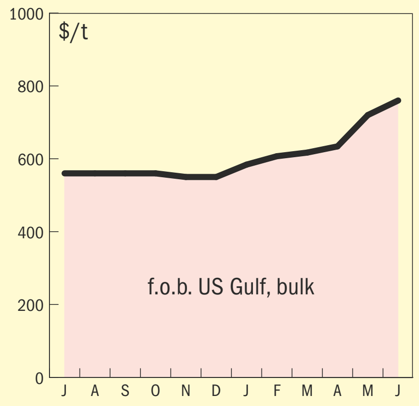
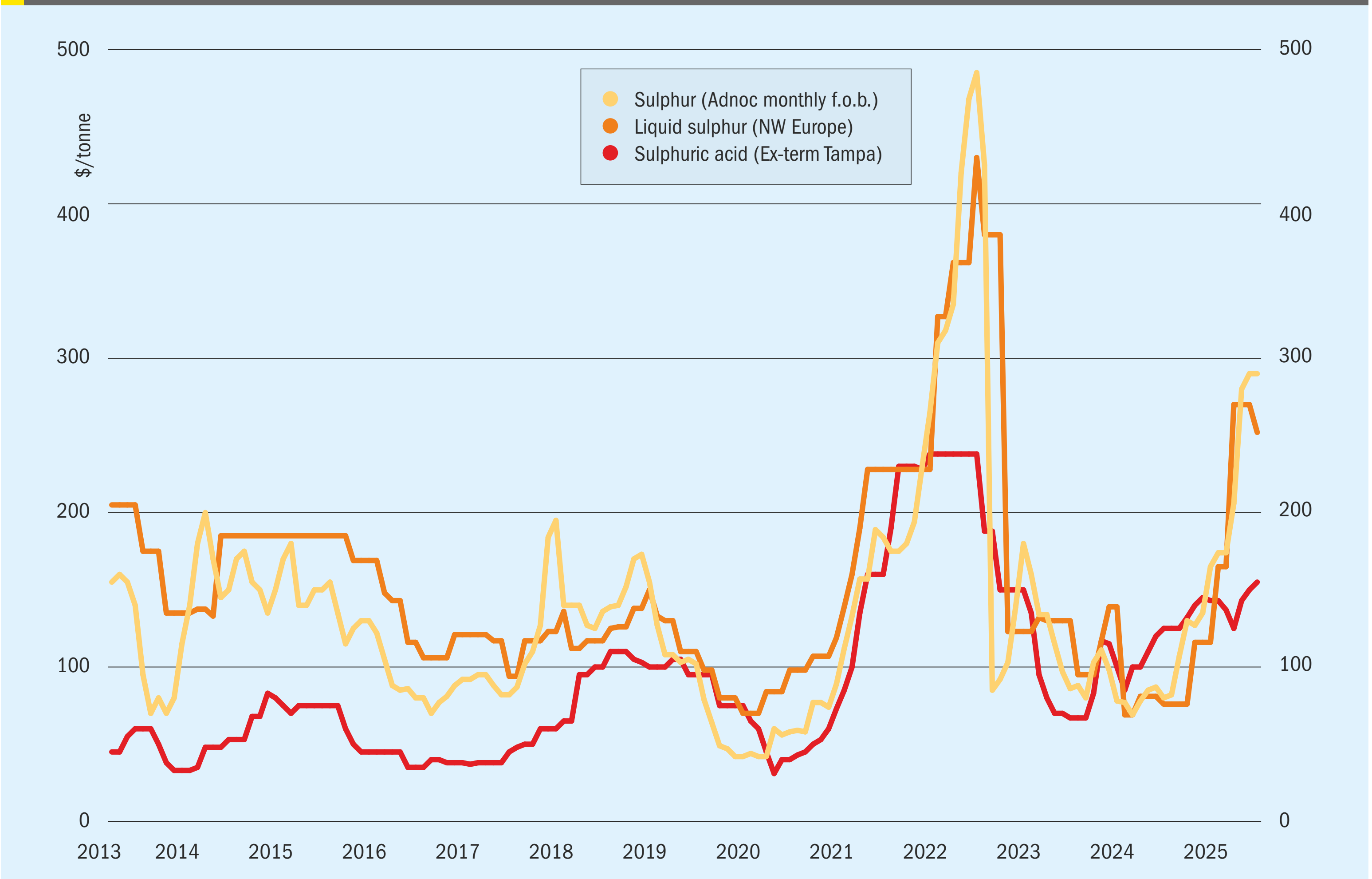


Market Outlook

Historical price trends $/tonne



Source: CRU

SULPHUR

- Global sulphur prices are expected to experience decreases over the next few weeks. Buyers in Asia report that they are covered for contracted supply throughout July, and domestic prices in China are likely to decrease further, putting downward pressure on sulphur prices.
- Indian spot buying may only resume closer to August, targeting deliveries into September, when operational needs begin to align with tighter inventory cycles. Further corrections are anticipated as traders report minimal inquiries from Indian buyers, even as global sulphur prices continue to decrease.
- Early 2025 saw a short short-term mismatch of supply and demand which triggered the price surge. But this is expected to be short short-lived as inventory drawdown and demand seasonality are expected to cause the price to move lower in 2025 H_2.
- However, over the past year and a half, demand growth in phosphates and market tightness has been masked by global stock drawdowns, but in the medium term the market deficit is expected to see price increases over the next year.

SULPHURIC ACID

- The global sulphuric acid market is expected to experience limited trading activity in the immediate term as availability tightens further. Still, global prices are likely to experience periods of stabilisation and slight increases in the coming weeks as demand sporadically enters the market to cover urgent requirements until availability improves further into Q3.
- Availability in Japan and South Korea remains tight, with producers currently quoting the earliest possible date to purchase material as September, according to industry sources.
- Key DAP/MAP spot price benchmarks have moved further upwards as a bullish tone continues to pervade the market due to tight availability. The lack of available spot cargoes means it remains very much a seller's market despite exceptionally poor affordability.
- Growth in smelter and sulphur burner-based acid supply in Asia is expected to cut import requirements in the second half of 2025. Weaker traded demand will limit export opportunities from China.
- New demand in Chile and Peru will maintain the long-distance trade requirement in the Pacific, counteracting lower import demand in SE Asia.
- India's Fertilisers and Chemicals Travancore Limited (FACT) issued a fresh tender for sulphuric acid import in early July, inviting bids for a cargo of 10,000-12,000 tonnes for delivery 25-30 July.
- Contracts for the supply of sulphuric acid in Europe for the third quarter of 2025 have registered increases in the range of €2-5/t, according to multiple market sources. This puts the 2025 Q3 contract prices at €160-188/t c.fr. up from the Q2 price which was €158-183/t c.fr. The price for Q1 was set at €155-180/t c.fr.

Sulphur Industry News

CHINA

Production begins at Dukouhe-Qilibei

PetroChina has started production at Dukouhe-Qilibei, the last of three major sour gas fields in its high-sulphur Chuandongbei cluster in southwest China. The Dukouhe-Qilibei field's hydrogen sulphide content reaches up to 17.1%, the highest of any integrated gas field currently in production in China. PetroChina confirmed that commissioning was completed on 30 June, with the Dazhou gas processing plant now running at its full design capacity of 4 million cubic metres per day. The Chuandongbei cluster originally comprised three key sour gas block: Luojiazhai, Tieshanpo, and Dukouhe-Qilibei, and was initially developed under a partnership between Chevron and PetroChina, with Chevron leading the early-phase project development. However, Chevron exited the project in 2020, transferring full control to PetroChina following operational delays and cost challenges. PetroChina says that the completion of Dukouhe-Qilibei solidifies its capabilities in handling high-sulphur content gas fields and marks a significant boost to China's domestic gas supply, particularly in inland regions with growing industrial demand.

Topsoe technology chosen for Chinese SAF plants

Topsoe has been selected by Zhongneng Yida New Energy Co., Ltd to deliver technology for production of sustainable aviation fuels (SAF) at a new facility to be located at the city of Shijazhuang in the Shenze Economy Development Zone of Hebei province. Zhongneng Yida plans to export the produced SAF to European and local Chinese markets. Topsoe will provide its HydroFlex® technology and catalysts as part of the agreement. The facility will produce 400,000 t/a of SAF, utilising used cooking oil for the feedstock.

Yin Feng, President of Zhongneng Yida, said: "Shenze's policy advantages, location advantages and environmental advantages are increasingly prominent. Driven by the global 'carbon peak, carbon neutral' background, bioenergy as a strategic fulcrum of national energy layout has become Shenze County's future development of the leading industry."

Zhongneng Yida expects to start construction in the third quarter of 2025 with operations to commence in first half year of 2027. It is expected the facility will initially export to the European market, with plans to also target the local market in China.

Topsoe has also been selected by Zhejiang Jianglan Bio-Energy Technology Co. Ltd to deliver technology and services for SAF production. Once fully operational, the plant is set to produce 300,000 t/a of SAF which will initially be exported to European markets. Construction is expected to start in September 2025, with operations expected to commence in December 2026. The project is located in Zhoushan City in the eastern province of Zhejiang, China, and will also use Topsoe's HydroFlex® technology, licensing, technical expertise and engineering services as well as its proprietary catalysts for SAF production.

CANADA

Northern Nutrients restructuring and expansion

Northern Nutrients, a manufacturer of enhanced nitrogen sulphur fertilizers, has announced a new ownership structure following an investment by Shell Trading Canada. Shell Trading Canada has invested in expanding Northern Nutrients' current facility, resulting in the formation of a new joint venture. The expansion will result in a tripling of current capacity of 50,000 t/a to 150,000 t/a of sulphur-based fertilizers. The company's facility near Saskatoon produces enhanced nitrogen sulphur fertilizers using Shell Thiogro technology. Their flagship product, Arctic S, is 11% nitrogen and 75% micronised elemental sulphur. Northern Nutrients says that its collaboration with Shell underscores their shared dedication to providing retailers and farmers with high-quality and efficient fertilizers and meet the growing demand for innovative fertilizer products.

"Since local production of Arctic S began in 2022, the market response across North America has

exceeded our expectations making now the perfect time to expand our production capacity, and Shell is the perfect partner to do it with." says Ross Guenther, CEO & co-owner of Northern Nutrients.

Oil sands production to reach record this year

S&P has raised its 10-year production outlook for the Canadian oil sands. The latest forecast expects oil sands production to reach a record annual average production of 3.5 million bbl/d in 2025 (5% higher than 2024) and exceed 3.9 million bbl/d by 2030; half a million barrels per day higher than 2024. The 2030 projection is 100,000 bbl/d (or nearly 3%) higher than the previous outlook. Despite a lower oil price environment, the analysis attributes the increased projection to favourable economics, as producers continue to focus on maximising existing assets through investments in optimisation and efficiency. While large up-front, out-of-pocket expenditures over multiple years are required to bring online new oil sands projects, once completed, projects enjoy relatively low breakeven prices.

The outlook continues to expect oil sands production to enter a plateau later this decade. However, this is also expected to occur at a higher level of production than previously estimated. The new forecast expects oil sands production to be 3.7 million bbl/d in 2035. Export capacity, already a concern in recent years, is a source of downside risk now that even more production growth is expected. Without further incremental pipeline capacity, export constraints have the potential to re-emerge as early as next year, the analysis says.

IRAQ

CPECC to build Ar-Ratawi gas processing plant

TotalEnergies has awarded the China Petroleum Engineering & Construction Corporation (CPECC) the engineering, procurement, supply, construction and commissioning (EPSCC) contract to build its new Ar-Ratawi gas processing plant in Iraq. CPECC subsidiary China Petroleum Pipeline Engineering will build two midstream gas pipelines connecting the Majnoon and West Qurna 2 oilfields to Artawi-based processing plant. The planned gas pipeline infrastructure comprises a 114-kilometre sour gas pipeline built with 26-inch diameter pipes, an 83-kilometre, 20-inch sour gas pipeline, and an 83-kilometre, 20-inch sour gas pipeline. The awards form part of the TotalEnergies-led Gas Growth Integrated Project (GGIP) in Iraq, which is valued at $10 billion.

Signed in 2021, the GGIP project features four sub-projects led by a consortium comprising TotalEnergies (45%), Basrah Oil Company (30%) and QatarEnergy (25%), and includes:

- The Associated Gas Upstream Development (AGUP), which aims to develop production from the Ratawi field by upgrading the existing facilities to reach a capacity of 120,000 bbl/d during phase 1, followed by 210,000 bbl/d during phase 2 by building a new plant.
- The Ar-Ratawi Gas Midstream Project (GMP), which aims to eliminate flaring and recover the gas from several oil fields. Collected and processed, the gas will then be transported by pipeline to supply the local power plants, thereby improving the electricity supply to this region, which is regularly affected by power cuts. Until the commissioning of the GMP, scheduled in 2028, the ArtawiGas25 Project will reduce flaring on the Ratawi field from the end of 2025, followed by the neighbouring Majnoon and West Qurna fields. Eliminating flaring at these three fields represents a reduction of approximately 6 million tons of CO_2 per year.
- The Common Seawater Supply Project (CSSP), which involves building a seawater treatment plant between the ports of Khor Zubair and Umm Qasr. The plant will be capable of treating 5 million barrels of water per day during phase 1. The filtered water will be piped to the Zubair, Rumaila, Majnoon, West Qurna and Ar-Ratawi fields to maintain pressure in the fields. It will replace the fresh water currently drawn from the rivers and groundwater. This project will reduce water stress in the area and free up 250,000 cubic meters of fresh water per day for irrigation and local agricultural needs.

UNITED STATES

AMETEK and Worley Comprimo collaborate on automated burner control

AMETEK Process Instruments has collaborated with Worley Comprimo, part of Worley's Technology Solutions, to provide sulphur recovery unit (SRU) stakeholders with critical analytical measurements combined with advanced burner control technology to deliver enhanced automated air control management. The companies say that their 2ACT™ Solution is a fully automated system that minimises SRU upsets, enhances reliability, and delivers strong returns on investment. At the heart of this partnership, the innovative 2ACT™ Solution offers an all-in-one approach to advanced air control – significantly boosting SRU performance and efficiency while reducing operational costs. 2ACT uses AMETEK's IPS-4 ultraviolet and infrared analyser to measure H_2S, CO_2, NH_3, H_2O and total hydrocarbons (THCs) by continuously sampling the acid gas upstream of the SRU. The change in air demand requirement is then calculated, with main and trim air adjustments implemented automatically by the feed forward control scheme designed by Worley Comprimo. The companies say that the benefits of the 2ACT Solution include maintaining an optimal H2S to SO_2 ratio at the outlet of the Claus Plant to maximise recovery efficiency, mitigating damage to tail gas treatment unit (TGTU) components, lowering SO_2 emissions and carbon footprint with improved uptime and plant throughput.

Mike Hevey, Division Vice President and Global Business Manager at AMETEK said, "While we have the measurement device and experience, it was important to work with a leading partner to provide a completely automated solution for plant operators. Worley Comprimo covers all aspects of the sulphur value chain, making them the ideal fit, enabling our two companies to deliver this solution that ultimately reduces downtime, costs and emissions".

Hazardous area certifications for wall mountable analysers

In other news, AMETEK says that its 993X series of analysers, encompassing the 993X and 9933, are now ATEX and IECEx Zones 1 and 2, and ETL (North America)

PHOTO: AMETEK

Ametek's 993X analyser.

Class I Division 2 compliant for use in hazardous locations with ambient temperature up to +60ºC. Built with IP66 rated enclosures, the 993X analysers can be installed outdoors, or in minimally temperature-controlled enclosures, reducing both capital and operating costs.

The 993X series of analysers use ultraviolet spectroscopy to measure hydrogen sulphide, carbonyl sulphide, and methyl mercaptan in natural gas and biomethane gas streams. These analysers are also used to measure hydrogen sulphide, carbonyl sulphide, carbon disulfide, sulphur dioxide, and hydrogen in sulphur removal and recovery operations.

Michael Gaura, senior product manager explained, "Due to increasing demand from our customers and with the need to deliver an analyser that meets strict safety standards, we have continued to extend the capabilities of our highly successful 993X analysers. Using an integrated cooling system to maintain internal temperatures of the enclosure, the 993X analysers are designed to operate in higher ambient temperatures and locations where explosive atmospheres may occur, making the analysers compliant to ATEX & IECEx Zone 1 & Zone 2, as well as Class I and Division 2 locations."

KAZAKHSTAN

KazZinc to invest in increased SO_2 recovery

Kazakhstan Zinc (KazZinc) is progressing with plans to reduce sulphur dioxide emissions from its Ust-Kamenogorsk site following an environmental audit in December 2024 as a result of smogs caused fugitive emissions which forced residents to stay indoors. The site has reduced emissions from 69,000 t/a in 2011 to 15,000 t/a, but plans to invest $210 million in in new technologies, including sulphur dioxide recovery systems and upgraded filters for solid particle capture. The key measure is the modernisation of gas purification units which is expected to reduce SO_2 emissions by 2,200 t/a by 2026. Another important initiative is the construction of the "Hydropolimet" workshop at the KazZinc Ridder metallurgical complex, which aims to reduce sulphur dioxide emissions by 714 t/a.

INDIA

Anti-dumping duty on insoluble sulphur

India India has imposed five-year anti-dumping duties on six Chinese imports, including insoluble sulphur, mainly used in the vulcanisation of rubber. The move follows an investigation by India's Directorate General of Trade Remedies (DGTR) last year, following a complaint by Oriental Carbon and Chemicals in March 2024. The period covered by the investigation was from 1st Jan 2023 to 31st Dec 2023, while the injury investigation period ran from April 2020 to 31st Dec 2023. DGTR made a determination that Chinese exporters had been selling the six products at unfairly low prices, adversely affecting the profitability of Indian producers. DGTR says that the duties it has imposed are "aligned with WTO norms" and aim to protect domestic industries from unfair trade practices and address the growing trade imbalance with China. According to the trade authority, the market share of the countries subject to duties "has been significantly increasing" while local Indian industry's capacities are "lying idle" amid growing demand.

Sulphuric Acid News

CHINA

Works begin on Kaiyang LFP project

Guizhou Phosphorus Chemical Group has begun site clearing work in preparation for a major mining and downstream fertilizer and chemical project at Kaiyang in Guizhou province started. It is planned to complete the construction of the first phase of the 600,000 t/a lithium iron phosphate (LFP) production line by the end of 2025. The whole scheme is projected to cost $4.6 billion, with participation from the Guiyang Municipal Government and Guizhou Phosphorus (Group) Co., Ltd., China National Nuclear Huayuan Titanium Dioxide, China Mining Resources Group and other companies. The project comprises 1.4 million t/a of ferrous sulphate heptahydrate production, with co-production of 400,000 t/a of titanium dioxide, 600,000 t/a of iron phosphate, 600,000 t/a of lithium iron phosphate, 150,000 t/a of lithium carbonate, 10,000 t/a of lithium fluoride, 20,000 t/a of lithium hexafluorophosphate, 100,000 t/a of copper smelting, and phosphogypsum decomposition to produce sulphuric acid, with power cogeneration and other public utilities. Phosphate ore is processed to produce iron phosphate, which is then combined with ferrous sulphate, a byproduct of titanium dioxide production, to produce lithium iron phosphate, which is ultimately used in new energy vehicle batteries. It is expected that the first batch of production lines will be put into production in 2026 and the entire industry chain will reach full production in 2028. After completion, Guizhou will become the world's largest production base of phosphorus-based positive electrode materials, accounting for more than 30% of the national market share.

Guizhou Phosphate is already China's largest phosphate fertilizer producer, with an annual production capacity of 2 million t/a of wet-process purified phosphoric acid and a domestic market share of 64%, of which 54% is in the new energy sector. ■

Smelters process Chilean concentrate for free

The mid-year negotiations between Antofagasta (AMSA) and Chinese smelters have concluded with a historic settlement of $0/0¢. While unprecedented, the outcome is not surprising, as it lands slightly above the midpoint of the believed negotiating range, from -$15/-1.5¢ proposed by Antofagasta +$10/1.0¢ from the Chinese smelters. Moreover, this result aligns with market participants' rumours circulating prior to the agreement. Separately, rumours suggest Q3 contract negotiations between one top miner and Chinese smelters concluded at levels ranging from -$25/-2.5¢ to (+)$5/0.5¢.

As is to be expected in long-term negotiations, the agreed price remained firmly above the first half average of spot terms, although stands out this time is the absolute difference of $24/2.4¢ units, which far exceeds the $17/1.7¢ unit deviation observed in 2021. Although this does not imply a perfect correlation between the first-half average spot terms and the mid-year benchmark, it does suggest that smelters could have faced a more challenging scenario, potentially even forcing them to accept negative terms under tighter market conditions.

NEW ZEALAND

Ballance to end phosphate manufacturing at Mt Maunganui

Ballance Agri-Nutrients, the New Zealand farmer and grower co-operative, says that it has entered into consultation on a proposal to cease manufacturing of sulphuric acid and single super phosphate (SSP) at its Mount Maunganui site. The proposals envisage net job losses of 62 roles, but the intention is for the co-operative to remain onsite utilising the proximity to the port for nutrient storage and distribution, and for its national support office. Ballance would continue to manufacture phosphates at its Awarua facility in Invercargill and urea at its Kapuni facility in Taranaki. Ballance CEO Kelvin Wickham says this proposal is part of a wider process the organisation has been going through over the past year to get ahead of changes in the sector and identify future opportunities to support New Zealand farmers and growers. "In the coming years, we expect to see an increased range of products and services that more efficiently and effectively deliver essential nutrients for farmers and growers, which will result in reduced overall demand for single super phosphate from historical peak volumes," he said. "The number of existing facilities currently making this product in New Zealand means there is an overcapacity of supply. Our current facilities at Mount Maunganui also require substantial investment to keep them operating reliably and will face increasing regulatory constraints to be able to operate heavy manufacturing into the future."

KAZAKHSTAN

Karatau expansion onstream next year

EuroChem says that it expects the Phase III expansion project at its Karatau phosphate development in Kazakhstan to be onstream by 2026. In its Annual Report, EuroChem says that it signed an agreement with the China National Chemical Engineering Co. in May 2024 for the engineering, procurement, construction and commissioning of the chemical complex, and construction is now underway. The company says that it has also had state permits for the construction of additional sulphuric acid production, where the installation of large-capacity equipment is already underway and the first product is expected in 2026. The fertilizer plant is expected to have a capacity of around 1 million t/a, with a construction cost of $1.1 billion for the project. Phosphate reserves at Karatau are put at 41 million tonnes.

TURKMENISTAN

Turkmenabat reports production figures

The S.A. Nyyazov Chemical Plant in Turkmenabat produced 115,850 tonnes of sulfuric acid during the first five months of this year, according to local press reports. The plant also produced 11,297 tonnes of mineral fertilizers over the same period, including 5,227 tonnes of nitrogen-based and 6,070 tonnes of phosphorus-based fertilizers. The Turkmenistan government recently approved the construction of a new plant at the facility to produce 350,000 t/a of superphosphate and 100,000 t/a of ammonium sulphate. South Korea's Daewoo Engineering & Construction Co. has been awarded the EPC contract for the plant.

Casale awarded fertilizer plant PDP contract

Casale has signed a process design package (PDP) contract with Daewoo Engineering & Construction Co for two new fertilizer plants. These are being commissioned by Turkmenhimiya, Turkmenistan's state-owned chemical company, as part of a production complex in Turkmenaba, the country's second-largest city.

The two new fertilizer plants will manufacture granular ammonium sulphate (AS) and single superphosphate (SSP), respectively. Once completed, the Turkmenaba complex will produce 350,000 t/a of granular SSP using CULTIVA-SPhos, Casale's proprietary technology for granular SSP production; and 100,000 t/a of AS using CULTIVA-PIPEX, a flexible and proven Casale process technology which is also used for NPK production.

"This latest contract highlights once again the trust in Casale's process know-how and technology portfolio and confirms the value of our Phosphate and Nitrogen fertilizers portfolio in supporting large-scale fertilizer projects with high agronomic and operational performance," Casale said in a statement. "We thank Daewoo Engineering & Construction Co. for their confidence and look forward to building a strong and lasting partnership. This collaboration reflects Casale's commitment to driving sustainable agricultural development and delivering innovative solutions tailored to local market needs."

INDIA

CIPL to build phosphoric acid plant by 2027

Caitlyn India Pvt Ltd (CIPL) has announced a $46 million investment to build a 50,000 t/a phosphoric acid plant in India. The plant aims to reduce import dependence and boost the country's fertiliser self-sufficiency. Commissioning is planned for the financial year 2027. The facility, to be set up in a port-accessible industrial zone in southern India, will use hemihydrate-dihydrate technology to produce high purity phosphoric acid and cleaner gypsum by-products. A captive sulphuric acid unit will also be included to support efficient operations. Initially, the acid produced will supply Indian fertiliser manufacturers, with plans for captive use in future fertiliser production.

"India's phosphoric acid market is expanding rapidly, but domestic supply continues to lag behind demand," said Agnivesh Agarwal, Director, CIPL. "This investment reflects our commitment to support the country's fertiliser sector with high-quality, locally produced inputs, while also building a globally competitive, sustainable manufacturing facility."

CIPL says that it plans to source phosphate rock from Morocco, Jordan, and Egypt through long-term contracts to ensure stable supply and pricing.

EGYPT

New phosphoric acid plant

Egypt's Minister of Petroleum and Mineral Resources, Karim Badawi and New Valley Governor, Mohamed Al-Zamlout were present at the signing of a framework agreement between a consortium of Egyptian public companies to build a new phosphoric acid plant at Abu Tartour in the New Valley region. The project aims to maximise added value and increasing the economic return on Egyptian phosphate ore by using it in higher-yield industries rather than exporting it as a raw material. The Egyptian state-owned consortium includes Abu Qir Fertilizers; East Gas Company, Mineral Resources and Mining Industries Authority; Misr Phosphate, AT-PHOS, Petroleum Projects and Technical Consultations Company (PETROJET), and Engineering for the Petroleum and Process Industries (ENPPI), all of which are shareholders in the project. The contractor agreement was signed with a Chinese consortium of China State Construction Engineering Corporation (CSCEC) and East China Engineering Science and Technology Co (ECEC).

At a total investment cost of $658 million, the plant will produce 250,000 t/a of high-grade commercial phosphoric acid (100% P_2O_5) in the first phase, using phosphate ore from Abu Tartour mines. Minister Badawi said that the project's implementation represents a milestone towards shifting from raw material production to the establishment of integrated mining industries that achieve high added value, in addition to tapping new horizons for Egypt in the field of mining industries built on its mineral wealth. Construction is expected to begin early in 2026 and the plant is aiming to be commercially operational by 2028.

MoU signed for exploration of phosphate production

The Egyptian Mineral Resources and Mining Industries Authority has signed a memorandum of understanding (MoU) with El Sewedy Capital Investments to establish a partnership for the exploration, exploitation, and production of phosphate rock in the El-Sebaeya region of the Nile valley, with downstream beneficiation and a feasibility study for establishing a factory to produce phosphate fertilizers.

MOROCCO

OCP certifies low cadmium phosphates

OCP Nutricrops has received a certification that its customised phosphate fertilizers, developed specifically for the European market, meet the EU's stringent low cadmium content requirements. The certified fertilizers contain less than 20 milligrams of cadmium per kilogram of phosphorus pentoxide (P_2O_5), far below the European Union's regulatory ceiling of 60 mg/kg. OCP Nutricrops says that it plans to expand this low-cadmium benchmark across all its fertilizer products worldwide by the end of 2025. Reducing cadmium in agricultural fertilizers is considered a public health priority across Europe. This initiative is closely aligned with EU goals to mitigate food-related health risks and safeguard ecosystems from harmful contaminants.

ALGERIA

Sonatrach awards Saipem phosphate project FEED contract

Saipem has won a front-end engineering design (FEED) contract from Sonatrach for an integrated phosphate fertilizer project in Algeria. The contract was awarded through a dual competitive process, enabling the design work to be conducted by both Saipem and a competitor company. Sonatrach will assess and compare the two FEED options from both parties, select the best technical and economic design, and then proceed with the direct award of an engineering, procurement and construction (EPC) contract to execute the project.

The FEED contract covers front-end services for the complete engineering design of a new fertilizer complex. This includes phosphate mining infrastructure in the Bled El Hadba area, together with process and ancillary units supporting fertiliser production in the Oued Keberit area.

This is Algeria's first integrated phosphate project encompassing both ore mining and fertilizer production. Once operational, the project will have the capacity to extract 10 million tonnes of phosphate rock and produce six million tonnes of phosphate fertilizers annually. ■

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48

People

Nishant Kanodia, chairman of Matix Fertilisers and Chemicals Ltd, has been appointed to the board of directors of the International Fertilizer Association (IFA). The appointment was formalised at the IFA Annual Conference 2025 in Monaco, with the theme of 'Investing in the Future of Food'. With approximately 500 members across more than 80 countries, IFA champions policy, innovation, and sustainable fertilizer practices that contribute to global food security.

Alzbeta Klein, CEO & Director General of IFA, said: "We are delighted to welcome Nishant Kanodia to the IFA Board. India's pivotal role in global agriculture, together with Mr. Kanodia's visionary leadership, will be instrumental in advancing IFA's mission for sustainable, resilient food systems worldwide."

India's agricultural sector has transformed a mid-20th-century food scarcity to becoming a leading global producer of staples, cereals, pulses, fruits, and vegetables. Through technology adoption, nutrient management, and farmer empowerment, India now plays a central role in global food security and consciously contributing to climate-resilient farming.

Speaking on his induction to the IFA board, Nishant Kanodia said: "It is a privilege to join the IFA board at a time when India is increasingly central to global food security. The need for balanced nutrient management and innovation-driven growth has never been greater. I look forward to supporting IFA's efforts to empower farmers, protect ecosystems, and enhance productivity globally and in India."

Nishant Kanodia, Chairman, Matix Fertilisers and Chemicals.

Under Mr. Kanodia's leadership, Matix Fertilisers has established itself as a market leader in eastern India, with a 20% share of the region's urea market. It produced a record 1.47 million tonnes of fertilizer in the 2024-25 fertilizer year at its facility in Panagarh, West Bengal, operating at over 115% of annual rated capacity.

Williams Companies have named **Chad Zamarin** to succeed **Alan Armstrong** as president and chief executive officer. Armstrong, who has served as the company's chief executive for the past 14 years, will become executive chairman of the Williams board of directors, effective, July 1, 2025, the company said. Zamarin, who joined the company in 2017 and has served as executive vice-president of corporate strategic development since 2023, will also join the board. **Stephen Bergstrom**, current chairman of the board, will transition to lead independent director.

Armstrong, who joined Williams in 1986 as an engineer, has served in various roles throughout the company, moving up to senior vice-president midstream before becoming chief executive officer in January 2011. During Armstrong's tenure, Williams has expanded its reach and now handles one-third of all US natural gas volumes through gathering, processing, transportation, and storage services, the company said in a press release.

Brazil's state-owned oil and gas giant Petrobras has confirmed that **Magda Chambriard** will be the company's new Chief Executive Officer (CEO). Chambriard was nominated by Brazil's Ministry of Mines and Energy (MME) to replace **Jean Paul Terra Prates**, the company's former CEO who stepped down from his positions as CEO and member of the board of directors. With a Master's degree in chemical engineering and a degree in civil engineering, Chambriard specializes in reservoir engineering and formation evaluation, coupled with oil and gas production. After working at Petrobras for 22 years, she was assigned to the Brazilian National Agency for Petroleum, Natural Gas, and Biofuels (ANP) as an advisor to the Exploration and Production Directorate in 2002. Six years later, she assumed the position of Director at ANP, moving on to become General Director in 2012.

Calendar 2025

AUGUST

20-22
2025 Round Table for Smelters, Roasters and Refineries, SANTIAGO, Chile
Contact: Viviana Rojas, Holtec
Tel: +56 9 8390 1221
Email: viviana.rojas@holtec.cl

25-28
AFPM Annual Summit, GRAPEVINE, Texas, United States
Contact: American Federation of Petroleum Manufacturers
Web: https://summit.afpm.org

SEPTEMBER

8-15
Sulphur Experts' Amine Treating and Sulphur Recovery Technical Training Course, KANANASKIS, Alberta, Canada
Contact: Jamielynn Russell, Sulphur Experts
Tel: +1 403 215 8400
Email: Jamielynn.Russell@SulphurExperts.com
Web: SulphurExperts.com/Courses

9-12
Brimstone Sulphur Symposium, VAIL, Colorado, USA
Contact: The Brimstone Group LP
Email: info@thebrimstonegroup.com
Web: https://www.thebrimstonegroup.com/symposium/

10-11
Oil Sands Expo, CALGARY, Alberta, Canada
Contact: Bruce Carew, EventWorx
Tel: +1 403 971 3227.
Email: marketing@eventworx.ca

29-OCTOBER 2
Brazilian Sulphuric Acid Congress (COBRAS), GRAMADO, Brazil
Contact: Clark Solutions
Tel: +55 (11) 3472-3315
Email: marketing@clarksolutions.com

OCTOBER

1-2
TiO2 World Summit 2025, NASHVILLE, TN, United States
Contact: Smithers
Tel: +44 (0) 1372 802000
Email: eventseu@smithers.com
Web: https://www.smithers.com/en-gb/services/events/2025-conferences/tio2-world-summit-us-2025

6-17
Sulphur Experts' Sulphur Recovery Technical Training Course, NOORDWIJK, Netherlands
Contact: Jamielynn Russell, Sulphur Experts
Tel: +1 403 215 8400
Email: Jamielynn.Russell@SulphurExperts.com
Web: SulphurExperts.com/Courses

PHOTO: GLENCORE

Australia's acid conundrum

The progressive closure of smelter capacity in Australia poses potential problems for acid consumers across the country.

Glencore's Murrin Murrin operations

Last year CRU prepared a study on sulphuric acid supply for the Queensland government in the light of the closure of the Mount Isa copper smelter. At the same time, BHP announced the closure of its Nickel West smelter at Kalgoorlie in Western Australia for at least two and a half years. Other smelter closures or reductions in output are pending, all of which have the potential for major disruptions to flows of sulphuric acid across Australia.

Sulphur supply

Sulphur production in Australia is relatively limited, and comes from the country's few remaining refineries. Australia's oil production has been on a decline in recent years, down to 380,000 bbl/d at the end of 2024, from a peak of 550,000 bbl/d a decade earlier. Most of the oil comes from the North West Shelf off Western Australia, and is heavy but sweet. Heavy sweet crude is in considerable demand worldwide, and the oil producing region of Australia is on the opposite side of the country to most of its refining capacity, so Australia actually ends up exporting most of its oil production, and relying upon imported oil to feed its refining sector coming from Malaysia, Indonesia and the Middle East.

Australia's refinery capacity has likewise fallen precipitately from around 750,000 bbl/d in 2011 to just 235,000 bbl/d last year due to refinery closures. Only two major refineries remain operational after the recent closures of Altona and Kwinana; Geelong, near Melbourne, and Lytton near Brisbane in Queensland. Others have been converted into oil import terminals, as it has been cheaper to import fuel from overseas than produce it domestically. Australian refineries have also not been set up to recover high volumes of sulphur. The result is that Australian domestic sulphur production is just 23,000 t/a.

Sulphuric acid

Until recently it had been a different story for sulphuric acid. Australia is a major minerals producer and had developed domestic smelting capacity to process

Fig. 1: Australian sulphuric acid production and consumption

Source: CRU

some of these. A number of base metals smelters generated considerable volumes of sulphuric acid. Nyrstar operates two smelters in Australia; a zinc smelter at Hobart in Tasmania and a lead smelter at Port Pirie north of Adelaide with a total capacity of around 450,000 t/a of acid. BHP Billiton has a nickel smelter at Kalgoorlie in Western Australia with a capacity of 740,000 t/a of acid, and a copper smelter at Olympic Dam in South Australia with a capacity of 530,000 t/a of acid. Sun Metals, a subsidiary of Korea Zinc, operates a zinc smelter at Townsville in northern Queensland which produces 360,000 t/a of sulphuric acid. Finally, at Mount Isa in Queensland, Glencore operates a copper smelter which sends its off-gases to a sulphuric acid plant operated by Incitec Pivot Ltd with the capacity to produce 800,000 t/a of sulphuric acid. A further 400,000 t/a of acid can be generated additionally from a sulphur burning plant at the same site, usually when the smelter is not in operation. In total, there is around 3.5 million t/a of sulphuric acid capacity from smelting in Australia.

Closures

However, many of these smelters face economic and environmental challenges, and in recent years announcements and proposals for closures have been coming thick and fast. BHP suspended operations at Kalgoorlie in October last year due to low prices and overcapacity in the nickel market, with an announcement that the closure would last for at least two and a half years. Glencore announced last year that the Mount Isa copper smelter would be closing, with mining operations ceasing this year and the smelter running on imported concentrates until its closure in 2030. Nyrstar has also been facing economic difficulties and has reduced operating rates at the Hobart smelter by 25% and is looking to sell or close the Port Pirie smelter. All of these closures would remove nearly 2 million t/a of acid capacity from Australia.

Acid consumption – nickel

Australia has the largest reserves of nickel in the world, with estimated resources of 20 million tonnes, just under one quarter of the world's total, most of it (>90%) in Western Australia. Australia was a pioneer of high pressure acid leach production in the 1990s via Anaconda Nickel at Murrin Murrin, Preston Resources at Bulong and Centaur Mining at Cawse. Bulong and Cawse were fed in large part by acid from the Kalgoorlie smelter, but a 1.45 million t/a sulphur burning acid plant was built to feed production at Murrin Murrin. However, all struggled with technical issues, and Bulong closed in 2002, Cawse in 2008 and Anaconda Nickel went through a financial restructuring, re-emerging as Minara Resources, which was eventually bought by Glencore. A new project also opened in 2008 at Ravensthorpe, run by BHP, which also included a 1.45 million t/a sulphur burning acid plant, but this was sold to First Quantum Minerals, who refurbished and reopened it in 2011, before it was idled again in 2017. The revitalisation of the nickel industry by the electric vehicle battery market did lead to a restart at Ravensthorpe in 2020, but the recent decline in nickel prices led to the plant being idled again in 2024. Glencore has continued to successfully operate Murrin Murrin during this time, however.

> **"While there have been a number of new phosphate projects in development, proceeding to production has so far proved an insurmountable barrier.**

In the late 2010s and early 2020s there were a number of plans for new HPAL capacity in Australia, but some of the plans were predicated on acid output from smelter capacity which now looks doubtful, and the flood of Chinese investment into neighbouring Indonesia's nickel HPAL industry looks to have brought prices even for Class 1 nickel to lows which do not currently justify investment in Australia. One possible exception is the Sconi Battery Minerals HPAL project at Greenvale, QLD, which has secured offtake agreements for 71,000 t/a of nickel production.

Acid consumption – uranium

Australia is also the world's largest holder of uranium reserves. It is the world's fourth largest producer, though output has fallen to 4,800 t/a of U_3O_8 in 2022 with the closure of the Ranger mine. Almost all production now comes from two mines; Olympic Dam and Four Mile. BHP uses an acid leach to recover the uranium from the ore at Olympic Dam; about 80% of the uranium is recovered in a conventional acid leach of the flotation tailings from copper recovery and most of the remaining 20% is from acid leach of the copper concentrate also produced at the site, with the acid coming from the nearby smelter.

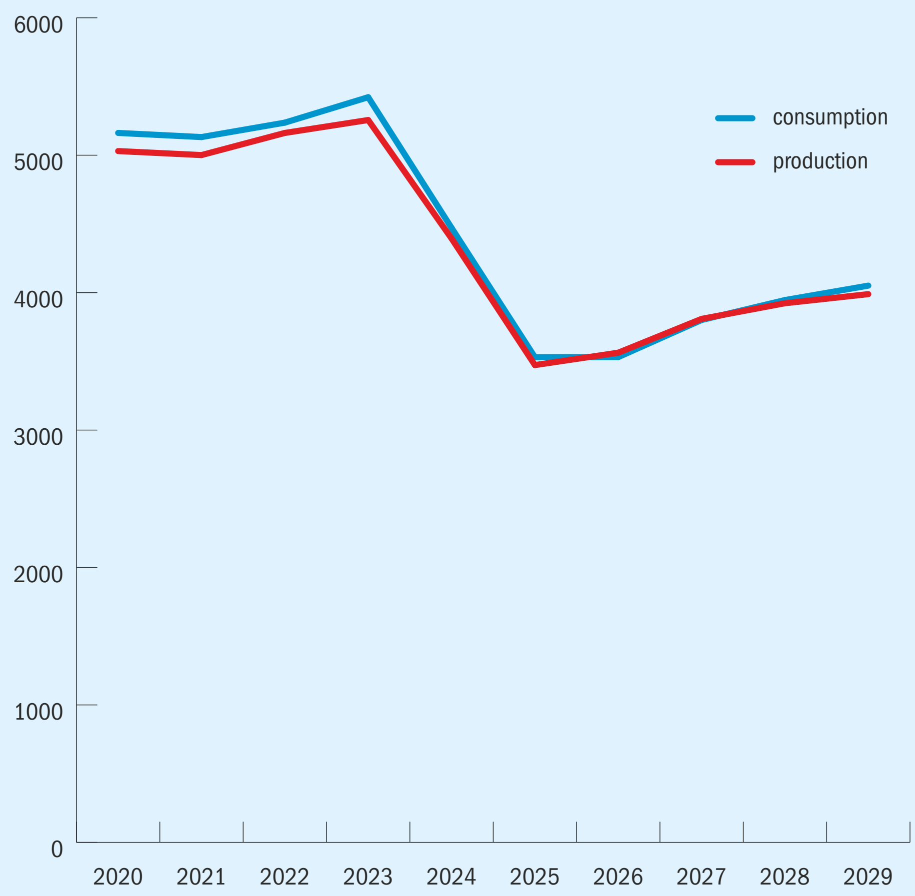
Acid consumption – phosphates

Australia's large acreages of farmland make the country a significant consumer of fertilizer. There is only one major phosphate producer, however; Incitec Pivot Ltd. The company's largest site is at Phosphate Hill, Queensland, where it has the capacity to produce 950,000 t/a of finished phosphates. Phosphate rock comes from Australia's only operating phosphate mine, the Duchess Mine 150km north of Phosphate Hill. Ammonia for MAP/DAP manufacture is produced on-site, and sulphuric acid is brought in from the smelter at Mount Isa, 160 km north.

IPL also operates a single superphosphate (SSP) plant at Geelong, Victoria, with a capacity of 350,000 t/a. Sulphuric acid to operate the SSP plant comes from Nyrstar's zinc smelter at Hobart in Tasmania.

As with nickel, while there have been a number of new phosphate projects in development, proceeding to production has so far proved an insurmountable barrier. The Ardmore phosphate project in Queensland was to have produced 800,000 t/a of phosphate rock concentrate at capacity, but went into receivership in March this year. Verdant Minerals' Ammaroo phosphate project, sited 300km north-east of Alice Springs, Northern Territory is also aimed at producing phosphate rock concentrate for export. Permits have been secured, but financing for the project remains an ongoing issue. Avenira's Wonarah phosphate project in the Northern Territory, one of the largest known phosphate deposits in Australia, has also received mining permits, and Avenira says that it will begin mining operations in Q4 2025, with a final targeted capacity of 1.3 million t/a of phosphate rock, though this will all be for export with no processing in Australia.

Fig. 2: **Australian acid production and consumption, 2020-2029, million t/a**



Source: CRU

demand for sulphuric acid in 2023 was approximately 1.23 million t/a, 95% of which was consumed by phosphate fertiliser production.

This demand has largely been met by Glencore's Copper Smelter at Mount Isa and Sun Metals' zinc smelter in Townsville. Some sulphur is also imported to feed sulphur burning acid capacity.

While the Mount Isa smelter is intended to continue operating beyond 2025, this is contingent on capital being available to maintain the asset, including the capital-intensive smelter re-brick every 4 years. It is unclear if the supply of economically viable third-party concentrates is sufficient for the smelter to operate at full capacity, and thereby supply sufficient acid feedstocks to meet current demand. In addition to potential supply chain disruptions, demand for sulphuric acid is expected to surge. A host of new critical minerals projects which fundamentally rely on sulphuric acid are in various stages of development across the State, including a suite of vanadium projects around Julia Creek, battery electrolyte manufacturing in Townsville, a large nickel-cobalt project near Greenvale and a host of copper oxide developments across the northwest. Total demand for sulphuric acid in 2035 could reach 2.86 million t/a from operating, committed and probable projects, and if all current speculative projects were to be developed, the total demand in 2035 could be as high as 5.23 million t/a. Options for additional supply of sulphuric acid include the importation of solid sulphur through the port of Townsville to feed additional sulphur burning acid capacity, and/or, potentially, the import of seaborne acid through the same route. The ability of Townsville to tranship sufficient volumes remains an open question however. The CRU study did also examine the local production of sulphuric acid through the reprocessing of mine tailings to produce a pyrite concentrate that can feed either a pyrite roaster acid plant or a sulphur burner acid plant operation to produce sulphuric acid. A hybrid of this option produces sulphur prill directly from pyrite feedstocks. This technology is currently being developed by Cobalt Blue, who have demonstrated that it can recover valuable minerals, such as cobalt, from pyrite concentrate. The process produces elemental sulphur as a by-product, which can be granulated into sulphur prill and distributed to end users for sulphuric acid generation via a sulphur burner acid plant at the end user site.

Impact of smelter closures

The wind down of BHP's Nickel West operations will remove acid supply from the company's Kalgoorlie nickel smelter, representing around 550,000 t/a of acid. Given the remote location of the Western Australia acid market from alternative global supply, the question is whether it will be possible to replace the lost supply to allow demand to continue. BHP has internal acid consumption of around 250,000 t/a at the Kwinana refinery with by-product ammonium sulphate generated from the waste acid stream. BHP has also been directing acid to its nickel sulphate production line, although demand has only small as the operation has yet to reach full capacity. Third-party acid demand is split between lithium-based acid consumption around Kwinana, the Lynas rare earth operation at Kalgoorlie, and other industrial end uses, for a total of 170-200,000 t/a. This has left the operation exporting up to 100,000 t/a to the international market. It is assumed that the nickel sulphate production will end due to the loss of feedstock, reducing the net-supply impact to 300,000 t/a. Lynas is the only demand not located at the coast, and so has a greater logistical challenge to replace the lost supply. However, Lynas has announced that BHP will source acid to fulfil its supply arrangements to Lynas, with the initial term of the contract running until June 2027. This and other demand around Kwinana will require acid inflows from outside of the region, either sourcing acid from smelters in southeast Australia or via imports from the international seaborne market.

As far as Mount Isa goes, demand for sulphuric acid in the region has historically been dominated by phosphate fertiliser production at Incitec Pivot's Phosphate Hill operation, with relatively minor demand coming from minerals processing (e.g., leaching of oxide copper ores) and industrial applications (e.g., water and wastewater treatment). Total

PHOTO: SAIPEM

Changing patterns of sulphur trade

New sulphur production from Chinese and Indian refineries and Middle Eastern sour gas and the ramp up of nickel leaching projects in Indonesia continue to change the direction of sulphur trade.

The Shah sour gas plant, Abu Dhabi.

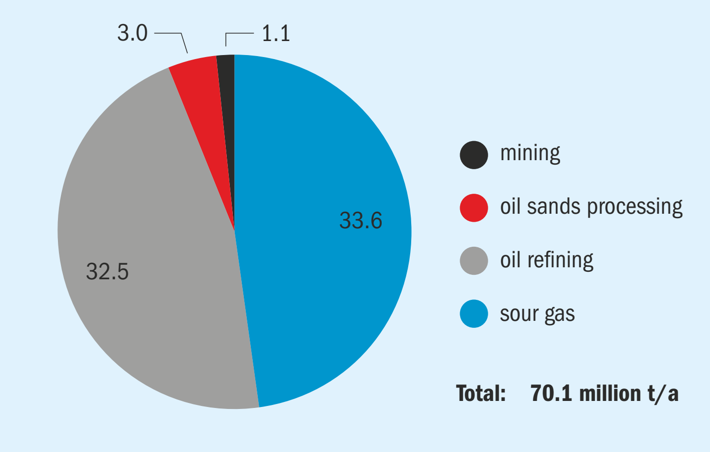
Sulphur is a widely traded commodity. Total elemental sulphur production in 2024 was just over 70 million t/a (see Figure 1), with most of that coming from oil refineries and sour gas processing. Total tonnage of sulphur traded across borders amounted to 39 million t/a, more than half of that total. While some additional sulphur is being produced in major consuming regions like China and India due to new refinery construction, much new demand is coming from countries without any large native sulphur production, such as Morocco and Indonesia, while new production is coming from countries without much sulphur demand such as the UAE, leading to increased volumes traded internationally.

Demand remains primarily from phosphate processing for fertilizers, as shown in Figure 2, but nickel processing for electric vehicle batteries has become a major growth area for sulphur and sulphuric acid demand, and Indonesia, the world's largest nickel producer, is attracting the lion's share of this. Sulphur demand for nickel processing, which stood at 4 million t/a in 2024, is forecast to more than double to 8.2 million t/a in 2029, with Indonesia representing most of this growth, and hence requiring more cargoes of sulphur and acid over that period. Indeed, while fertilizer demand for sulphur is expected to increase by 6.7 million t/a from 2024-2029, metal processing will add 5 million t/a over the same period – almost as much.

Supply – North America

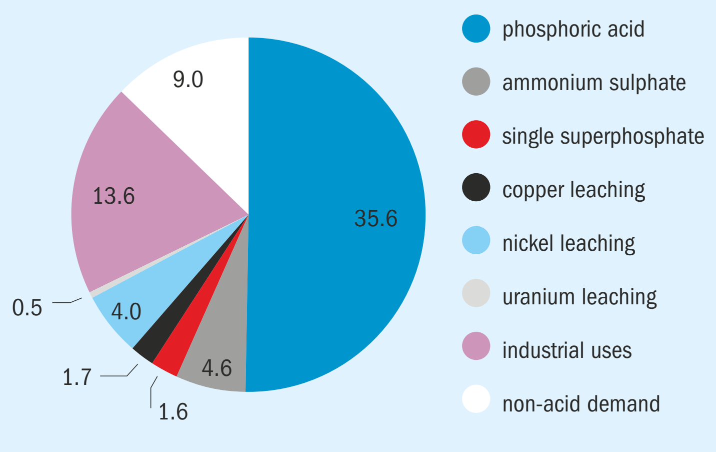
North America was the traditional exporter of sulphur to the rest of the world, primarily from Canadian sour gas processing, but also from refining. While the region remains a net exporter, supply is on a declining trend. Canadian sour gas fields

Fig. 1: **Sulphur supply by source, 2024**



Source: CRU

Fig. 2: **Sulphur demand by end use, 2024**



Source: CRU

are mature and production is falling there, though the rate of decline has slowed and some additional production from British Columbia is balancing continued declines in Alberta. Canadian sour gas sulphur production is expected to stabilise at around 1.4 million t/a by 2029. Sulphur from oil sands processing is likewise relatively stable, at around 3 million t/a. US refinery production is falling due to closures and refinery conversions to biofuels, as well as lower sulphur content of oils being processed. The closure of the Phillips66 refinery in Los Angeles is expected to be completed by the end of 2025. LyondellBasell ceased operations at its Houston refinery in 2025 Q1. Total US sulphur production is set to decline by 300,000 t/a out to 2029. All of this is set against increasing demand from metals processing, particularly new lithium mines. The US is set to become a net sulphur importer from 2026, with import volumes increasing over the next few years, some of it likely to come from Canada. Canada has exported around 4 million t/a and will continue to do so. Large stocks of sulphur remain in northern Canada and how much of that is melted down for sale remains an open question.

Supply – Europe

Europe is also a net exporter of sulphur. European production comes primarily from refining, totalling 2.7 million t/a in 2024, though the Grossenknetten gas field in Germany contributes 270,000 t/a, and there is the last remaining Frasch sulphur mine in Poland which produces another 330,000 t/a. Grossenknetten is forecast to close in 2027, while Europe's refineries also face closure and conversion to biorefineries. Overall, Europe is projected to become a slight net sulphur importer by 2028.

Supply – Central Asia

In spite of logistical difficulties and higher transport costs, Central Asia remains a net sulphur producing region, particularly Kazakhstan. After reaching a historical high in 2024, Kazakhstan's exports are expected to decrease this year to 4.0 million t/a as the stock drawdown seen last year slows.

Kazakhstan started a stock drawdown programme in 2023 with crushed lump sulphur sales which pushed exports to 4.8 million t/a in 2024. The sale of inventory is expected to conclude in 2025, and exports are anticipated to return to typical levels of 3.5 million t/a. Kashagan production remained unchanged in 2024, at 1.2 million t/a, but production at Tengiz rose to 2.6 million t/a across the year.

Meanwhile, higher sulphur prices are expected to lead to more exports from Turkmenistan, partially offsetting the decline in Kazakhstan sales. Turkmen exports are expected to reach 1.4 million t/a in 2025.

Russian production was 8.7 million t/a in 2024, but is on a declining trend, while Russian exports face difficulties with sanctions. At the same time, domestic phosphate production continues to increase, leading to higher domestic demand and lowering export volumes.

Supply – Middle East

Middle Eastern production remains the driving force behind new sulphur supply, with an addition 8.3 million t/a of sulphur expected between 2024 and 2029. Most of this will come from sour gas processing, including an expansion of the UAE's Shah sour gas field and Saudi Arabia's Al-Fadhili expansion, each generating around 0.4 million t/a of new production in 2024. This year Saudi Arabia will see the ramp-up of capacity at Jazan, adding another 0.3 million t/a. Longer term, the addition of Ghasha in 2027/28 and next phase of expansion at Shah in 2025/26, both in the UAE, will add a total of 4.7 million t/a of sulphur capacity between them, most of that at Ghasha. In Saudi Arabia, the Tanajib gas plant is expected to add 900,000 t/a of sulphur supply in 2026/27. Qatar's North Field Expansions (0.6 million t/a capacity) will be added in 2026 to support expanded LNG exports. There is also new refinery capacity in Saudi Arabia this year.

Demand – China

China remains the largest sulphur importer in the world by a long margin, importing 9.95 million t/a of sulphur in 2024. However, this is down from its peak of 11.7 million t/a in 2019, as Chinese domestic sulphur and sulphuric acid supply continues to increase. Total sulphur supply in China is forecast toclimb by 870,000 t/a in 2025, driven by increased oil oil-based availability. New capacity at the Yulong refinery is expected to come online in 2025 with a capacity of 0.60 million t/a. Gas-based supply will also increase by 300,000 t/a this year as increased gas feedstock from the Tianshanpo field boosts utilisation rates at Puguang. By 2029, availability is set to follow an upward trend as new refinery capacity commissions. Chinese sulphur production will actually overtake North American and CIS production by 2026, by which time it will be 12.9 million t/a.

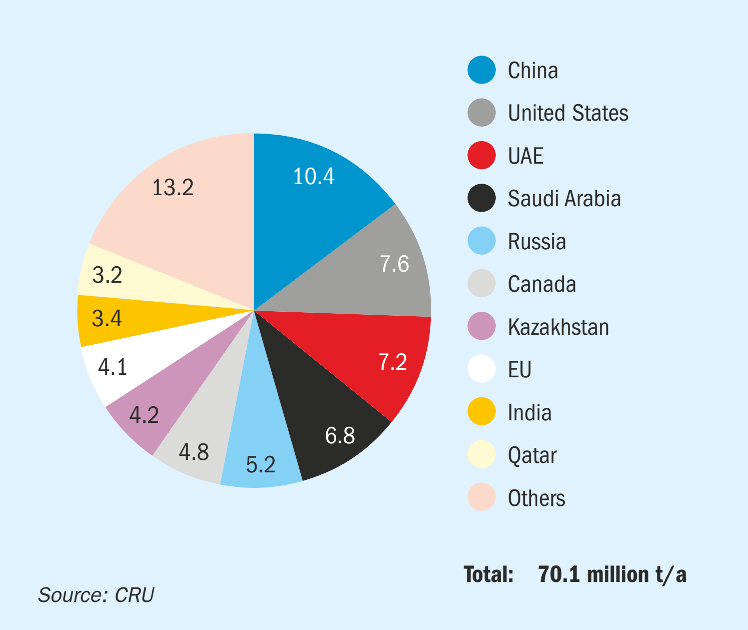
Domestic demand is projected to continue to increase as well, particularly from the ammonium sulphate sector, as China continues positioning itself as the dominant global supplier and, as we describe elsewhere in this issue, from the titanium dioxide industry. There will also be continued increases in phosphate demand, mainly from the battery industry. The lithium iron phosphate (LFP) sector is expected to account for around 900,000 t/a of sulphur consumption in 2025. Even so, sour gas and refinery additions as well as increased acid availability from smelting are expected to reduce overall Chinese import demand by around 3 million t/a by 2029 to around 7 million t/a.

Demand – Morocco

Morocco is the world's second largest importer of sulphur, all of it used for processing phosphates. Phosphate giant OCP commenced operations at its two new sulphur burners at the Jorf Lasfar site in 2024, increasing its sulphur consumption capacity by 800,000 t/a. Sulphur consumption in 2025 is expected to increase further, driven by a high phosphate pricing environment. An expansion of phosphate production over the period to 2029 will lead to an increase in demand of about 900,000 t/a. Sulphur purchases slowed in 2025 Q1, reaching 1.6 million tonnes, down 8% year on year and 24% on the previous quarter, as import trends in late 2024 suggested that Moroccan sulphur purchases exceeded the rate of product exports, resulting in higher inventory levels. For 2025, imports are expected to remain stable at 8.3 million t/a, but out to 2029 they are expected to increase to 9.9 million t/a, overtaking China as the largest importer of sulphur in the world.

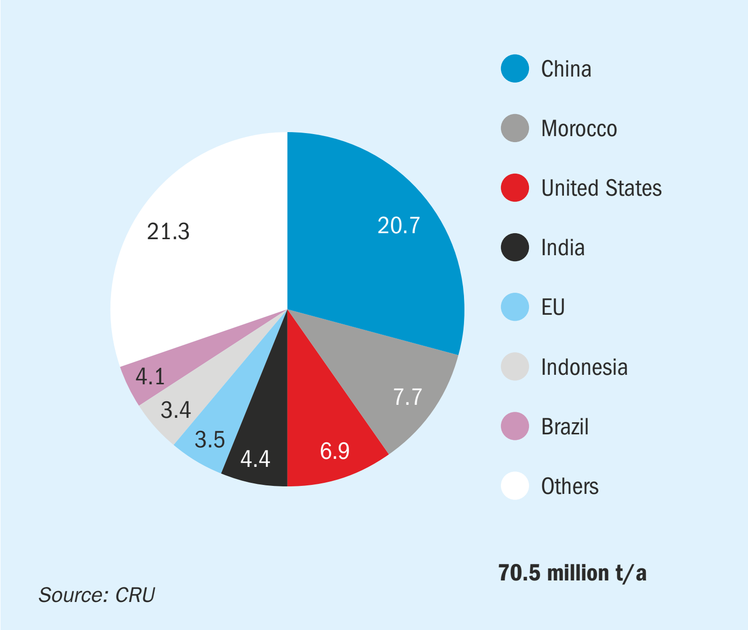
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48

Fig. 3: **Sulphur production by nation, 2024**



Source: CRU

Fig. 4: **Sulphur demand by nation, 2024**



Source: CRU

Demand – Indonesia

Indonesia's surge in sulphur demand is continuing, as new Chinese-backed high pressure acid leach (HPAL) plants for nickel processing continue to open and ramp up production. Imports up to April have surged by 120% year on year, reaching 1.5 million tonnes, and already representing 42% of total 2024 purchases. Nickel production figures for Q1 2025 suggest that buyers may have purchased sulphur ahead of their requirements. The upward trend has been driven by purchases to Obi Island and Weda Bay, explained by the increase in capacity at PT Lygend and the commissioning of the PT Huafei project in 2023. There will be further growth in sulphur burning capacity at PT Lygend and Huayue, along with the start start-up PT Meiming project in 2025. An additional project (PT Blue Sparking) will come online in 2026. Another project is the PT ESG in Morowali, which is expected to be commissioned in 2026 with 300,000 t/a of sulphur demand. Additionally, the ENC project, with a 1.0 million t/a capacity, is likely to start up in 2026 in the same region. There is also growth in non-acid sulphur demand, driven by the increase in nickel matte conversion, which uses around 0.6 tonnes of sulphur to produce 1 tonne of nickel.

Overall, Indonesian imports are expected to continue increasing as new nickel projects start or ramp up. For 2025, purchases are set to beat previous records at 4.3 million t/a, rising to 7.7 million t/a by 2029, potentially pushing China into third place in imports.

Demand – India

India is another major importer, mainly for phosphate production. India's import requirements remain strong in 2025, totalling 600,000 tonnes in Q1 2025, up 200,000 tonnes year on year. Most of these tonnes were for Iffco's Paradip operations, followed by PPL's Paradip site and CIL's Vizag plant. Sulphur requirements have increased due to the start start-up of new burners in 2024 or the expansion of sulphur sulphur-burning capacity in 2025. Indian sulphur demand is expected to remain stable at 4.4 million t/a in 2025. By contrast, supply will increase by 400,000 t/a due to the ramp-up of Indian Oil's Panipat refinery expansion. But production will not be able to meet the sustained growth in demand, which will be reflected in an increase in import requirements, forecast to reach 2.1 million t/a by 2029.

Demand – Brazil

Brazilian imports have remained robust this year, with figures to May up 26% on 2024 The state of Minas Gerais has been the primary driver of this growth. Consumption is set to increase as the phosphate sector continues recovering and a new phosphate plant continues its initial ramp -up. EuroChem's Serra do Salitre phosphate plant was launched in mid mid-March 2024, and it is expected to reach full output by the end of this year, with sulphur consumption capacity of 330,000 t/a. Growing demand will maintain import growth throughout the forecast period, reaching 2.8 million t/a in 2029, up from 2.5 million t/a in 2024.

Sulphur trade

From the foregoing, it seems clear that Middle Eastern exports will continue to dominate the traded market Since 2016, the Middle East region has accounted for 41-46% of global trade. The addition of new capacity pushed this share up to 49% in 2024 and is set to continue increasing to 59% by 2029. The UAE – i.e. Abu Dhabi - will be the major slice of this. UAE exports are expected to increase from

7.0 million t/a in 2024 to 11.4 million t/a in 2029, reinforcing its position as by far the region's leading exporter. Additional capacity at Ghasha plans to transport sulphur to forming capacity at Ruwais via pipeline but additional forming and loading infrastructure at the port is likely to be necessary by 2028/29.

Saudi Arabia will be the second major exporter, with sales increasing from 4.8 million t/a to 5.5 million t/a in the same time frame in spite of increased domestic phosphate production. Similarly, the boost in supply will be reflected in Qatar's exports jumping from 3.1 million t/a in 2024 to 4.1 million t/a in 2029.

In terms of the direction of this trade, Morocco's growth in phosphate production will see it become the largest sulphur importer in the world by 2029, closely followed by Indonesia as it ramps up nickel production for car batteries. China will remain a major importer, but will drop behind Morocco and Indonesia due to increased sulphur supply within China.

Titanium dioxide and sulphuric acid

Titanium dioxide is one of the major chemical uses for sulphuric acid outside of phosphate and metals processing, and sulphate route plants remain concentrated in China.

Titanium dioxide is a major industrial chemical and a significant use for sulphuric acid. It finds use mainly as a pigment; titanium dioxide is a brilliant white compound with a high refractive index. This means that when it is dispersed in a binding agent, typically a resin of some kind, it tends to have a greater difference from the refractive index of the binder, and hence tends to look whiter and more opaque than other comparable white pigments such as calcium carbonate or zinc sulphate. This gives e.g. paints greater opacity and 'hiding power'; the ability to cover an underlying coat without the colour showing through, and as such makes titanium dioxide highly in demand for paint and ink formulations. It is also widely used in the paper industry and in plastics for much the same reason, and it is also used as a whitening agent in toothpaste and many other household items. It is also extremely stable with respect to direct sunlight, and so micro-fine grades are used in cosmetics and sunscreens. Overall the paints and coatings industry represents around 55% of the titanium dioxide market, plastics 25% and paper 9%.

In terms of tonnage, the global market for titanium dioxide was around 6.2 million t/a in 2024. Because it is used in so many finished consumer products, and because the paint industry is closely tied to the fortunes of the construction industry, titanium dioxide demand tends to fairly closely parallel GDP growth, and has averaged around 2.5% over the long term.

Table 1: Production of titanium oxide ores, 2023, million t/a

China	3.1
Mozambique	1.6
South Africa	1.1
Australia	0.6
Canada	0.5
Norway	0.4
Other countries	1.9
Total	**9.2**

Source: USGS

Anatase vs rutile

Titanium dioxide has two main crystal structures, anatase and rutile (there is also a third form, brookite, but this is not widely used). Anatase is a bipyramidal structure, while rutile is tetrahedral. This gives rutile titanium dioxide a higher refractive index than the anatase phase (about 2.7 – 2.8 as compared to 2.55) and hence it has slightly higher opacity and hiding power. It also has higher mechanical strength, and weathers better when exposed to sunlight and rain. However, it is also generally more expensive to produce. For this reason, anatase tends to be favoured for less demanding applications such as highway paints, interior paints and plastic filling. Untreated rutile is used in the paper industry, and treated rutile for demanding exterior paint applications.

TiO_2 production

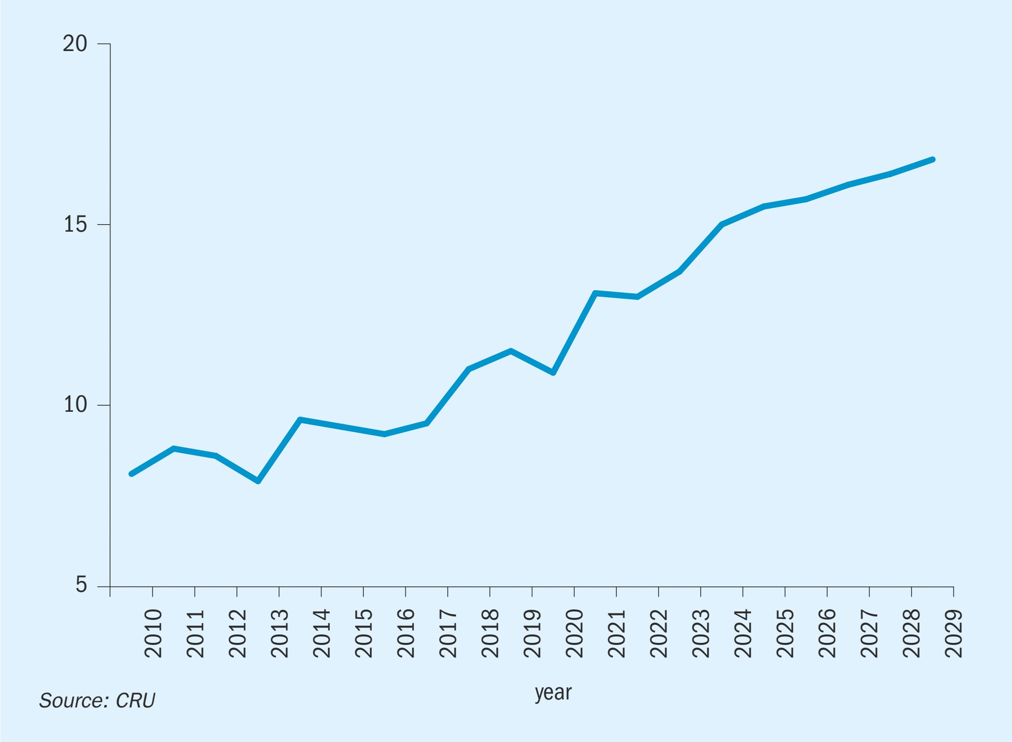
Titanium dioxide is produced from titanium-bearing rock, which tends to be mined in places such as China, Mozambique and South Africa. Table 1 shows mined production from the main producing nations in 2023. Anatase titanium dioxide comes from ilmenite, which is the main titanium ore, accounting for 90% of all production, while rutile ore is mined mainly in the US, Sierra Leone and South Africa.

There are two major competing routes for processing titanium ore; treatment with sulphuric acid, or via chlorination and subsequent oxidation. Production of finished titanium dioxide is split roughly 50-50 between the chloride and sulphate routes.

The chloride route mixes the ore with carbon and reacted in a fluidised bed with chlorine gas at 900C to produce titanium tetrachloride. The mixed chlorides are cooled. Iron, manganese and chromium chlorides can be removed by condensation. The remaining vapour is condensed to a liquid and fractionally distilled to produce a pure form of $TiCl_4$. This is then reacted with oxygen to form titanium dioxide and recover the chlorine to a recycle. The titanium dioxide produced is exclusively the rutile form. While chloride route TiO_2 is widely regarded as a superior product, chlorine availability depends on the chlor-alkali industry, which electrolyses sodium or potassium chloride to yield chlorine gas and sodium or potassium hydroxide, and depends on electricity as the main 'feedstock', which affects cost. It also requires large volumes of chlorine gas, which presents potential safety issues.

In the sulphate process, the titanium-bearing ore is dried, ground and then agitated with concentrated sulphuric acid in a batch or continuous exothermic reaction. The titanyl sulphate is hydrolysed to produce a colloidal TiO_2 hydrate, which needs to be washed and filtered prior to feeding into a calciner at 900-1,250°C to produce TiO_2 It tends to be a lower cost process overall, depending on the cost of acid, but unless there is careful control of the reaction it generally produces a lower grade product. It also generates dilute sulphuric acid waste which requires treatment, though process improvements mean that acid recycling has reduced the volumes of waste acid produced. Enhancing the recoverability

Fig. 1: **Acid consumption for TiO_2 production, 2010-2029**



Source: CRU

and saleability of by-products such as iron sulphates, iron oxides, gypsum and spent sulphuric acid can all help improve the efficiency and environmental credentials of sulphate-based plants.

The quantity of sulphuric acid consumed in the process mainly depends on the type of ore feedstock, and can vary between around 2.5 tonnes per tonne product and 4.2 tonnes per tonne product. This means that sulphuric acid costs can have a bearing on titanium dioxide production at the margins – anatase grade TiO_2 typically retails for around $2,000-3,000/tonne, of which sulphuric acid cost represents perhaps a few hundred dollars. In general, every $10/t increase in the price of sulphur pushes up the price of manufacturing titanium dioxide by about $9/t. This can be problematic for titanium dioxide producers, as sulphuric acid costs are driven by phosphate and metals markets. On the other hand, TiO_2 consumers such as paint manufacturers are generally relatively able to pass costs on to end users, and acid costs really only impinge on titanium dioxide markets when they reach very high levels.

China

During the 1990s, the chloride route seemed to be winning out in the US and Europe, as well as the Middle East, due to its higher quality product and lower levels of acid waste. However, the sulphate route returned with the rise of Chinese production. Chinese production of TiO_2 has grown rapidly this century, from around 1.1 million t/a in 2010 to 4.8 million t/a by 2024, with total installed capacity reaching 6.05 million t/a in 2024 according to producer Titanos. Around 80% of Chinese production uses the sulphate route, and now accounts for most sulphate route production worldwide. Outside of China, there have been very few new greenfield TiO_2 plants built in the past 30 years. There was a wave of new chloride-route plant construction during the early 1990s, and some sulphate plants built in India and Malaysia, but most new capacity has been in China. Chinese titanium ore mining has expanded rapidly this century, and as Table 1 shows China now mines 3.1 million t/a of ore, making it the largest miner worldwide, but the country's finished TiO_2 capacity has outstripped China's ability to feed it with domestically produced ore, and so in order to feed TiO_2 production it must also import large volumes of titanium ores from elsewhere in the world. Chinese imports of titanium ores reached 4.3 million t/a in 2023.

All of this explains why China has come to dominate the use of sulphuric acid in the TiO_2 industry. In 2024 China used 13.0 million t/a of sulphuric acid for titanium dioxide production, representing 86% of all sulphuric acid use in TiO_2 manufacture. Europe represented another 1.0 million t/a (7%), with small volumes also consumed in Japan, Brazil, India, Canada and Malaysia.

Chinese production of TiO_2 continues to increase. Production increased by 606,000 t/a (16.5%) in 2024 compared to 2023. Production runs significantly ahead of domestic demand, particularly as the housing and real estate sectors in China – the main use for paints - are in a slump caused by overcapacity. As a result China exports large tonnages of TiO_2 elsewhere, with total exports of 1.9 million t/a in 2024, an increase of 16% on 2023. India was the main destination (15% of exports), as well as Brazil (7%), Turkey (6%), South Korea (5%), Russia, Indonesia, Vietnam, and the UAE.

Anti-dumping

Large exports of titanium dioxide from China have in turn led to anti-dumping investigations in various countries to protect domestic production. In 2024 the EU, India, Brazil, and Saudi Arabia all launched anti-dumping investigations. In January this year the EU agreed anti-dumping duties on Chinese TiO_2 for five years, with levels of euro 250/t for Anhui Jinhe Group, euro 740/t for Lomon Billions Group, and euro 640-740/t for other companies. Nevertheless, Chinese producers expect that exports will rise to 2.05 million t/a in 2025, an 8% increase on 2024, as domestic consumption remains relatively weak in spite of a recovery in industrial coatings, plastics and polymers.

Increasing production

As Figure 1 shows, while global economic conditions can cause slowdowns or contractions in titanium dioxide production, such as the dip in 2020 caused by the covid-19 pandemic, in general it continues to grow at GDP-level rates. On the production side, China's push for increased TiO_2 output seems to be showing no signs of slowing down at the moment in spite of weak domestic demand. Essentially all new marginal production is expected to come from China over the next five years. While there is some chloride route production and new chloride route plants planned, much of this increase will come from sulphuric acid route production, and this will mean additional acid demand. As shown in Figure 1, acid demand for titanium dioxide production is expected to rise from 15.0 million t/a in 2024 to 16.8 million t/a in 2029, an increase of 1.8 million t/a, with 1.6 million t/a of that projected to come from China, and India representing most of the remainder.

Sulphur fertilizers – the processes, the products

While sulphur is regarded by many as the fourth crop nutrient, soils globally are becoming increasingly sulphur deficient. Fortunately, there are proven and successful process technologies available for incorporating sulphur – in elemental or sulphate form – into urea, the world's most widely applied commodity fertilizer. **Mark Brouwer** of UreaKnowHow.com reviews the main production options and highlights key reference installations.

Sulphur is present in all crops and plays an important metabolic role. It is essential for the formation of proteins, amino acids, vitamins and enzymes, being vital for photosynthesis, energy metabolism and carbohydrate production. Sulphur also contributes to the flavour and aroma of crops such as onions and can therefore influence the quality of farm produce.

In crop nutrition, sulphur is vital for early crop establishment and improves resistance to environmental stress. Deficiency stunts early plant growth, leading to yield losses later on, and is exacerbated by the following conditions:

- light and sandy soils with low organic matter;
- sulphur leaching during high winter rainfall;
- low sulphate mobility during dry spring conditions;
- slower mineralisation at low temperatures;
- low input of organic matter and mineral sulphur;
- low atmospheric deposition of sulphur to soils.

PHOTO: NORTHERN NUTRIENTS

Canada's Northern Nutrients produces Artic-S, a urea product that incorporates micronised elemental sulphur, using Shell Thiogro technology.

Crops can typically remove between 15 to 30 kilograms of sulphur per hectare from soil. Root vegetables, onions and brassica, especially oilseed rape (canola), have a particularly high demand for sulphur. Pasture and other widely grown crops such as coffee, corn, cotton, rice, soybean, sugarcane and wheat also require moderately high sulphur applications. For these crop types, sulphur requirements can match or even exceed demand for phosphorus.

Increasingly widespread sulphur deficiency is having an impact on crop yields and quality in many regions. The reasons behind growing global soil deficiency include:

- declining industrial and vehicle so_2 emissions and, consequently, less deposition of atmospheric sulphur to soil;
- greater sulphur removal due to expansions in the land area devoted to crops and higher crop yields;
- the increasing prevalence of high-analysis fertilizers with little or no sulphur content.

Sulphur demand

Globally, it is possible to estimate crop nutrient demand for sulphur by multiplying different crop growing areas by their specific sulphur requirements. Regional sulphur deficits can then be calculated by comparing this demand with actual sulphur fertilizer applications.

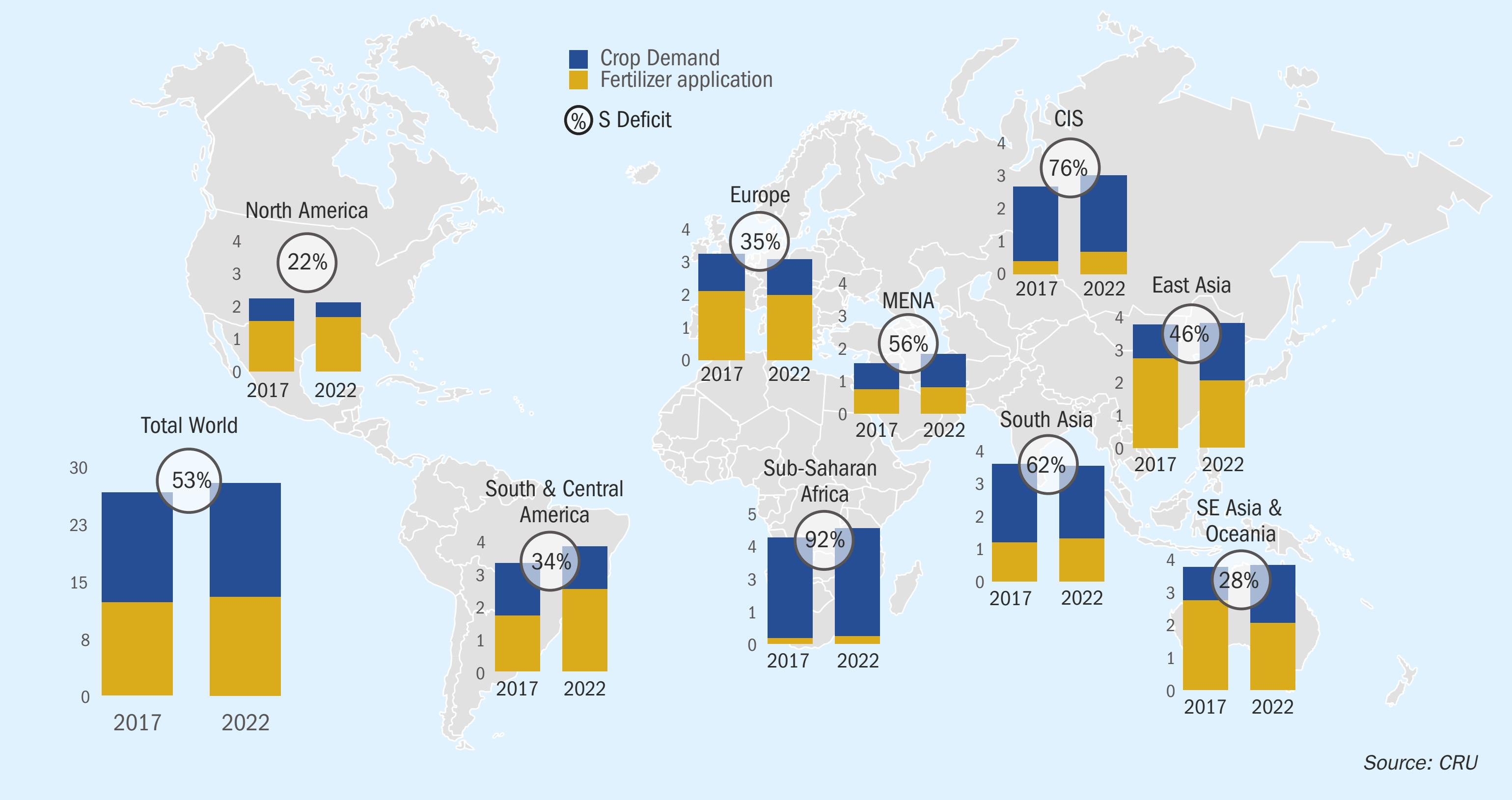
Only around half of the global sulphur requirement from crops is being met by fertilizer applications currently, based on CRU estimates.

All global regions are calculated to be operating with a sulphur nutrient deficit, this being most pronounced in India, Africa and the CIS region. Despite high levels of sulphur nutrient application in East Asia and South Asia, sulphur nutrient deficits in these two regions are calculated at 46% and 62%, respectively (Fig. 1).

Sulphur and nitrogen – inseparable nutrients

Importantly, sulphur does not act alone as a plant nutrient, as it works in tandem with nitrogen to enable the formation of amino acids during protein synthesis. Sulphur is also part of the plant enzyme required for nitrogen uptake. Sulphur and nitrogen are inseparable nutrients because of this, according to major fertilizer producer Yara International:

Fig. 1: **Global sulphur nutrient crop demand and deficit, by region, 2017 versus 2022**



"Many agronomists now consider sulphur to be the second most important nutrient after nitrogen. Certainly, sulphur is an essential nutrient, closely linked with nitrogen in biological processes with both elements forming an inseparable team.

"Previously, crop requirements were generally met from atmospheric deposition, so sulphur was confined to a secondary role. However, today it is back in its rightful place as an essential component of optimum nitrogen management."

The link between nitrogen and sulphur metabolism in plants has been known for many years. As a general rule, every kilogram of S enables 5-10 kilograms of N to be used fully in crop growth and ultimately maximise crop yields.

As the world's most popular commodity fertilizer, enriching urea (U) with sulphur, by adding elemental sulphur (ES) or ammonium sulphate (AS) – to create U+ES and UAS products, respectively – can be an effective approach that addresses both soil sulphur deficiencies and improves nitrogen use efficiency (NUE)

Sulphate is readily available for uptake by plants but can be prone to leaching, especially under high rainfall conditions. While elemental sulphur remains in soils longer than sulphate, its plant availability depends upon its oxidation to sulphate – with this being controlled by soil conditions and other factors. Generally, elemental sulphur particles below 20 microns in size are better dispersed in soils and more prone to microbial oxidation.

Enriching urea with sulphur or sulphate

This article reviews and summarises the different commercial finishing technologies used to create U+ES and UAS fertilizers. Recent industrial references are also included as examples.

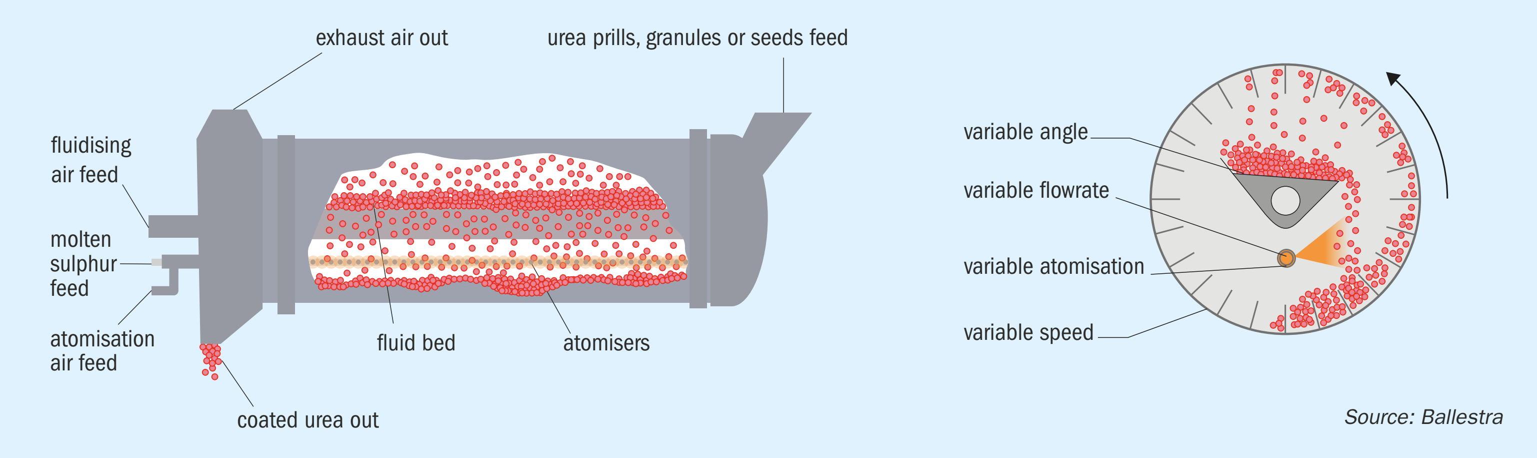
In practice, there are four main finishing options:

- prilling;
- fluid bed granulation;
- drum granulation;
- IPCO rotoform pastillation.

Each of these finishing technologies, while having their own distinct pros and cons, have been successfully used by fertilizer producers to manufacture urea products enriched with sulphur in elemental or sulphate form.

Prilling tower.

Fig. 2: **The innovative Bi-Fluid Drum granulator (BFDG) developed by Italy's Ballestra is suitable for sulphur-coated urea production**



Source: Ballestra

Prilling

Around 75% of urea plants globally use prilling as their finishing technology. Urea melt (99.6 wt-%) is fed to a rotating prilling bucket (or shower heads with numerous small holes) located at the top of a prilling tower (see photo). This creates droplets of urea melt that solidify as they fall from the top of the tower – essentially an empty vertical cylinder of great height – and are cooled by a large volume of air flowing upwards in counter current.

Prilling tower capacities can range between 100 t/d and 4,000 t/d. The urea prills obtained typically have a diameter of 1.7-2.1 mm with a crushing strength of around 1 kg/cm^2. These prills, due to their relatively low strength, are generally not suitable for bulk blending processes or long-distance transport – and are usually bagged for local consumption instead.

The main advantages of the prilling process are its simplicity and its flexibility when it comes to incorporating additional crop nutrients. Kreber, for example, offers prilling tower technology for both U+ES and UAS. Valuably, adding ES or AS to prills improves handling properties by increasing crushing strength and their diameter.

Fluid bed granulation

Most of remaining 25% of urea plants operate a fluid bed granulation unit for fertilizer finishing. Capacities range from 500 t/d to 4,000 t/d. The concentration of urea melt varies between 96-98.5 wt% depending on the fluid bed granulation technology (Uhde, Stamicarbon, TOYO, Casale etc.). Fluid bed granulation is generally a more complicated process than prilling and, consequently, sprayer design and spraying conditions can have a real influence on overall urea plant performance.

Similar to prilling, large air flows are used to remove heat during solidification. Urea granules (average size typically 3 mm) are larger than prills and have a higher crushing strength (3 kg/cm^2). Fluid bed granulation is typically used in export-oriented urea plants as the robust granules obtained are suitable for both bulk transport and bulk blending.

Drum granulation

Globally, some ten urea plants currently use drum granulators in their finishing sections. Capacities vary between 100-500 t/d, although Ballestra's new bi-fluid drum granulator (BFDG) – see Fig. 2 – can handle higher capacities due to its superior cooling performance. Typically, 96 wt-% urea melt is used as feed and, again, large air flows are required during solidification to remove heat.

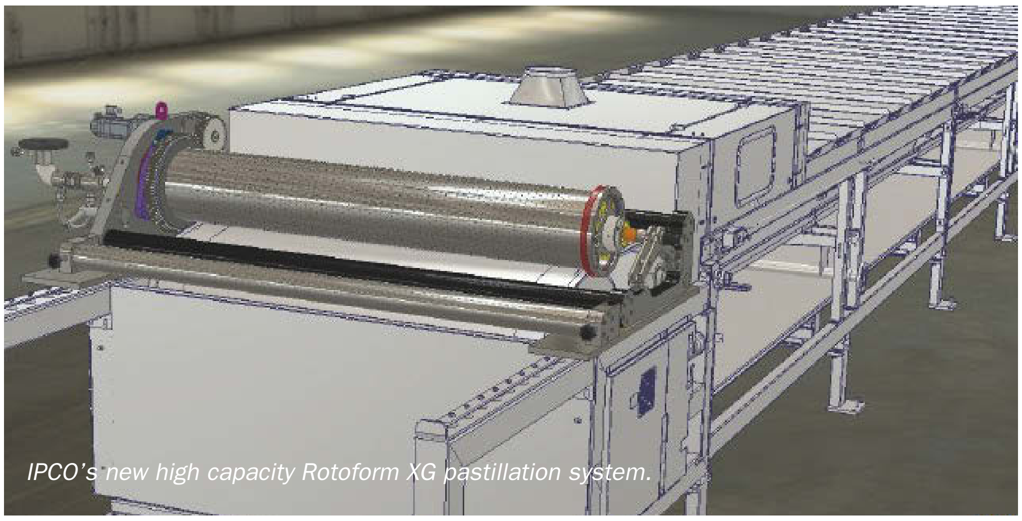
Drum granulation is a more flexible process, compared to fluid bed granulation, and thanks to a simpler sprayer design can be used to create multi-nutrient fertilizers as well as applying a coating. The granules obtained have similar properties to those from fluid bed granulation. Additionally, drum granulation can also be used to 'fatten' prills and convert these into granules, although the resulting crushing strength is lower than that of conventional granules.

IPCO Rotoform pastillation

Ten or more IPCO Rotoform urea finishing units are operating currently, with many more units installed for sulphur pastillation. Each line has a 125 t/d capacity and uses a 99.6 wt-% urea melt. Heat is removed during solidification by cooling water. The process helps to avoid atmospheric emissions as hardly any air flow is required.

Rotoform equipment generates very uniform pastilles and allows the size of these to be varied from 1-5 mm. The crushing strength of pastilles is intermediate between that of prills and granules. IPCO recently introduced the Rotoform XG high capacity pastillation system for fertilizer finishing (see photo).

IPCO can also supply upstream solutions including blending and grinding units (Fig. 3) that, by combining liquid and solid

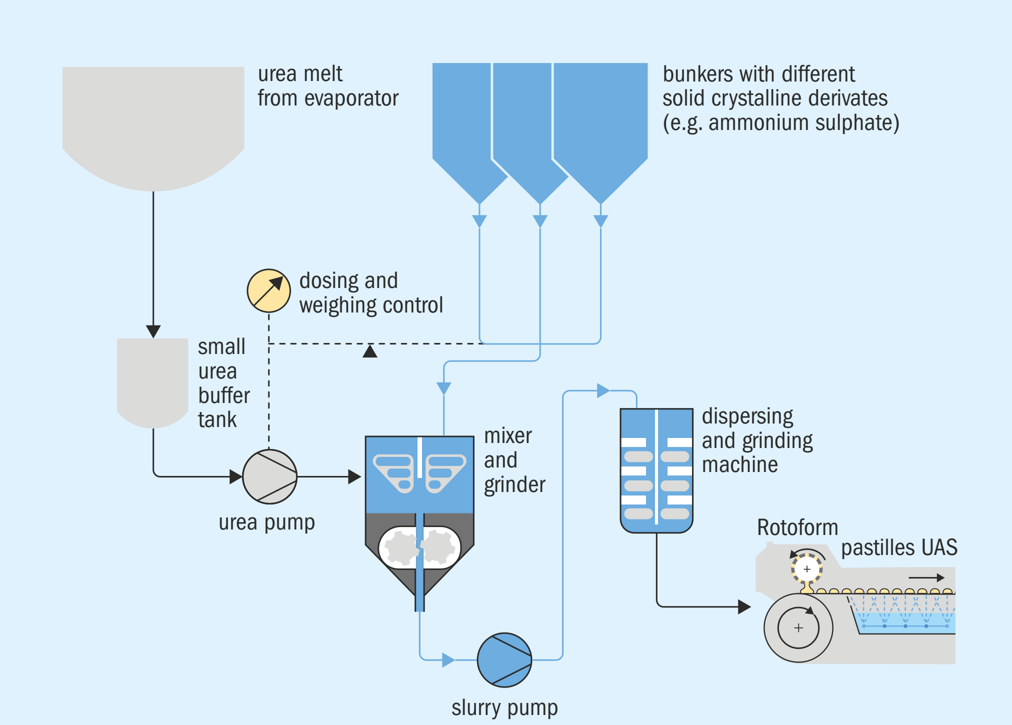


IPCO's new high capacity Rotoform XG pastillation system.

PHOTO: IPCO

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48

Fig. 3: **IPCO mixing and blending plant – for efficient dosing, weighing, mixing and grinding with accurate control and easy maintenance**



Source: IPCO

raw materials, enable the production of specialty urea products such as:

- urea + elemental sulphur;
- urea + ammonium sulphate;
- urea + potassium;
- urea blended with micronutrients.

Urea plus elemental sulphur (U+ES) production

Successful production of U+ES has a number of requirements:

- The ability to cope with the different melting melt points of urea (133°C) and elemental sulphur (115°C)
- Then properly mix the urea melt and sulphur melt using an emulsifier. This is necessary as they are immiscible, like oil and water.
- Finally, the elemental sulphur needs to be finely dispersed and incorporated within prills, granules and pastilles as micron-size particles. This is necessary to provide a large available surface area that will subsequently allow soil bacteria to quickly convert elemental sulphur into plant-available sulphate.

Three companies, Yara International, Shell Sulphur Solutions and Sulvaris, have developed technologies that combine elemental sulphur with urea (including a patented emulsifier) and – except for Yara – license these to third-party fertilizer producers.

Shell Sulphur Solutions successfully commercialised its patented Thiogro technology in the early 2000s. This was initially developed for dispersing sulphur within granulated ammonium phosphates. Sulphur-enhanced phosphate lines have subsequently been licensed and installed at phosphate fertilizer plants in Asia, North America and Australia. This includes a major collaboration with SinoChem in China (*Sulphur* 381, p24). Shell also landed a major licensing deal with OCP Group in 2016. This allows the Moroccan phosphate giant to produce its own range of highly concentrated sulphur-enhanced fertilizers using Thiogro technology at its Jorf Lasfar site.

Shell subsequently introduced Urea-ES – a product with a nitrogen content of 37-43% and containing a 7-20% dispersion of micronised sulphur in a urea matrix – to the market in 2015. This was followed in 2017 by the introduction of high sulphur urea product Special-S (11-0-0-75ES).

Shell has successfully collaborated with both thyssenkrupp (Uhde Fertilizer Technologies) and IPCO, leading providers of fluid bed granulation and Rotoform pastillation, respectively. These partnerships mean Urea-ES and Special-S technologies are now widely available to producers wishing to expand their portfolios to include sulphur-enhanced fertilizers.

In the US, Thiogro technology was installed at Two Rivers Terminal's production site in Moses Lake, Washington state, in 2018. The company produces highly concentrated Special-S pastilles (11-0-0-75ES) for the Pacific Northwest and California markets using IPCO Rotoform equipment.

H Sulphur Corp, one of Asia's leading sulphur suppliers and sulphur-bentonite producers, commissioned the first ever Special-S production plant in South Korea in 2019 using Thiogro technology under license from Shell. The company has successfully sold and shipped Special-S to customers in Canada, Australia and Brazil under its own Super S brand name.

Canada's Northern Nutrients has been producing Special-S (10-0-0-75, Artic-S) and Urea-ES (38-0-0-18+stabiliser) products under license from Shell using two IPCO Rotoform units since 2022 (see main photo). In comparison to AS, the highly concentrated Special-S formula delivers transportation, storage and application cost savings by efficiently moving almost double the per tonne nutrient content through the supply chain.

In the Middle East, RNZ International has been producing the sulphur-enhanced Purti NS Plus fertilizer (10-0-0+75S) at its Kizad production plant in Abu Dhabi since 2022 using Thiogro technology under license.

Calgary-headquartered Sulvaris has commercialised a proprietary micronised sulphur technology (MST®) that reduces elemental sulphur to an average size of less than 10 microns. MST® has successfully been incorporated into a range of fertilizers, including AS, monoammonium phosphate (MAP), potash, triple superphosphate (TSP) and urea ammonium nitrate (UAN).

In collaboration with Nutrien, the world's largest fertilizer producer and retailer, Sulvaris has developed a product that combines with MST® with MAP. This is marketed by Nutrien under the brand name Smart Nutrition™ MAP+MST®.

Sulvaris has also created a patented urea + MST® product. This is manufactured by incorporating micronised elemental sulphur directly into the urea melt during granulation. The resulting Urea + MST® granules have a 5-12 percent elemental sulphur content. The Canadian company is also collaborating with Netherlands-based prilling experts Kreber on incorporating MST® into urea prills.

Urea ammonium sulphate (UAS) production

Successful UAS production is a particular challenge because the two components have a eutectic point at around 9-12% AS, depending on the water content. Increasing AS content beyond this significantly increase the melting point and therefore creates a suspension at higher AS levels.

Despite this potential drawback, Casale, IPCO, Stamicarbon, Toyo/Agrofert and Yara International have all successfully developed production processes for UAS. Again, all these companies – except for Yara – license their UAS technologies to third-party fertilizer producers.

In Germany, Toyo and Agrofert (formerly SKW) have jointly developed a UAS production route using Toyo's 'spouted bed' fluid bed granulator. The process uses a solid AS feedstock prepared with a mixer-grinder. The 500 t/d unit has been in operation since 1998 and produces a 33-0-0-12 fertilizer, corresponding to around 50% AS by weight.

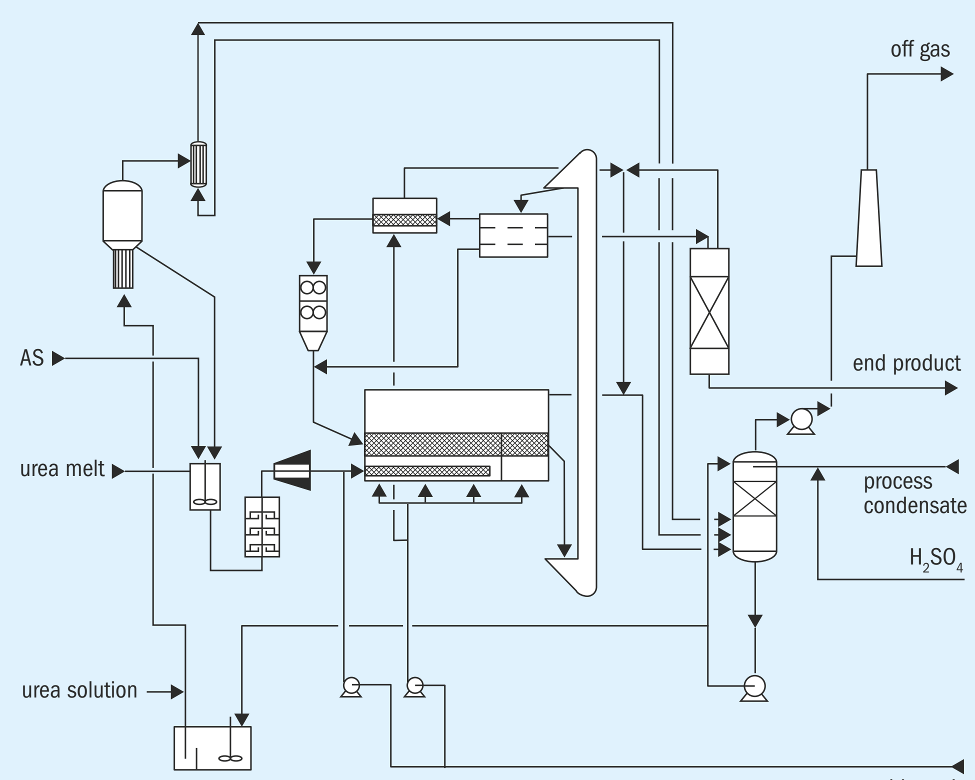
Yara has been producing UAS at its Sluiskil plant in the Netherland since 1998. The company added another 2,000 t/d capacity UAS fluid bed granulation line at the site in 2020.

Sluiskil operates as an integrated urea/UAS unit that generates AS within the urea melt plant. Sulphuric acid is added to the urea solution downstream of the high-pressure CO_2 stripper using a pipe reactor. The heat of reaction between ammonia and sulphuric acid reduces energy consumption by helping to evaporate water. Sluiskil produces a 40-0-0-5.6 UAS product, this corresponding to an AS content of around 23%.

In Poland, Grupa Azoty Pulawy has been producing UAS from two IPCO Rotoform pastillation units (125 t/d capacity each) since 2013. These consume a solid AS feedstock prepared with a mixer-grinder which also features a slurry pump. The site produces a 36-0-0-8 fertilizer with 35% AS content.

Stamicarbon designed its first commercial UAS plant for EuroChem's Novomoskovk Azot production site. This was formally opened in December 2018 as Russia's first urea-UAS plant with a capacity of 400 t/d for urea and 600 t/d for UAS. Stamicarbon's UAS process is designed for 0-50% AS content, with up to 32% being realised. This process (Fig. 4) also uses a solid AS feedstock prepared with a mixer-grinder.

Fig. 4: **Stamicarbon's UAS granulation process**



Source: Stamicarbon

Most recently, China's Xinjiang Xinji Energy Recycling was expected to start up a 1,900 t/d capacity Casale UAS fluid bed granulation unit in December 2024. The plant, which consumes a solid AS feedstock, is fully flexible with the ability to produce either standard urea or UAS with an AS content of up to 25%.

Casale uses a 'double granulator' design to avoid reaching the eutectic point in UAS production. This enables the continuous production of UAS at any composition between 0-25% AS under optimum granulation conditions, by allowing melts of different compositions to be fed to separate sections of the granulator. This flexibility also provides the plant operator with the ability to continue production even if the supply of AS becomes unavailable or is reduced.

Conclusions

- While sulphur is regarded by many as the fourth crop nutrient, soils globally are becoming increasingly sulphur deficient.
- Fortunately, there are several proven and successful process technologies available for incorporating sulphur – in elemental or sulphate form – into urea, the world's most widely applied commodity fertilizer.
- Beneficially, the addition of sulphur also increases the nitrogen use efficiency (NUE) of urea.
- The production of urea plus elemental sulphur (U+ES) fertilizers requires an emulsifier to properly disperse sulphur particles within granules, prills and pastilles.
- The elemental sulphur is also micronised so it can be quickly converted into plant-available sulphate by soil bacteria.
- Successful urea ammonium sulphate (UAS) production is a particular challenge because the two components – urea and ammonium sulphate (AS) – have a eutectic point at around 9-12% AS.
- Despite this potential drawback, the nitrogen industry's main technology licensors and leading fertilizer producer Yara International have all successfully developed production processes for UAS.

Author's note

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Reference

Brouwer, M., 2024. Proven process technologies for urea fertilisers enriched with elemental sulphur or ammonium sulphate. *International Fertiliser Society Proceedings*, 890. ISBN 978-0-85310-527-5.

Sulphur: Past, Present, Possibilities

MEScon 2025, which took place in Abu Dhabi from 19-22 May 2025, provided delegates with renewed energy, new connections, and fresh ideas to apply across the sulphur value chain. From legacy learnings to frontier innovation, this year's theme, "Past, Present, Possibilities", remained a guiding thread throughout.

The 2025 Middle East Sulphur Conference (MEScon 2025), organised by CRU and UniverSUL Consulting and hosted by ADNOC returned to the Conrad Abu Dhabi, Etihad Towers for four days from 19 to 22 May. This year's compelling programme celebrated sulphur's legacy while charting a bold course toward its future. Held in the heart of the world's largest sulphur-producing region, the event brought together global industry leaders, operators, innovators, and researchers under this year's unifying theme: past, present, possibilities.

MEScon 2025 – Workshop day

MEScon 2025 kicked off with a high-impact Workshop Day, bringing together professionals from across the sulphur value chain for a full day of learning, collaboration, and technical exchange. Attendees had the opportunity to explore real-world challenges, cutting-edge technologies, and practical solutions across three concurrent workshops and several open forum sessions.

Workshop 1 – Steam and heating considerations in sulphur plants

Led by CSI Ametek, this deep-dive technical workshop focused on the fundamentals and field applications of steam heating systems in sulphur plants. From steam tracing to condensate return, participants gained valuable insights into system design, thermal requirements for different process streams, and lessons learned from operational upsets. Instructors shared practical examples – complete with "war stories" – that highlighted the importance of good design and proactive maintenance in avoiding corrosion, cold spots, and run-down plugging.

PHOTO: CRU

The MEScon annual operations roundtable brought together a panel of global experts to address pressing issues across the sour gas value chain.

Workshop 2 – Navigating sulphur recovery challenges

Sulphur Experts led an engaging, choose-your-own-adventure format where the audience selected the day's focus topics, including emissions, corrosion, plugging, and safety incidents. Real case studies sparked candid discussions, and participants were encouraged to contribute their own experiences and photos, making for an interactive and memorable session. The collaborative atmosphere fostered peer learning and helped equip attendees with practical takeaways to improve plant reliability.

Workshop 3 – Middle East Sulphur Summit

This focused workshop offered a comprehensive overview of sulphur forming technologies and handling best practices. Presentations from Enersul, IPCO, Samref, ASRL, and DuBois Chemicals highlighted granulation, pastillation, wet prilling, product quality control, remelting, dust mitigation, and acid control. The discussion-driven format ensured attendees left with a clearer understanding of emerging technologies and real-world implementation strategies.

MESconnect

At midday, MESconnect participants came together for their first in-person mentor–mentee meet-up, offering a valuable opportunity to break the ice and spark meaningful conversations that carried on throughout the week. Distinctive ribbons were distributed to help identify mentors and mentees during the event, along with MESconnect BINGO cards designed to encourage interaction through fun, goal-oriented prompts. Brief anecdotal spotlights featuring mentor–mentee stories were shared on stage throughout the conference.

MEScon annual operations roundtable

One of the long-time highlights of the conference, the operations roundtable, brought together a panel of global experts to address pressing issues across the sour gas value chain. From gas treating and sour water stripping, to sulphur recovery, tail gas treating and sulphur handling challenges, the session facilitated the sharing of operational hot topics for discussion amongst the audience.

Technical showcases

The afternoon concluded with a fast-paced series of 15-minute technical showcases, chaired by Ganank Srivastava of BR&E. Rapid-fire talks featuring breakthrough developments in gas treating, mass transfer modelling, decarbonisation strategies, SO_2 control, and incinerator performance were presented.

highlighting the importance of the region to the future of sulphur.

The morning continued with an insightful State of the Industry session, where CRU's Dr Peter Harrisson provided a global sulphur market overview. Presentations followed on China's emerging demand trends (Unilink), sulphur use in Indonesia's growing nickel and HPAL sectors (Neo Energy), and advances in sulphur science and technology from Khalifa University and other sulphur innovators, including Element 16, Sultech and Wilson International. The session highlighted new avenues for sulphur deployment in fertilizers, and energy storage – underscoring its important role in the global economy.

Angie Slavens took to the stage to introduce the conference objectives.

MEScon 2025 – Day 1

MEScon 2025 officially opened its main conference with a compelling program that celebrated sulphur's legacy while charting a bold course toward its future.

The day began with the opening ceremony, where ADNOC executives reaffirmed the UAE's pivotal role in the global sulphur landscape. Adel Al Jaberi (SVP, ADNOC Sour Gas) welcomed attendees, followed by a keynote address from Musabbeh Al Kaabi (CEO, ADNOC Upstream), who reflected on the region's evolution from sulphur producer to innovation pioneer. A video was shown, which showcased the history and growth of MEScon over the past 11 years. MEScon co-founder, Angie Slavens of UniverSUL Consulting, then took the stage to frame the conference's objectives and the spirit behind this year's theme. During her talk, Angie asked the audience to share their thoughts on the conference theme with respect to the sulphur industry which resulted in feedback

Smart sulphur: Digitalisation and AI in action

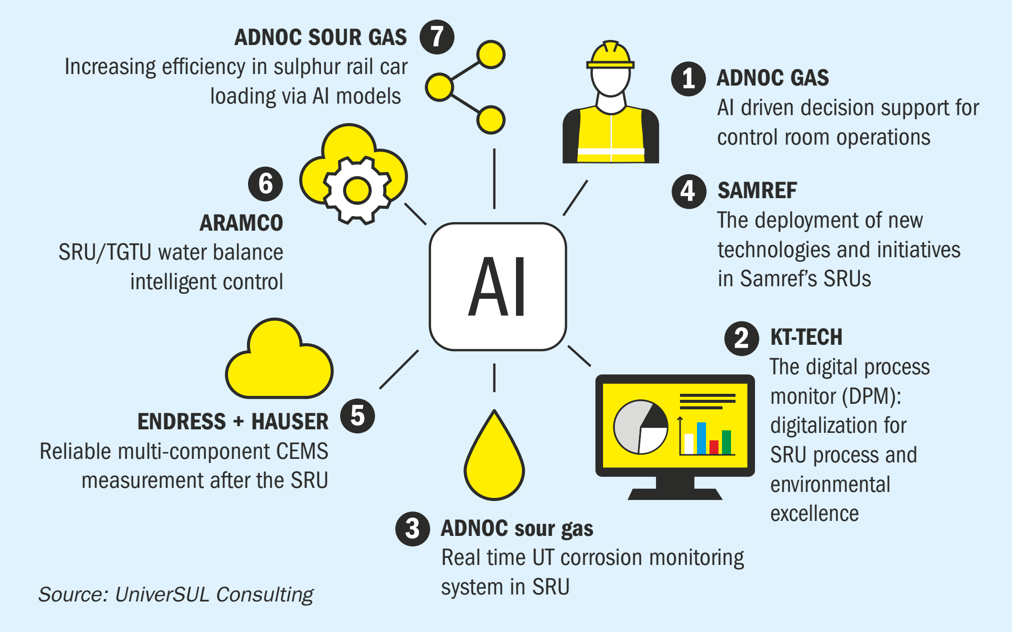
The afternoon session showcased how digital tools and AI are transforming plant performance, safety, and emissions monitoring. From real-time corrosion tracking and intelligent water balance control to AI-enhanced SRU loading and PLC upgrades, speakers from ADNOC, KT-Tech, Samref, Aramco, and others offered a look at the next frontier of operational excellence (see Fig. 1). The session concluded with an engaging panel discussion and interactive quiz to reinforce key takeaways.

MEScon 2025 – Day 2

Day 2 of MEScon 2025 continued the conference's momentum with a dynamic program focused on sustainability, innovation, and operational excellence across the sulphur value chain. With strong engagement from operating companies and technology leaders, the day highlighted practical strategies for driving efficiency, reducing emissions, and optimising performance, solidifying MEScon's position as the global hub for sulphur industry collaboration.

The day began with a session titled "Going green in a yellow world." Alya Al Ali (ADNOC Sour Gas) framed the session's objectives around sulphur's evolving role in the energy transition and circular economy. Presentations explored innovative H_2S recycling (Fluor), sustainability advancements in ultra-sour operations (ADNOC Sour Gas),

Fig. 1: **Smart sulphur session on Day 1**



Source: UniverSUL Consulting

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decarbonisation pathways for natural gas (ADNOC Gas), and SRU optimisation strategies (Worley, NMDC, Aramco). The session concluded with a lively panel discussion, reinforcing the industry's collective push toward greener operations.

Poster spotlights

Poster spotlights took place on Day 2 and Day 3 of the conference, complementing the conference's technical themes. The poster sessions provided a platform for emerging research and operational case studies, as well as offering delegates the opportunity to engage directly with presenters and dive deeper into technical innovations beyond the main sessions.

Sweet solutions for sour gas

The afternoon featured the "Sweet solutions for sour gas" session, highlighting advances in sour gas production and treating. Presenters from ASRL, ADNOC Offshore, ExxonMobil, BASF, BR&E, Wood, and ADNOC Gas tackled challenges such as sulphur deposition in gas production systems, regenerable sulphur solvents, SRU integration with upstream units, and leveraging digital tools to enhance plant performance. Edward Vera Douglas from Aramco chaired the session and provided thoughtful questions and insights throughout the afternoon.

MESconnect insights

In the morning, Angie Slavens of UniverSUL Consulting and Elmo Nasato of Nasato Consulting took the stage to share insights they've been offering to their mentees throughout the event. Elmo encouraged attendees to embrace lifelong learning, while Angie emphasised the value of stepping outside one's comfort zone to foster growth. Kicking off the afternoon session, Alyaziya Abdulla Alkaabi of ADNOC Sour Gas reflected on her meaningful conversations with mentors and professionals, and her contributions to the MESconnect wall.

PHOTO: CRU

ADNOC showcased their latest innovations at the MEScon exhibition.

PHOTO: CRU

The MESconnect wall, where participants shared their visions for the sulphur industry over the next decade.

PHOTO: CRU

Mohammed Al Blooshi moderated the poster spotlight on Day 3.

MEScon 2025 – Day 3

MEScon 2025 concluded with a powerful finale that brought sulphur recovery, tail gas treating, and forming & handling technologies into sharp focus. As the industry looks toward a future shaped by reliability, environmental stewardship, and innovation, Day 3 delivered practical insights and technical depth to cap off a highly impactful week.

The day opened with remarks from Ali Al Hendi (ADNOC Gas) on behalf of the MEScon Technical Committee, followed by session framing from Rob Marriott (ASRL). The morning's technical block featured field-tested lessons from commissioning, start-up, and optimisation efforts at major facilities including Aramco Jazan and Petronas Melaka. Experts from Ametek, CSI Ametek, NCL, and Axens provided insights into gas-phase chemistry, sealing technologies, and novel catalyst ideas in tail gas treating units.

A key highlight was the session's panel discussion, which invited open dialogue between presenters and the audience – reinforcing MEScon's mission to create a collaborative space for peer exchange in the world's largest sulphur-producing region.

Shaping sulphur: Forming and handling

In the afternoon, the focus shifted to solid sulphur logistics with a session led by Sultan Alshamsi (ADNOC Gas). Aramco, IPCO, and ADNOC Sour Gas shared strategies to enhance reliability and performance in sulphur solidification. The session covered why and how to solidify sulphur, best practices in sulphur handling, and emerging dust and spill control solutions. Samref and DuBois Chemicals presented a compelling case study on overcoming persistent dust challenges, while ADNOC Gas rounded out the session with insights on advanced mitigation strategies.

MEScon continues to be a place where global collaboration, regional leadership, and technical excellence converge to shape the future of the sulphur industry.

Advances in sulphur dust suppression and acidity control

Although elemental sulphur is relatively non-toxic, it presents significant risks when stored or transported. **Jeff Cooke** of DuBois Chemicals Canada highlights advancements in both dust suppression and acidity control, including the development of novel agents designed specifically for use with elemental sulphur.

Globally, there is a growing emphasis on minimising the environmental and occupational impacts of industrial activities. Regulatory bodies are tightening restrictions, and heightened public scrutiny – fuelled by rapid information dissemination via social media – has placed additional pressure on companies to adopt safer, more environmentally conscious practices. This is particularly true in the energy sector, where elemental sulphur – produced as a by-product of sulphur removal from oil and gas – is handled in large quantities during storage and transportation.

Although elemental sulphur is relatively non-toxic, it presents significant risks when stored or transported in prill, pastille, lump, or crushed forms. Fires and explosions can be triggered by static electricity, embers, or sparks. Moreover, the handling of solid sulphur frequently leads to the generation of fine dust particles. Without appropriate dust control methods, this dust becomes not only a product loss and air quality issue but also a severe fire and explosion hazard.

Sulphur dust accumulates during material transfer, particularly through harsh handling or areas with turbulent airflow. Fine particles become airborne or settle on infrastructure surfaces – especially indoors – where they can be disturbed and dispersed, potentially exceeding the lower explosive limit of 35 g/m^3. Compounding this risk, sulphur oxidising bacteria can colonise sulphur surfaces in humid environments (such as coastal terminals), metabolising sulphur and excreting sulphuric acid. This acid can corrode metals and damage infrastructure if not properly controlled. Acidic sulphur is often deemed of lower quality and value.

To mitigate these risks, sulphur handlers typically apply dust control agents, implement acidity control measures, and follow disciplined maintenance protocols. Traditionally, these dust suppressants and acidity control agents are delivered via water-based sprays.

Advances in sulphur dust suppression

To be effective, dust suppressants must rapidly wet the entire surface immediately after application by spray. Application locations should be where all sides of the sulphur can be easily reached, such as during transfer at conveyor headboxes and/or chutes. The goal is to bind fine particles before they can become airborne. Agglomeration helps prevent dusting, while adhesive properties enable fines to adhere to larger particles. Rapid wetting also limits release of fine particles generated through mechanical attrition.

Since sulphur is inherently hydrophobic, traditional water-only sprays are often ineffective. An optimised dust suppressant should possess low surface tension, be capable of rewetting, and offer a degree of lubricity – just enough to reduce attrition without compromising material flow or pile stability.

Designing a dust control system requires understanding the dust generation mechanism, the variables influencing it, and the limitations of the dust control method itself. Effective systems address both prevention (eliminating dust formation) and collection/elimination (removing already airborne dust).

Collection/elimination measures

Dust collection or elimination strategies function by reacting to dust that has already become airborne. These include water curtains, fogging systems, and mechanical air filtration units such as baghouses and cartridge filters. While effective under tightly controlled conditions (such hoppers), these systems come with notable limitations that reduce their practicality in many sulphur handling operations.

Wind and environmental sensitivity

Water curtains and fogging systems are highly susceptible to wind and air currents. In open or semi-open environments such as domes, transfer towers, or loading facilities, crosswinds can easily displace fine mist or fog, rendering the system ineffective at targeting dust-laden air streams. As a result, dust often bypasses the intended capture zone entirely.

Lack of persistence

Unlike chemical dust suppressants that bind to the sulphur and provide ongoing dust control throughout the material's handling lifecycle, physical collection methods only operate at the moment and location of application. They offer no residual protection. Once airborne dust is missed by a fog or curtain, or once the treated air moves beyond a filtration zone, control is lost. This makes these systems reactive rather than preventative.

Complex air management requirements

Air filtration systems require careful control of airflow patterns to capture dust effectively. Ducting must be installed to direct ambient air to centralised collection units, and high-powered blowers must overcome system resistance. These setups are often impractical in outdoor facilities or where operations are spread out or frequently reconfigured.

High operating and capital costs

Filtration systems demand significant energy inputs, especially for large-scale air handling. Fan motors, filter changes, and maintenance all contribute to operating costs. Additionally, the capital investment required to design and install ducting, access platforms, and collection housings can be substantial, particularly if retrofitting is involved.

Seasonal and climate constraints

In colder climates, water-based fog and mist systems are limited by freezing conditions. Even when antifreeze additives are used, nozzles and pipes are prone to clogging, and ice formation on the treated surfaces can pose operational hazards.

Intermittent efficiency and overspray risk

The efficacy of knockdown systems depends on achieving and maintaining a fine balance between droplet size, density, and distribution. Oversized droplets can saturate sulphur or equipment, causing product handling problems, while undersized droplets may evaporate before capturing dust. Overspray can also result in excessive moisture on surrounding walkways and structures, creating slip hazards or unintended corrosion.

For all these reasons, while collection/elimination measures may play a supporting role in a broader control strategy, they are best suited to enclosed, engineered environments with stable airflow and controlled climate. As standalone solutions, they lack the reliability and persistence of direct chemical applications, which remain the most robust means of preventing sulphur dust emissions and their associated hazards.

PHOTO: DUBOIS CHEMICALS

Fig. 1: Water sitting on the surface of hydrophobic powdered sulphur.

Preventative measures

Liquid-applied suppressants remain the most efficient method for sulphur operations. Applied directly to the material via engineered spray systems, they promote:

- agglomeration of existing fines or adhesion to larger particles;
- reduction in generation of new fines;
- prevention of escape of dust during processing.

To address the performance needs of dust prevention applications, DuBois Chemicals has developed Dustbind 1888C, a sulphur-specific concentrated formulation which builds on the success of our benchmark product, Dustbind S5.

Dustbind 1888C can be effective in doses as low as 1-3 ppm (grams per tonne sulphur) and is applied in diluted form in ratios up to 1:1000 Dustbind:water depending on the requirements of the operation.

Entirely flexible, this product can be applied as a traditional hydraulic spray, a coarse, penetrating foam (through air induction), or a creamy foam (with an external compressor). The recommended application method of application is using a hydraulic, foamless spray or a coarse penetrating foam.

The fundamental basis of the performance of Dustbind 1888C, and all other DuBois Dustbind products, is their inherent ability to immediately wet and penetrate the substrate bulk, coating the surface and preventing the small particles from escaping. Water is often used as a dust control agent on sulphur and other hydrophobic materials with little success. In Fig. 1, water can be seen sitting on the surface of powdered sulphur, without the slightest wetting or penetration, similar to water on wax. Clearly water alone is not sufficient to control dust on sulphur.

An example of the efficiency of Dustbind dust control agents can be seen in the before/after pair of photos in Fig. 2. The first photo is sulphur treated with water being stacked in an indoor storage area. There is clearly significant dust generation occurring. Once the sulphur was treated with the Dustbind agent, there was essentially zero dust generated from even the aggressive stacking operation shown.

Acidity control in elemental sulphur

In addition to dust, elemental sulphur piles are vulnerable to acid generation caused by sulphur-oxidising bacteria (SOB), especially in warm, moist storage environments. These bacteria metabolise sulphur into sulphuric acid, which can damage concrete pads, steel reinforcements, storage buildings, and conveyance equipment.

Acidity control agents have been developed and formulated to inhibit bacterial colonisation and thus prevent acid generation. Not normally pH neutralisation agents, these products prevent the acid problem before it starts. Typically applied through the same spray infrastructure used for dust suppression, these treatments provide a persistent action, resisting leaching and offering ongoing protection.

Fig. 2: Dust control before (left) and after (right) the use of Dustbind dust control agents.

PHOTO: DUBOIS CHEMICALS

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48

The ideal acidity control agent must:

- be chemically compatible with sulphur and dust suppressant formulations;
- resist leaching during rain events;
- provide a residual barrier to bacterial colonisation;
- maintain efficacy in both tropical and temperate environments.

The integration of acidity control agents into existing dust suppression programs offers a streamlined and cost-effective approach to managing both physical and chemical degradation in elemental sulphur storage and transport.

Traditional SLS-based products and their limitations

Historically, sodium lauryl sulphate (SLS) has been widely used in elemental sulphur treatment. While SLS-based products offer good acidity control functionality, they suffer from several key limitations:

- limited durability in wet conditions;
- high foaming tendency, complicating equipment operation and material handling;
- potential to nourish sulphur-oxidising bacteria rather than suppress them;
- corrosive byproducts in moist, warm environments leading to infrastructure damage;
- environmental concerns regarding aquatic toxicity and regulatory compliance;
- relatively high cost.
- These drawbacks have led to the development of next-generation agents offering improved longevity, environmental compatibility, and microbial resistance.

Neutrasul – A new generation acidity control agent

DuBois Chemicals has recently introduced a next-generation acidity control agent, branded as Neutrasul, representing a significant advancement in the treatment of elemental sulphur. Designed to overcome the limitations of traditional SLS-based products, Neutrasul provides a robust, adaptable platform for managing acid formation in sulphur storage and transport environments.

Neutrasul is notable for its ability to be tailored to meet specific operational needs, providing flexibility and performance across a wide variety of use cases. The product is available in a portfolio of formulations, each optimised to balance key properties:

Temperature range: Can be handled, stored, and applied at temperatures as low as –20°C or lower, making it suitable for cold climate applications where the sulphur will eventually warm.

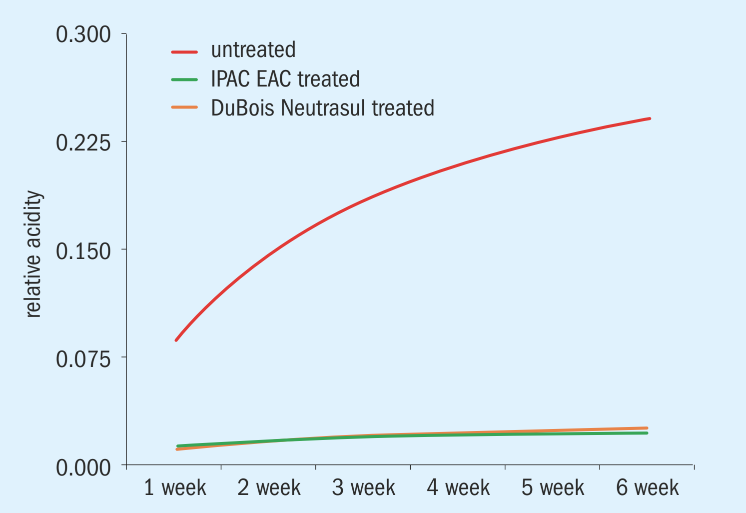
Health and safety: Can be formulated to be entirely non-hazardous, enhancing worker and environmental safety.

Cost efficiency: Neutrasul can be applied at a significantly lower cost than traditional formulated SLS products.

Handling and storage: Unlike many SLS-based agents, Neutrasul exhibits excellent stability in storage with no phase separation, simplifying logistics and inventory control.

These combined advantages make Neutrasul a compelling choice for sulphur handlers seeking an advanced, cost-effective, and safe solution to long-standing acidity control challenges. When incorporated into an integrated dust and acidity management program, Neutrasul can enhance equipment life, reduce maintenance, and ensure regulatory compliance even in demanding environments.

Fig. 3: Performance of Neutrasul and IPAC EAC on elemental sulphur



Source: Dubois Chemicals

Neutrasul has been tested extensively by DuBois, with testing verified by Alberta Sulphur Research Laboratories. The chart in Fig. 3 shows virtually identical performance between DuBois Neutrasul and IPAC EAC on elemental sulphur over a period of six weeks.

In summary, through the judicious use of properly applied chemical agents, both sulphur dust and acidity issues can be easily remedied. Proper design, installation and service will ensure trouble-free operation of your sulphur handling systems.

Improving operations and monitoring in the acid industry

PHOTO: SHUTTERSTOCK.COM/PANUWAT PHIMPHA

Metso is using a digital process twin as the core component of its digital solutions for sulphuric acid plants, which are currently under contract execution. In this article, Metso describes how digital solutions can profit from the deep integration of a digital process twin in the sulphuric acid technology, helping to improve operation, monitoring and reporting in the acid industry.

Steffen Haus, Collin Bartlett, Sagar Bhatta, Santhosh Sobhanakumari, Jochen Grünig, (Metso).

Many process design steps in modern manufacturing rely on the extensive use of process simulation models. Over the past decade, Metso has developed a suite of solutions for digitalisation in the value chain of sulphuric acid production[1,2]. Examples of significance include the Wet ESP Optimizer and the High Efficiency Scrubber Optimizer to support monitoring and control of metallurgical gas cleaning plants; and Sulphuric Acid Digital Solutions[3]. These digital solutions utilise a wide variety of methodologies, such as logic based algorithms, process modelling, KPI monitoring, etc.

However, a key component in the digital solutions for sulphuric acid plants is a high-fidelity process simulation, the so-called digital process twin. To understand the importance of a digital process twin, one must understand that the utilisation of process simulation models has evolved significantly in recent years.

Earlier, the focus was to use simulations predominantly to calculate the heat and mass balance of a process. Nowadays, simulation models or digital process twins are used for additional purposes that embrace process design, engineering related topics as well as pre-design of equipment, dimensioning, etc.

Closing the feedback loop between the digital process twin within the digital solution and operational data allows for progress and advancement on simulation accuracy and reliability or trustworthiness. This is an opportunity for an entire industry and can result in a win-win situation between plant designers and operating companies.

Thus, a traditional simulation model is converging towards a digital process twin. These process twins are now finding their way into digital solution offerings, which affect the daily process plant operation. The technology will provide an opportunity to improve operations, to monitor equipment or entire process sections, and to provide neutral and fact-based reporting to plant operations and management.

Metso is currently using such a digital process twin as the core component of the digital solutions for sulphuric acid plants, which are currently under contract execution. In this article, three key topics of the digital process twin will be discussed in more detail, namely:

- **Digital process twin concept** – how Metso's simulations are integrated into its digital solutions, a commercial offering for on-site use by the plant operating company.
- **Data historian/data lake integration** – enriched data is retrieved by using the digital process twin. This enriched data can be utilised to provide additional information content into an on-site data historian.
- **Reporting** – enriched data can be utilised for enhanced reporting, e.g., including longer-term trending and monitoring of information, which is not normally available, but which can be retrieved by a digital process twin.

Digital process twin concept

Metso has developed proprietary process unit models for all relevant key process equipment of the sulphuric acid plant. These unit models are used within full plant simulations. Fig. 1 details the integration of proprietary process unit models into a full plant simulation.

These process unit models have been validated against real-world operating plants and provide the required accuracy for reliable process design. Furthermore, the unitary models already have inbuilt relevant equipment design features. For example, early dimensioning of the equipment can be realised and allow full flowsheet simulation based on equipment design decisions. High-fidelity and validated unitary models can therefore be combined very efficiently into a full process simulation. Changes of dimensioning or other design decisions to a certain process unit will immediately become visible within the full process flowsheet calculation.

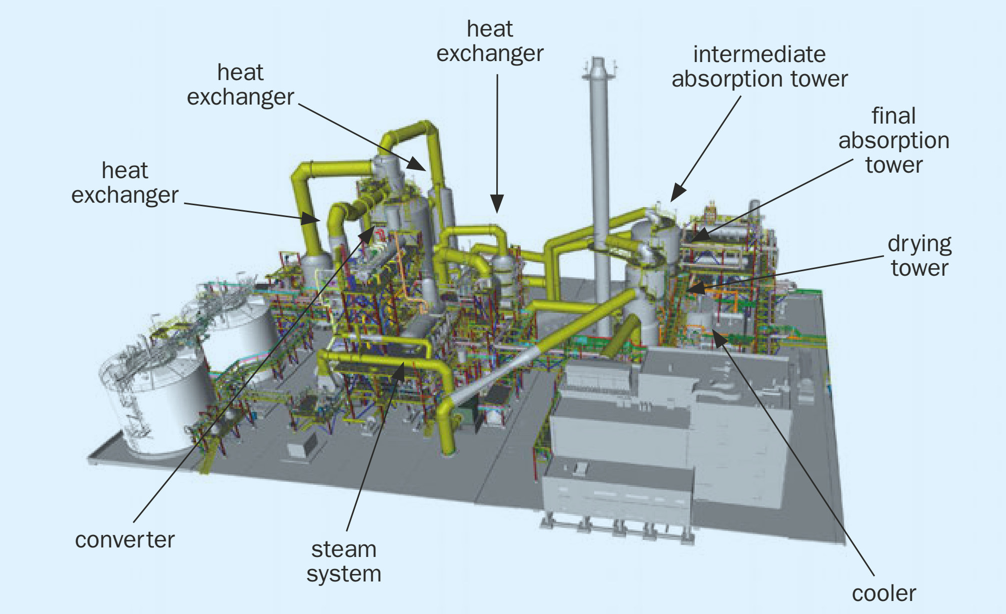
It is worth noting that the full digital process twin capabilities of the unit model integration into one platform has the advantage that process upgrades and modifications can be investigated or designed very efficiently. An example is the development of the LUREC-S process, shown in Fig. 2[4]. Process engineers can rely on validated process unit models of key process equipment and can simulate the effect of a process adaptation or modification very quickly and effectively.

Compared to the "good old days", when a simulation merely had the target to calculate the heat and mass balance for a certain condition, e.g., design plant load, the consequent and decisive utilisation of the digital process twin comes with a few beneficial changes in the plant design flow. One should not consider a process simulation as the main goal of process modelling, rather the thinking should adopt to a sequence of "concept to design to production".

Furthermore, a feedback loop of operational data and information into the digital process twin can also be envisaged in the very near future or is already in implementation. It is well understood that in the process industry, a fully operational feedback loop is still very challenging, however a more digitalised industrial environment will truly open opportunities for optimised feedback loops. With such digital developments, achievement of a win-win scenario between plant designers and operating companies is a significant step closer.

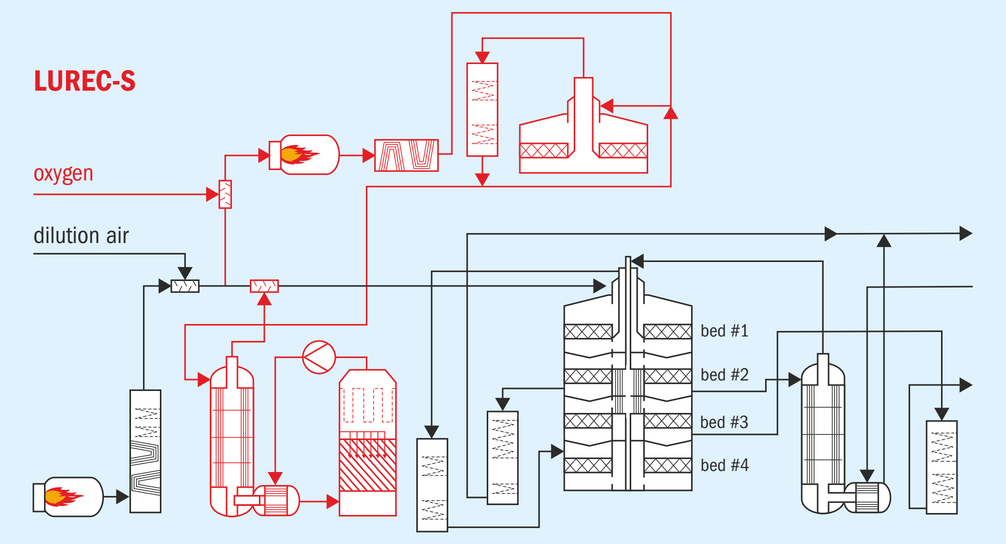
The digital process twin concept within a platform will thus allow for adjusted thinking in the plant design process. The step sequence concept of design to production, plus feedback loop, will increase the design efficiency and will mitigate the risk for design errors.

Fig. 1: **Proprietary process unit models for all relevant key process equipment are available for integration into a full plant simulation**



Source: Metso

Fig. 2: **Digital process twin - an advantage in calculation of process modifications. Example: LUREC-S**



Source: Metso

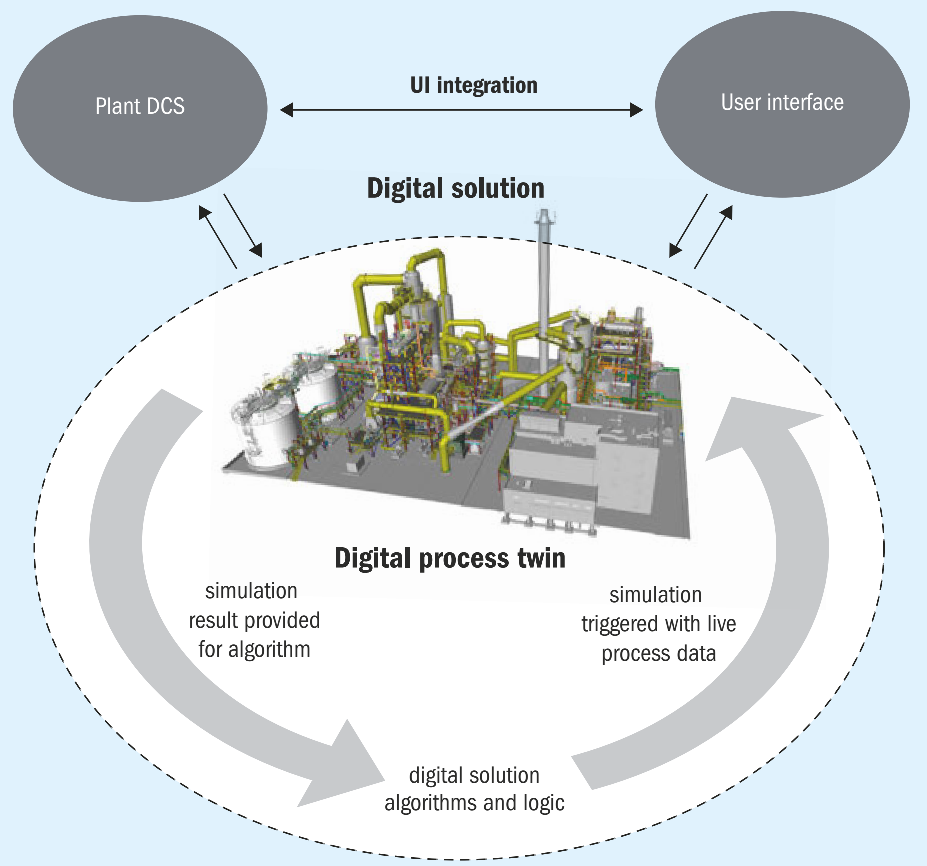
Digital process twin integration into Metso digital solutions

The digital process twin is also beneficial for Metso's digital solutions. Within this use case, the process twin is running calculations with live plant data, measured via traditionally installed field instrumentation. This can be done either for the full plant model, for a single piece of equipment, or for specific sections of the process plant, and is dependent on the use-case. One simple example is the monitoring of a heat exchanger, where an ideal instrumentation configuration consists of all instruments required to calculate the enthalpy at inlet and outlet and at both the cold and hot side. Typically, such an instrument configuration is not available. Thus, the digital process twin can be used to estimate missing information.

In such cases, the digital process twin is integrated into and utilised as an integral part of the Metso digital solution. Dependent on the plant instrumentation, Metso process engineers identify the required configuration of the simulation models, meaning that the simulation is set up in such a way that available instrumentation is utilised, so that the combination of plant instrumentation and plant process model provides a reliable and comprehensive overall understanding of the live plant operation. Non-measured data becomes available via the digital process twin and can be used for process optimisation or assessment of health-status of the equipment.

A good example of this relates to heat exchanger monitoring, involving the integration of a parameter for fouling in the unit model equations. The monitoring of the unit therefore becomes independent of the plant load or process conditions since operational conditions are inherently integrated by using the digital process twin, and not only monitoring and evaluating certain individual plant instrumentation data. This is a huge advantage of having the digital process twin as an integral part of the digital solution. This saves the application designer from normalising operational data to make it comparable, since this step is handled by the digital process twin. High fidelity and validated process unit models, digital process twin, and live operational plant data are combined and utilised together to retrieve relevant and valuable process insights.

Fig. 3: Information flow from process equipment to digital solution and digital process twin



Source: Metso

The full information flow is shown in Fig. 3. The plant data is made available to the digital solution via its interface with the plant distributed control system (DCS). The algorithms in the digital solution can then query the digital process twin calculations with real-time measured plant data. The digital process twin calculation results are thus available for the algorithms and logic within the digital solution. The results are shared to the users via a specific user interface (UI). It is also possible to integrate parts of the UI directly into the DCS.

The information retrieved from the digital process twin via the digital solution algorithms can be numerous, and several examples are detailed below:

- non-measurable, but calculated process information, such as the earlier example of fouling effects in heat exchangers;
- longer term trends of certain process/ performance KPIs or equipment parameters, such as heat-transfer coefficients calculated by the digital process twin;
- the health status of equipment becomes available by combining digital process twin results with interpretation of these results within the monitoring algorithms.

As a result, enriched information is available, which is hidden in the data without a digital solution and the associated digital process twin, and this information is made available to operations personnel via specific digital solution screens. It is also possible to integrate such information into the plant DCS system and both options allow ad-hoc decision making in the control room considering this real-time information.

An on-site digital solution is a real opportunity to develop a functional feedback loop of operational data into the digital process twin. The on-site simulation results need to be checked for consistency, and together with the experience of running the digital process twin can loop back into the simulation and design modules, which form the core of the digital twin. This will result in more accurate and highly dependable unit model libraries for the relevant key process equipment of the sulphuric acid plant over time.

In addition to providing the data for ad-hoc local operational decision-making support, calculated and simulated information can be very valuable for longer-term analysis and optimisation purposes.

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48

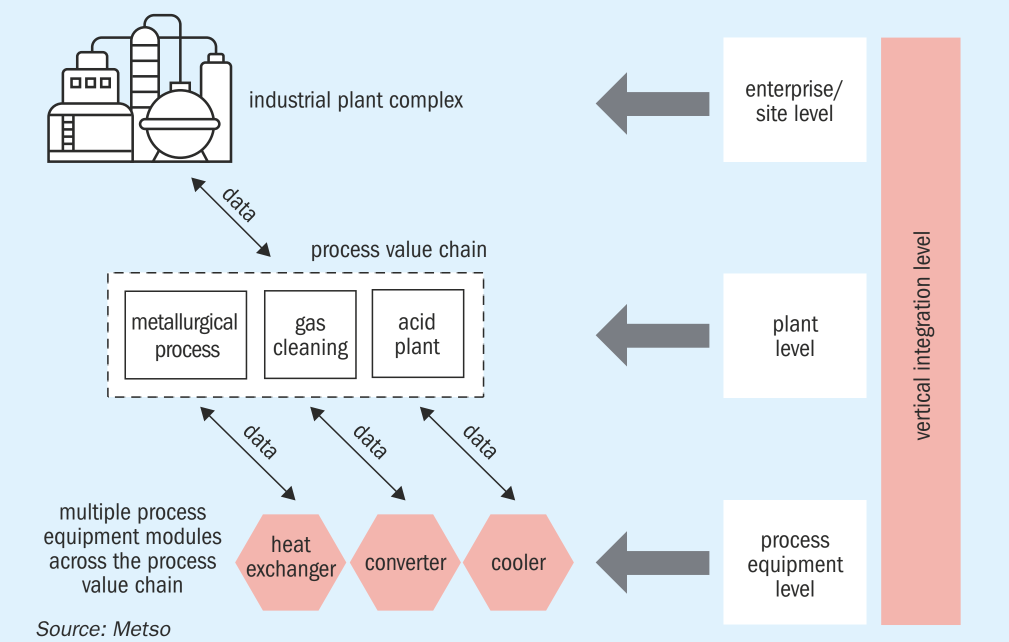
Data integration and longer term plant evaluation

While the previous chapter highlighted the use of ad-hoc information within the daily operation, another major impact of digitalisation in general, and a digital process twin in particular, is the benefit for longer term operational data evaluation. It is highly recommended that such enriched information from the digital process twin is integrated into a higher level data storage system – these systems are commonly referred to as a data historian, or more recently as a data lake. Typically, operating companies use data historian systems for storing production data and making the data available to various user groups. Integration of equipment-specific model calculation results have been discussed in significantly more detail elsewhere[3]. Therefore, this article shall review only the major aspects of data and information integration and what the longer term evaluation offers to the operating company.

The essence of the earlier publication is that a digital transformation within the process industry requires a collaborative effort amongst various stakeholders. A plant designer as a single player cannot provide all the necessary solutions on enterprise level. Vice versa, a provider of data-based solutions on the highest level, enterprise- or site-level, lacks the details on the equipment or the process plant level. At the equipment level, digital process twins or process simulations offer insights into the details of the process operation, which would remain hidden without digitalisation effort on a very detailed technical basis.

Data collected from equipment or a plant-level digital solution is integrated into a plant or enterprise-wide solution and the key factor is the sharing of data with higher level systems. These solutions collect and synchronise data of various kinds (for example, operational and maintenance data) and together with enriched data calculated by the digital process twin of the plant, a plant section, or an individual piece of equipment. These various layers of digital solutions make data accessible to various stakeholders of the operating plant. Such information can then be utilised, for example, for longer-term analysis of the plant or equipment performance over time, as well as its potential optimisation. The vertical integration of data from different detail levels is visualised in Fig. 4.

Fig. 4: **Recap of visualisation of different stakeholders within an enterprise-wide digitalisation approach[3]**



Source: Metso

Returning to the heat-exchanger example from earlier, such equipment shows efficiency degradation over a longer period in a sulphuric acid plant. Such degradation does not generally occur within days or weeks, rather within months or, more commonly, years. This means, the operating personnel typically have no visibility on the health status of the heat exchanger, if the equipment is operating within the limits of the plant control system warning/ alarm system. Very slow process effects, such as fouling of the heat exchanger, are more than likely remaining 'unrecorded'. That said, such health status information would be very valuable for on-site maintenance teams for better shutdown planning activities based on actual status, rather than empirical knowledge.

The physical and thermodynamic model of the equipment, in this case the heat exchanger, provides such information on a continuous basis via the digital process twin. It should be noted that a fouling coefficient will not be used on an ad-hoc analysis, rather the information will be trended and evaluated over a longer period to be able to visualise the degradation of the heat exchanger. Information is thus available to the operational or maintenance team via an interpretation of the longer-term behaviour, or via a threshold on a parameter calculated within the digital process twin.

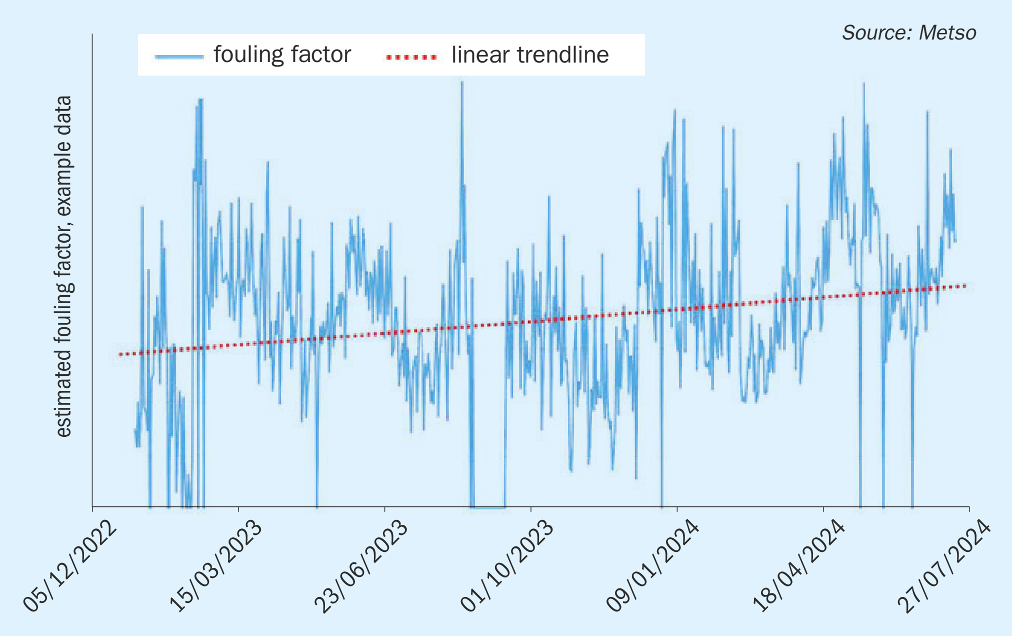
An example trend for a fouling development in a heat exchanger is visualised in Fig. 5, showing artificial but representative data. The fouling factor itself is calculated via the digital process twin. Nevertheless, a certain noise level within the calculated signal is expected in a real-world example, originating from the noise of the algorithm input data, such as temperatures, pressures, etc. It is worth mentioning, that any mismeasurement in the process can lead to noisy data when applying a simulation based digital process twin. Thus, a linear trendline is added to simplify the analysis. This trend can now be used for an easy interpretation of the digital process twin calculations for the respective operational and maintenance teams.

The heat exchanger is only a generic example within the gas cleaning and/or sulphuric acid plant configuration, but further digital solution use cases, which are based on the digital process twin calculations, are available and currently under implementation. In addition, mathematical optimisation algorithms are based on the results of the digital process twin simulation. In terms of information integration into the longer-term databases or data lake, basically all calculated information can be made available and stored for longer-term analysis. It should also be noted that the near-future machine learning algorithms are expected to benefit from such information that emanates from the digital process twin.

Closing of the feedback loop via on-site digital solution operation to the simulation basis within the digital process twin is very important. The longer term availability of information offers an opportunity for in-depth and very accurate model review

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48

Fig. 5: **Example of a long-term fouling trend (artificial data)**



and in so doing, the digital process twin will be inevitably improved over time. This will allow for a continuous improvement of the simulation accuracy and increase the predictability of process operational changes, or of the reliability of the monitoring algorithms. The operating company will ultimately profit from a more accurate digital process twin, if integrated into the on-site process operation.

Digital process twin solution in reporting

All data, directly measured or digital process twin enriched, can be utilised in reporting and many different reporting tools are available on the market. Most operating companies have their own reporting tools in operation, handling key operational KPIs, such as production rate or emission levels. These KPIs and the associated reporting are relatively easy to configure and will not require a digital process twin.

The addition of the digital process twin within the digital solution can be seen as a toolkit for further, in-depth process reporting. Insights, otherwise hidden, can therefore be added to existing reporting systems. To give a few examples, a process engineer could be interested in calculated information over a specific period, such as the conversion rates in the respective converter bed, or the aforementioned fouling factor in heat exchangers. The combination of the digital process twin with longer-term trending or reporting systems makes the data instantaneously available and there is no need for an on-site process engineer to perform time consuming manual modelling exercises.

The result of such a simulation model calculation is continuously available via the digital process twin and is stored in the respective database and therefore historically results from process calculations are available instantaneously. It is expected that such an approach can significantly reduce the time required to perform a detailed analysis of a certain event or a certain process plant behaviour. The digital process twin therefore ensures that the information basis for such an analysis is comprehensive for any required investigation.

With respect to reporting, many operating companies utilise periodical reporting to various stakeholders in the organisation and the configuration of such reports is today easily compiled and tailored to specific user group needs. For example, a high-level management report is more focussed on overall KPIs, such as production rate, plant availability, or emission KPIs, whereas operational teams are more interested in the process details, such as information that is calculated via the simulation model.

Conclusions

Metso has identified the digital process twin as a key component in the success of digital solutions for sulphuric acid plants and acknowledges that the role of legacy simulation models has evolved into the first-generation digital process twin of today. Although the digital process twin should not be considered as a stand-alone tool, it is a support tool for further benefits. In other words, apart from using high-fidelity simulation modules for the key process equipment during the plant design process, the digital process twin is the central element within a multitude of digital solutions.

Monitoring algorithms and optimisation solutions are based on the integrated digital process twin. As an example, heat exchanger monitoring can benefit from the digital twin since not all required instrument measurements are available. Missing information is therefore provided by the digital process twin, offering an opportunity to gain further process insights into the plant and equipment, which would otherwise remain unknown or inconclusive.

The calculated information is not only used directly within digital solution applications but also provided to higher level data historian or data-lake architectures. That means, the detail simulation on equipment level provides information, which can be ultimately valuable on the plant- or enterprise-wide reporting systems.

Finally, the opportunity to integrate deep process understanding, based on digital process twin calculations, into neutral reporting systems is expected to positively impact the plant operations in the longer term. Data analytics can be enhanced by having results from such calculations available. Combining process calculations, measured instrument data, and key operational KPIs into a user-specific reporting solution will maximise the understanding of operations and allow well-informed operating plant decision making to take place. ■

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Meeting growing demand for solidified sulphur

Varun Mathur is Market Manager for the Middle East region at industrial processing company IPCO, one of the world's largest suppliers of sulphur solidification systems. In this article, he highlights the reasons for converting sulphur into a solid form, and compares two of the technologies most commonly used to achieve this.

Sulphur is key to the success of products and processes used by a whole range of different industries, from agriculture, rubber and chemicals to food, pharmaceuticals, and personal care products.

In the agricultural sector, where it is often referred to as the fourth major nutrient (after nitrogen, phosphorus, and potassium), its use first boomed when sulphur was removed from fossil fuels and no longer fell onto fields from the atmosphere. Today, the need for sulphur-enriched fertilizers continues to grow.

PHOTO: IPCO

Processing of bulk solidified sulphur.

It is also an element that is produced in ever greater quantities due to stringent environmental regulations requiring reduced levels of sulphur in fuels (hence greater volumes being extracted) and growth in overall output.

Most of the elemental sulphur arriving on the market is recovered through desulphurisation of natural gas and oil using the Claus process. The result is molten sulphur, delivered at a temperature of 145–150°C and a form that presents a range of challenges in terms of storage, handling and transportation:

Temperature control: Molten sulphur remains in a liquid state within a narrow range (125–145°C) and any deviation will result in either solidification or increased viscosity. Maintaining this range requires heating systems and insulation, both of which contribute to capital and energy expenditures.

Fire and explosion hazards: The flash point of molten sulphur ranges from 168–188°C, while auto-ignition can occur at temperatures between 248–261°C. The flammability of sulphur, especially when combined with its potential to emit hydrogen sulphide (H_2S), creates serious fire and explosion risks.

Vapour control: H_2S is particularly dangerous due to its broad explosive limits (4.3–46%) and toxicity. Vapour control systems are essential, especially in storage tanks, to avoid dangerous accumulations.

Corrosion: Molten sulphur is inherently corrosive, necessitating specialised storage tanks made from stainless steel or high-performance alloys.

Electrostatic discharge: Molten sulphur can accumulate electrostatic charge during transfer, requiring rigorous grounding and bonding measures to prevent discharge-related accidents.

Dangers of SO_2: Sulphur fires release sulphur dioxide (SO_2), a highly toxic – sometimes lethal – respiratory irritant.

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Environmental and regulatory pressures: Handling molten sulphur will require compliance with multiple safety and environmental regulations, including but not limited to:

- IMDG (International Maritime Dangerous Goods)
- IATA (International Air Transport Association) Regulations
- OSHA (Occupational Safety and Health Administration) Standards
- EPA (Environmental Protection Agency) Guidelines

For these reasons and more, handling molten sulphur is generally only commercially viable when it is processed close to the refinery where it was extracted. But sulphur is now a global commodity, often shipped from continent to continent for processing, so usually needs to be converted into a form that is safe and practical to store, transport, and reprocess.

Solidifying sulphur reduces the risks of fire, H_2S vapour, and SO_2 emissions, eliminates the need for costly heated equipment, and enables it to be stored, traded and transported around the world by road, rail and ship. A premium quality solidified product also enables easy, accurate metering and dosing too, essential for downstream reprocessing.

Solidification isn't without its own costs and challenges of course. There's the initial capital investment of the solidification equipment, and the energy consumption of the process. The solidified product can release sulphur dust if incorrectly handled, and this must be mitigated.

And if the end application requires molten sulphur, then the cost of remelting must also be factored in. But overall there's no real argument: if sulphur is to be stored for any length of time, or transported over any significant distance, it needs to be solidified.

Premium quality forming

It was in order to establish standards for solidified sulphur – and its suitability for transportation (i.e. export) – that, in the late 1970s, SUDIC (Sulphur Development Institute of Canada) set about defining what has now become globally recognised as a 'premium' quality product.

In determining this quality, SUDIC looked at friability and fines content, both critical to efficient, clean and environmentally safe production and handing. The other major factor was moisture content; excess moisture not only adds weight, leading to unnecessary transportation and remelting costs, but also results in increased acidity, causing corrosion in conveyors, silos, trucks, rails cars and ship holds. A 'wetter' product is also more susceptible to freezing into lumps during cold weather, a significant factor in North America and Russia.

Together, these factors determine not only the quality of the formed sulphur but also the ease with which it can be handled and the potential impact on the environment during storage and transportation (formed sulphur can be handled as many as 15 times between solidification and subsequent reprocessing).

Sulphur solidification processes

There are three main methods of solidifying sulphur: wet prilling, indirect belt cooled pastillation, and drum granulation.

In the wet process, droplets of sulphur are sprayed down through a forming tank where they come into direct contact with a counter-current of cooling water. While dewatering screens are used to reduce the moisture content in the solid product, the resulting levels – typically up to 3% – are well in excess of the 0.5% moisture content defined under SUDIC 'premium' quality standards.

Both forms of dry processing deliver a product with a moisture content within the SUDIC standards.

Dry forming – or pastillation – offers a number of other advantages over prilling, notably predictable and constant bulk density and consistency of formed size: prill sizes will typically range from between 1-6 mm, sometimes bigger, whereas pastilles and granule sizes can be controlled by process parameters.

Dry formed sulphur also benefits from low friability and low fines content, leading to low dust emissions in the working environment, less risk to operator health and minimised risk of explosions.

Pastillation and granulation both deliver a SUDIC-quality product and each process has distinct advantages tailored to specific industrial needs. To compare them the following sections will look at two of IPCO's systems, the Rotoform pastillation process and the SG drum granulator.

Rotoform pastillation

This is the only indirect solidification system on the market and the world's most widely used sulphur pastillation process with more than 700 installations to date.

The Rotoform consists of a heated, cylindrical stator and a perforated rotating shell that turns concentrically around the stator, depositing sulphur drops across the whole operating width of a continuously running steel belt (Fig. 1). The circumferential speed of the Rotoform is synchronised with the speed of the belt, ensuring that drops are deposited accurately, consistently and without deformation.

The belt is cooled by water sprayed on the underside and the resulting heat transfer results in rapid solidification of the product. This indirect cooling method means there is no contact between the sulphur and the water and no risk of cross-contamination. The sulphur droplets are

Table 1: **Dry sulphur forming: pastillation versus drum granulation**

	Advantages	Disadvantages
Pastillation	● Very good size distribution of solid product ● No cleaning of exhaust air required ● Cooling water is recycled	● Several units are required in parallel to achieve higher capacities ● Release agent required
Drum granulation	● Very high capacity can be achieved with a single unit ● Very low friability of solid product	● Cooling water is a consumable ● Scrubber is needed to remove dust from exhaust air

Source: IPCO

Fig. 1: **Rotoform pastillation**

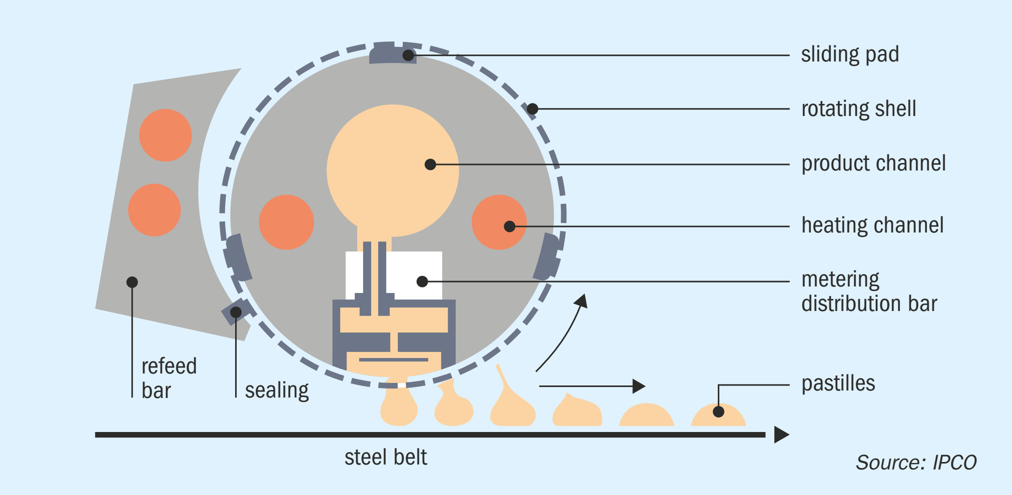
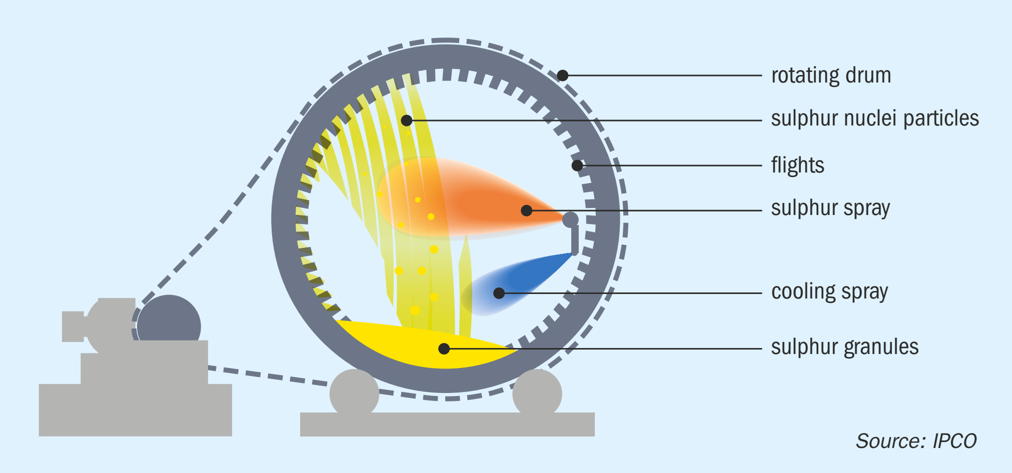


Fig. 2: **SG drum granulation**



then discharged as solid, hemispherical pastilles at the end of the cooling system.

This single step, liquid-to-solid process results in a high-purity, low-dust, and dimensionally consistent product, one classified as 'premium' as defined by SUDIC. Uniformity of shape and size makes them free-flowing for easy handling and precise dosing, while a predictable high bulk density is a major advantage in terms of storage and transportation.

In terms of capacity, IPCO's Rotoform S8 system enables throughputs of up to 5.5 t/h, and the Rotoform HS is a high speed model with a capacity of up to 11.5 t/h. Where greater capacity is required, multiple lines can be operated in parallel.

SG drum granulation

In contrast, drum granulation is a much higher capacity process, producing larger, coarse, round granules by rotating molten sulphur within a tumbling drum (Fig. 2). Particles grow in size as sulphur builds upon seed particles, creating bulkier outputs suitable for large-scale applications.

Solid sulphur seeds are generated externally from the drum by freezing sprays of liquid sulphur in a water bath at controlled pressures to form the desired size range. These particles are then conveyed into a rotating drum with appropriately placed flights attached to its inner surface. These flights create curtains of falling sulphur particles inside the drum while moving them towards the discharge end.

The sulphur particles are progressively enlarged to the required size by coating the curtains of particles with liquid sulphur using spray nozzles on a header running the length of the drum.

The temperature inside the drum is moderated by the evaporation of water from spray nozzles located inside the drum. The result is a high-quality, low dust granulated product that meets SUDIC standard product specifications.

Two models are available: the SG20 sulphur granulator, with a solidification capacity of up to 800 t/d, and the SG30, a unit capable of granulating 2,000 t/d, the highest capacity solution available to the sulphur processing industry.

Choosing the most appropriate technology

So which one to choose? Both technologies have their advantages and disadvantages as shown in Table 1:

Capacity considerations aside, the answer will very often depend on how and where the solidified product will be used. Pastilles are small, smooth, uniform, and hemispherical in shape, whereas granules are spherical, large, and coarse. These qualities make the former better suited to precision dosing, while the later are ideal for large-scale applications,

In agriculture for instance, one of the largest markets for formed sulphur, the accurate distribution and fast nutrient release of sulphur bentonite pastilles make them best suited to smaller-scale farming, whereas granules are ideal for gradual nutrient release in broad-acre agriculture.

Other typical applications for premium quality pastilles include the rubber industry, ensuring consistency in vulcanisation processes, and chemical manufacturing, where the purity of the end product supports stable and consistent production of sulphuric acid. Pastilles are also ideal for use as preservatives and antioxidants in the food industry, where they are preferred for their low dust and high uniformity, and for pharmaceutical products requiring safe, reliable, and high purity sulphur inputs.

Granules are also widely used for the production of sulphuric acid, typically in bulk, mass-scale operations where cost is a key consideration. Other applications include metallurgy, where sulphur is used in bulk for large-scale ore processing and metal extraction, and in construction, incorporated in sulphur concrete for acid and salt resistance. Sulphur granules are also used on a wide scale in soil pH correction for environmental reasons.

Conclusion

The transformation of sulphur from a difficult-to-manage molten substance into a safe, reliable solid form is a necessity in today's industrial ecosystem. As global demand for sulphur grows – driven by the needs of agriculture, energy, chemicals, and healthcare – solidification offers a robust solution to these challenges, whether through high-precision pastilles or bulk-ready granules.

Safety in design of sulphur forming and handling

David Savage of Matrix PDM Engineering discusses the importance of management and control of sulphur dust during the forming and handling of sulphur throughout the entire solid sulphur lifecycle while maintaining commercially acceptable product that contains less than 2.0% overall moisture.

PHOTO: MATRIX

Sulphur forming with outdoor storage and handling, Calsulco, Long Beach, California.

Dust control of formed sulphur during forming and handling continues to be a major safety issue that must be addressed during the technology selection and design process. Sulphur dust when airborne can be harmful to personnel as a skin, eye, and lung irritant and is considered by most local environmental authorities as a violation if the dust is allowed reach the local waterways and ports. Another major issue that is often overlooked is the need for proper forming and handling of sulphur throughout the solid handling process to minimise the risk of a dust explosion resulting in an extremely long downtime and large financial losses. Proper moisture and/or dust suppression significantly reduces sulphur dust becoming airborne while still maintaining the proper amount of moisture (< 2%) on the solid sulphur product to meet "premium grade" product requirements as defined by the National Standard of the People's Republic of China (GB/T 2449-2006).

> **Safety during the initial design and front-end feasibility is the lowest cost and can have the greatest impact on the facility.**

Safety in Design (SiD) refers to the integration of hazard identification and risk assessment early in the design process to eliminate or minimise risks throughout the lifecycle of a project. It emphasises the significance of incorporating safety measures from the initial stages of design to prevent accidents, reduce costs, and ensure compliance with legal standards. In addition, it considers the safety of substances, materials, products and processes for human health and the environment as much as possible in the design phase.

Safety is often considered as a condition where employees and operators are working and undertaking tasks that do not result in an injury. Safety of employees is most important and should always be considered first; however, safety of the equipment to minimise the potential for equipment failure, accidents, and environmental impacts that result in a loss of operational availability and facility production are also critical. This article provides insight into Matrix PDM Engineering's approach to ensure safe operation of the facilities and the importance of operations personnel and equipment design.

Matrix corporate core values include "Safety" and support its full commitment for safety from the initial design of the facility and supporting equipment and extends to the construction and ends with the client personnel and operations. The safety hierarchy is a simplistic and obvious concept that says that the manufacturer should first try to eliminate the hazard through design. Then, if it cannot, it can implement the necessary safeguards to minimise the risk of such hazards or, as a last resort, provide warnings to the end-user.

How do we take "Safety in Design" to the next level? We work within an industry that is inherently risky and has many areas that impose risks to personnel and equipment safety. It is impossible to eliminate all risks; however, that does not mean we should accept the risks without evaluating and reducing the potentials (Fig 1).

During hazardous operations assessments, it is the responsibility of the HAZOP team to identify the areas and issues that need to be addressed. Once the probability and severity have been evaluated, it is up to the project to reduce anything that is considered “very high” or “high” however, the equipment suppliers and project teams should always consider areas that have been indicated as “medium” to continue to drive the design to as “low” risk as possible.

Safety during the initial design and front-end feasibility is the lowest cost and can have the greatest impact on the facility. The best way to provide the greatest impact to the overall design is for engineering and designers to “think outside the box”. The questions that should constantly be asked during the initial engineering phase are:

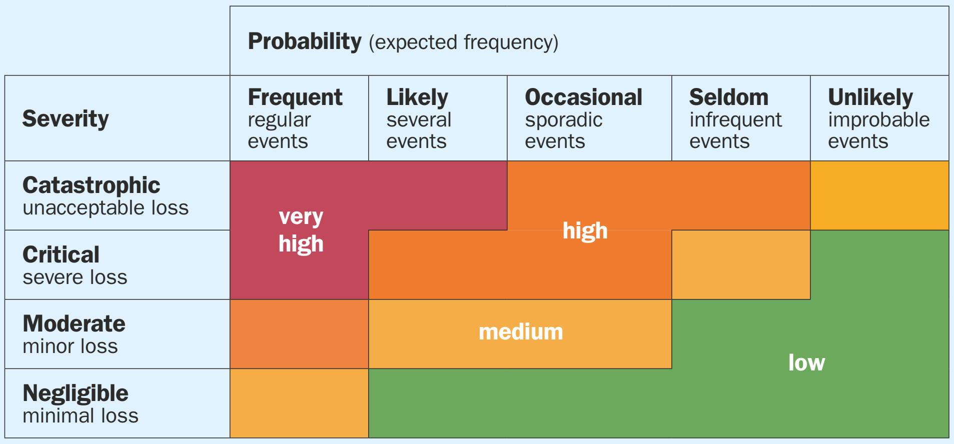
- Can we design prefabricated components to simplify site assembly and future disassembly?
- How can we reduce the need for onsite construction work to be performed at height?
- By using trenchless technologies, can we reduce the need for excavation?
- Have we considered using varied materials that will make it safer and easier for the construction team without compromising mechanical integrity?
- Can we hold an internal and external workshop with other disciplines, suppliers, and client to share ideas and best practices. Early discussion during P&ID generation and 30% model review can provide the most benefit to the overall project design. Most changes recognised during the 90% model review are ignored due to the complexity to change the entire facility to accommodate.
- Will the new equipment be assembled within an active and operating facility? How will this affect the need for added safety requirements on existing operations staff? Completing daily work permits, hot work permits, critical lifts, lock-out/tag-out, etc.
- Will the facility produce product that fully meets design requirements and provide the best solution at the lowest overall capital and operating costs while exceeding all environmental requirements.

Several tools and procedures that assist are used to help with the design process (Table 1). Hazard Identification can be simply completing Hazard Checklists or completion of a full hazard study review (HAZOP or HAZID). Once the hazards are identified and risks are assessed, the project team should explore all ways to eliminate or reduce those risks. All risks cannot be eliminated or reduced; therefore, procedures need to be created or modified to reduce the potentials of the risks resulting in a safety incident. With the advancements in 3D modelling over the past couple of decades, model reviews with strict guidelines and defined expectations need to be adhered to.

The main purpose for a safety in design checklist is to identify the potential hazards, verify the design has reduced or eliminated the hazards, design controls to further reduce the risk or severity of hazards, and document all continued risks with procedures.

Within the sulphur industry there are several hazards that are considered “very-high, high, and medium” that must be addressed during the design phase. The following list for hazard identification and risk assessment within sulphur forming, handling and blocking facilities is not intended to be a comprehensive list but does provide examples of issues that must be considered.

Fig. 1: **Risk assessment matrix**



Source: Matrix

Table 1: **Tools available to help in the design process**

Type	Tool examples	Aim
Hazard identification	• Checklists of common hazards • Hazard elimination and risk reduction record forms • Hazard study reviews (HAZOP and HAZID)	• Analyse all aspects of the project (including existing site and travel) • Undertake whole life design review • Apply lessons learned from previous projects
Risk assessment and risk reduction	• Risk mitigation forms • Hazard elimination and risk reduction record forms • Layer of protection analysis (LOPA) • Quantitative risk assessment (QRA)	• Evaluate hazards associated with specific design options and propose mitigation strategies
Procedure	• Managing health and safety in construction • Industry guidance for designers • New CII Design for Construction Safety Toolbox • Standards and approved codes of practice	• Integrate safety needs with other project goals • Using reviews to support and record decision making
Visualisation	• 3D/4D CAD (AVEVA) • Virtual construction • Building information modelling	• Visualise spatial-temporal conflicts • Identify difficult accesses • Optimise design

Source: Matrix

PHOTO: MATRIX

World's largest sulphur melting facility, Mosaic, Tampa, Florida.

Hazard identification and risk assessment in sulphur forming, handling and blocking facilities

Using a risk assessment matrix, examples can be evaluated, and mitigations are implemented for proper safe working practices and conditions.

Personnel hazards

- Hot surfaces
  - Hazards: burns
  - Assessment: probability frequent / severity moderate = high risk
  - Mitigation: all hot surfaces must be properly insulated. If hot surfaces cannot be properly insulated, barriers and guards should be used to protect personnel from potential burns when touching hot surfaces.

- Noxious gases exposure
  - Hazards: sickness, critical illness, hospitalisation, death
  - Assessment: probability frequent / severity critical to catastrophic = very high risk
  - Mitigation: majority of facilities utilise molten sulphur degassing. The resultant sulphur contains less than 10 ppmw of H_2S entrained in the molten sulphur. H_2S will partially evolve from the molten sulphur and can reach toxic levels if not properly vented. Additionally, personnel and area H_2S detection should be required within all sulphur recovery, forming, and melting facilities.

- Sulphur and sulphur dust exposure
  - Hazards: skin, eyes, inhalation
  - Assessment: probability frequent / severity moderate = high risk
  - Mitigation: reduce airborne dust with proper moisture and dust suppression. Proper amount of moisture on product and/or use of dust suppressant at all material handling points must be in service and properly applying correct amount of moisture.

Equipment hazards

- Materials of construction and compatibility with sulphur
  - Hazards: corrosion, erosion, equipment failure, loss of production, facility shutdown
  - Assessment: probability likely / severity moderate with possibility to be critical = medium/high risk
  - Mitigation: all equipment must be evaluated individually to determine best design to reduce overall impacts. Proper steel coatings should also be considered and properly maintained throughout the life of the facility.

- Potential failures of individual components and major equipment
  - Hazards: equipment failure, loss of production, facility shutdown, time to repair or replace equipment
  - Assessment: probability occasional to likely / severity critical = high risk
  - Mitigation: depending on the equipment, time to repair or replace the equipment may have significant impacts to the entire operation. With increasing issues with global supply of key materials and equipment, additional purchase on onsite storage of critical spares must be evaluated.

- Required system shutdown to repair, replace, and clean various key equipment.
  - Personnel hazards: confined space entry, hot surfaces, sulphur dust, heat exhaustion
  - Equipment hazards: failure, loss of production, facility shutdown, time to repair or replace equipment
  - Assessment: depending on technology: probability likely to frequent / severity critical = very high risk
  - Mitigation: depending on the technology and equipment, the time to repair or replace may have significant impacts to the entire operation. Some forming technologies require daily equipment cleaning, while other technologies use minimal rotating equipment with simplistic forming process.

- Sulphur and sulphur dust airborne during solid sulphur handling process resulting in high level of sulphur dust in atmosphere.
  - Hazards: sulphur dust fires, sulphur dust explosions
  - Assessment: probability occasional / severity catastrophic = high risk
  - Mitigation: proper moisture control of solid sulphur product is paramount to reduce the potential

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Table 2: **National standards of the People Republic of China – Sulphur for industrial use (GB/T 2449-2006 replaces GB/T 2449-1992)**

Item		Technical specification		
		Premium grade	**First grade**	**Acceptable grade**
Mass fraction of sulphur, %		≥ 99.95	≥ 99.50	≥ 99.00
Mass fraction of water, %	Solid sulphur	≤ 2.0	≤ 2.0	≤ 2.0
	Liquid sulphur	≤ 0.10	≤ 0.50	≤ 1.00
Mass fraction of ash, %		≤ 0.03	≤ 0.10	≤ 0.20
Mass fraction of acid (according to the amount of sulphuric acid), %		≤ 0.003	≤ 0.005	≤ 0.02
Mass fraction of organics, %		≤ 0.03	≤ 0.30	≤ 0.80
Mass fraction of arsenic (as), %		≤ 0.0001	≤ 0.01	≤ 0.05
Mass fraction of iron (fe), %		≤ 0.003	≤ 0.005	–
Mass fraction of residue on sieve*, %	Particle size above 150 µm	≤ 0	≤ 0	≤ 3.0
	Particle size between 75 µm and 150 µm	≤ 0.5	≤ 1.0	≤ 4.0

Source: Matrix

** The specifications regarding residue on sieve are only applicable to powder sulphur.*

and risk. Various sulphur forming technologies produce sulphur with less-than-optimal moisture content that requires additional water and dust suppressant to be applied after forming. Matrix PDM technology produces solid product with optimal moisture content that does not require additional water or dust suppression postproduction.

Environmental hazards

- Sulphur and sulphur dust contamination with surface water and potential high acidity water to effluent.
  - Hazards: high acidity water that must be pH controlled, Possible violation of environmental regulations
  - Assessment: probability occasional to likely / severity critical = high risk
  - Mitigation: proper housekeeping in the sulphur forming and material handling areas. Proper design of rainwater collection with testing and maintenance of equipment.

- Sulphur and Sulphur Dust airborne during solid sulphur handling process resulting in high level of sulphur dust in atmosphere and potential contamination of area land a water.
  - Hazards: sulphur dust explosions, sulphur dust going into waterways at point of origin and destination
  - Assessment: probability likely to frequent / severity critical to catastrophic = very high risk
  - Mitigation: proper moisture control of solid sulphur product is paramount to reduce the potential and risk. Various sulphur forming technologies produce sulphur with less-than-optimal moisture content that requires additional water and dust suppressant to be applied after forming. Matrix PDM technology produces solid product with optimal moisture content that does not require additional water or dust suppression postproduction.

Mitigation of the highest safety risk when dealing with solid sulphur

Most mechanical equipment issues can be resolved with proper selection of equipment, meeting latest project specifications, and minimising impacts to the overall process that results in facility shutdowns. Matrix PDM Engineering continues to evaluate its process and provides industry standard equipment that can be easily repaired or replaced within a single shift. Minimal moving parts and proper selection of materials provides the highest reliability while considering overall value of the facility.

Considering the three focus areas and overall facility safety, "sulphur and sulphur dust" issues appears in each group. Using the assessment formula, sulphur dust appears as very high and high within each group. Mitigation of sulphur dust is required using technology and engineering tools. Sulphur dust can be mitigated through the proper application of water or a mixture of water and dust suppressant.

Proper moisture control of solid sulphur product continues to be misguided within the industry. Several companies continue to reference an outdated and obsolete material specification that was disbanded in 1982. Currently there is only one internationally recognised solid sulphur specification. This specification was developed by the Chinese in 2006 (see Table 2).

The proper moisture content of all solid sulphur should be less than 2.0% for all three defined sulphur purities. China continues to lead the world in imported sulphur and uses the sulphur specification to define all imported sulphur and not as produced. Proper moisture content at the point of production, storage, and when the product is loaded onto the outbound vessel should be approximately 2.0% to ensure the dust is properly controlled. Final product leaving the point of origin should be approximately 2% to meet the import requirements of the only active solid sulphur specification.

Various independent studies and papers have been authored over the past four decades addressing proper moisture content of solid sulphur product. All authors agree that solid sulphur should be maintained with a moisture content of minimum 1.5% and various ports of origin within North America have imposed standards that require sulphur to be between 2% to 3%. This level of moisture significantly reduces the risk of sulphur dust fires, explosions, and airborne particulate. ■

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