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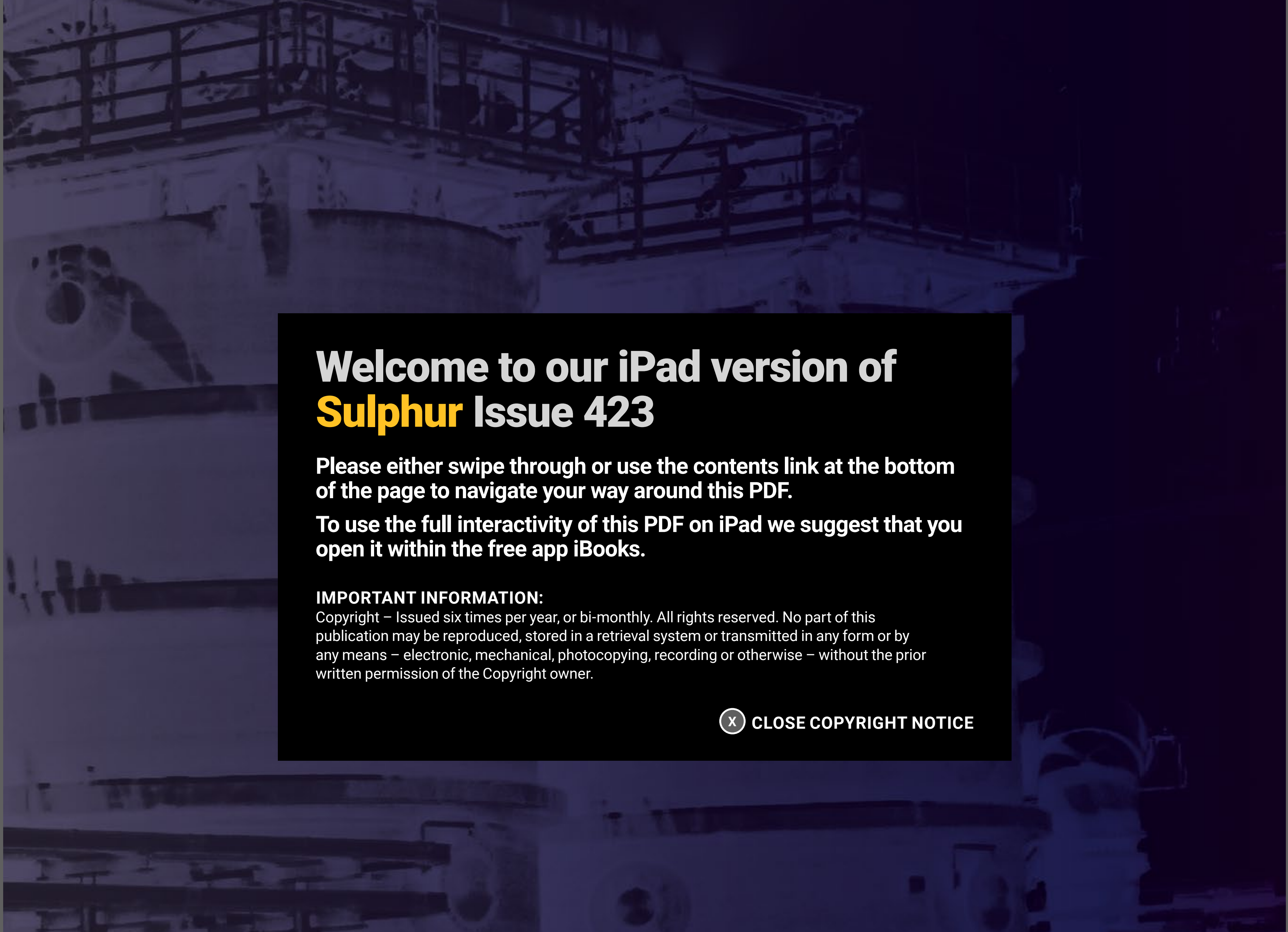

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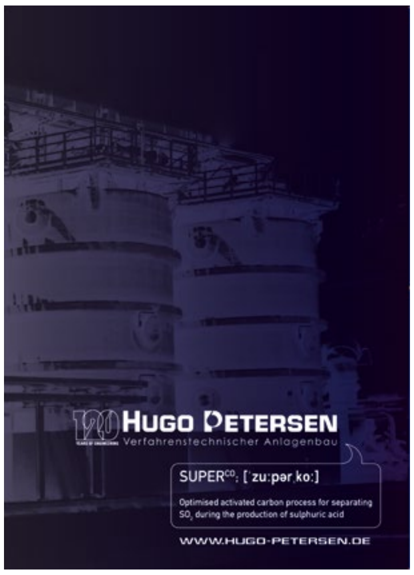

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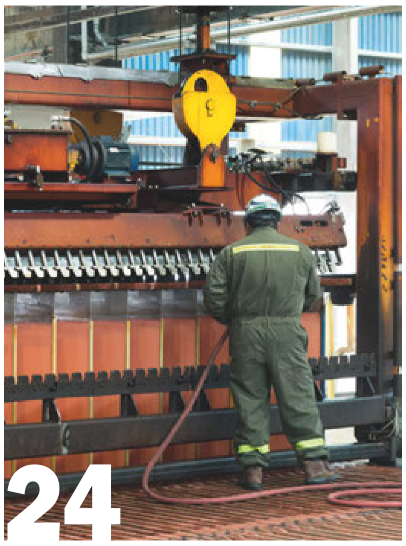

Acid in South America
Increased demand from phosphates and copper

Sulphur tail gas incineration
The pros and cons of thermal versus catalytic incineration

REGULARS

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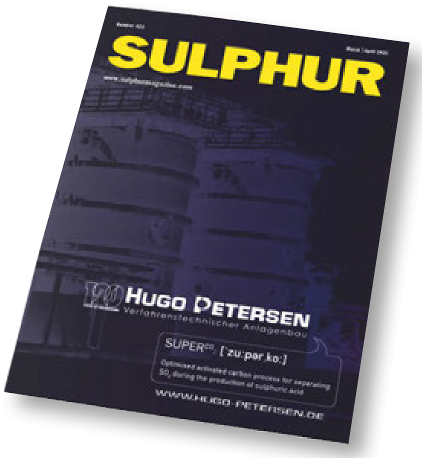
Published by:
CRU

Dire Straits



The effective closure of the Straits of Hormuz by Iran in the wake of US and Israeli attacks has sent shockwaves through all markets, but sulphur has been particularly badly affected. While the Straits carry 22% of global phosphate exports and 35% of urea, for sulphur around 45% of the 39 million tonnes transported internationally every year must traverse the narrow waterway, with major suppliers like Abu Dhabi and Saudi Arabia relying upon it for their export cargoes.

The sulphur market had already been tight prior to the attacks on February 28th, with a ban on exports from Russia extended to March 31st, and the lingering effects of a stoppage at Tengizchevroil (TCO) in January due to a fire at a power station helping to send prices to levels not seen since 2008. But the closure of Hormuz to shipping has led to a series of force majeure declarations and production cuts at major facilities in Bahrain, Kuwait, Qatar and Saudi Arabia. The impact on prices at time of writing has been significant but not yet critical. In Brazil, prices jumped \$40-60/t to \$560-590/t c.fr, while Mediterranean prices surged to \$580-590/t c.fr. However, panic buying has not – yet - materialised, largely due to regional buffers. Major fertilizer plant turnarounds in India and Brazil have muted immediate spot demand, while OCP in Morocco, a key importer, is reportedly well-supplied for March, with nearly 900,000 tonnes of pre-conflict cargo arriving via the longer Cape of Good Hope route. Adding to this, the temporary shutdown of four nickel HPAL plants in Indonesia following a landslide is expected to reduce regional sulphur demand, further tempering sentiment in Southeast Asia.

> “The impact on prices at time of writing has been significant but not yet critical ...”

For now, the market's direction depends upon how long this situation continues for. A swift resolution would likely release the significant volume of trapped cargo, putting downward pressure on prices. Conversely, a prolonged disruption would tighten the global balance considerably, likely leading to further price increases and potential demand destruction. President Trump has shown some signs that rising oil prices and the knock-on effect on gasoline pump prices at home may encourage him to declare victory and end the campaign. However, the selection of Mojtaba Khamenei as Iran's new Ayatollah seems a clear signal by Iran that it is in no mood for concessions, and the Islamic Revolutionary Guard Corps (IRGC) has said that it will determine when the war ends, not the US.

The extreme uncertainty has stalled forward business. Quarterly contract negotiations for Q2, which should be underway, have not yet started as market participants await clarity. Overall, CRU is forecasting a sharp price rise due to the supply shock, with the potential for further significant increases if the conflict is a prolonged one.

Richard Hands, Editor

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Price Trends

SULPHUR

Conflict in the Middle East has halted all vessel traffic through the Strait of Hormuz, effectively paralysing a region that accounts for 48% of global seaborne sulphur trade. As a result, the sulphur spot market has ground to a halt, with prices notionally holding unchanged in the $490-515/t f.o.b. range simply due to a lack of activity. No spot offers were reported out of the Middle East.

Reflecting the paralysis, producers either delayed or did not post their March sulphur selling prices. After an initial delay, QatarEnergy eventually announced its March price as a rollover at $520/t f.o.b. Market sources have since confirmed that ADNOC (UAE) has also settled its March price at a rollover from February at $530/t f.o.b. on 5 March. This counters earlier market expectations, which had pointed towards a downward correction for March before the conflict escalated. Of the major producers, only KPC (Kuwait) had yet to announce its price at the time of publication.

Amid the standstill, only one spot transaction has been reported since the conflict escalated: a 20,000 tonne Bahrain-origin cargo, which was sold to China at $555/t c.fr, reflecting the extreme premium required to secure any volume from the region. As the latest freight rates from the Middle East to China are unclear, the range was unchanged.

The reaction across major import markets has been varied. In China, the uncertainty prompted a sharp upward adjustment in domestic port pricing, reaching their highest levels since 2008; c.fr levels reached $550-560/t, up from $515-520/t. Domestically, the port spot price surged by $65/t from 27 February to a peak of $651/t on 4 March. Recent trades supporting these levels include 20,000 t of Bahrain-origin product sold at $555/t c.fr on the Changjiang river. The price surge is creating significant pressure on downstream phosphate producers. With sulphur now trading above domestic DAP and MAP prices, many are monitoring the situation closely rather than rushing to purchase. Large producers with existing inventories or access to cheaper domestic refinery sulphur are not under immediate pressure. In contrast, smaller MAP producers are facing potential production cutbacks due to poor affordability. Consequently, most port transactions are currently concentrated among traders. The geopolitical uncertainty has also weakened sentiment around China's 2026 phosphate export outlook, further reducing producers' buying interest. Total port inventories declined by 28,000 tonnes to 1.725 million tonnes by 5 March. The volume at Yangtze River ports saw the largest drop, decreasing by 24,000 tonnes to 702,000 tonnes, while Dafeng port's inventory remained stable at 140,000 tonnes.

In contrast, other key importers have adopted a more cautious, "wait and see" approach in a market where demand was already softening due to persistently high prices. This is particularly true in India and Indonesia, two markets heavily reliant on Middle East supply, where buyers have retreated to the sidelines to await clarity.

According to latest trade data, Indonesia imported 378,096 tonnes of sulphur in January, with approximately 78% of that volume sourced from producers in the Middle East, now directly impacted by the halt in shipping.

The market in Brazil remains quiet, though this is more attributable to a pre-planned period of maintenance at major fertilizer plants. Interest naturally turned to alternative sources, but buyers found limited options. Enquiries for North American cargoes increased, but suppliers in Canada and the US Gulf were already largely committed for the coming months. The global supply picture is further constrained by ongoing logistical issues, including heavy ice in the Baltic Sea and security risks in the Black Sea.

Mediterranean markets were quiet, with buyers in Turkey absent due to a lack of ammonia, and Tunisia out of the market, with the country's phosphate sector still navigating the fallout from a general strike at Groupe Chimique Tunisien (GCT) sites in mid-February.

SULPHURIC ACID

In spite of the chaos in other markets, the global sulphuric acid market has largely continued 'business as usual', with the immediate impact of the Middle East conflict confined to isolated logistical disruptions. This stands in stark contrast to the sulphur market, where the conflict has

Price Indications

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

Cash equivalent	October	November	December	January	February
Sulphur, bulk ($/t)					
Adnoc monthly contract	324	415	495	520	530
China c.fr spot	415	478	513	550	518
Liquid sulphur ($/t)					
Tampa f.o.b. contract	310	310	310	496	496
NW Europe c.fr	340	340	340	340	365
Sulphuric acid ($/t)					
US Gulf spot	128	135	145	153	163

Source: various

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effectively halted 48% of global seaborne supply, while the wider acid market watches for potential ripple effects.

The most direct logistical impact has been on Saudi Arabia's Maaden, a major importer now unable to receive shipments. This blockage, particularly of cargoes from India, has become the catalyst for a rerouting of trade. In response, Indian buyers are reportedly pushing back on their own contracted March volumes from Asia. This has reportedly created unexpected prompt availability in the Far East, easing the narrative of acute tightness that had previously defined the Japan/South Korea market and prompting Chinese traders to actively seek new outlets for surplus tonnes.

Traders are now looking to place these newly available Asian cargoes into Chile, but this is being met with weak local demand due to ongoing mine maintenance, keeping the Chilean market stable for now. Spot prices for sulphuric acid to Chile were assessed stable at $190-200/t c.fr, with the market balancing weak local demand against firm international replacement costs. The domestic market is currently well-supplied, with some buyers reportedly trying to delay incoming shipments. High stock levels have been compounded by recent operational issues at some major mines, which have temporarily reduced acid consumption over early Q1. As a result of the current slowdown, most buyers are reportedly covered until at least April and will not be looking for new spot cargoes for delivery earlier than June/July. Meanwhile, the Middle East conflict has altered some trade flows in the acid market. The disruption to the India-to-Saudi Arabia route has prompted traders to redirect spot cargoes from the Far East towards South America. A 30,000 tonne cargo was reportedly fixed to load in mid-April from Fangcheng, China for delivery to Mejillones. However, with freight for that route estimated at $91-101/t, the landed cost from China is calculated in the $241-261/t c.fr range, based on a Chinese f.o.b. of $150-160/t, making it largely uncompetitive.

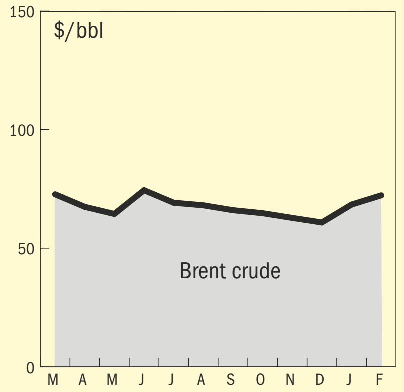
In Brazil, the market is also quiet due to local turnarounds, but forward sentiment has firmed considerably, with offers for May/June arrival rising on the perceived risk to future supply. In Northwest Europe, the market remains tight and sold out until April, which is the primary factor holding prices stable at $120-125/t f.o.b. The market remains underpinned by tight availability, with a consensus among sources that nearly all spot volumes are sold out through April. This scarcity is providing a firm floor to prices and has intensified talk around $130/t f.o.b. and above for any forward deliveries. While Europe has not been directly impacted by the trade flow disruptions stemming from the Middle East conflict, the global uncertainty is helping to support the firm sentiment in an already tight market.

In India, the market is under pressure. While subdued local demand has kept the weekly assessment stable at $170-180/t c.fr in early March, offer levels tightened due to rising feedstock costs and geopolitical risk. Heightened Middle East tensions have complicated feedstock flows. Traders report cargoes that had been bound for Maaden in Saudi Arabia are now stranded, prompting distressed sales into the market at roughly high $160s/t c.fr. Those forced disposals are available only in limited parcels, and many importers lack storage or the appetite to take on distressed material at present, given tight working capital and maintenance planning. Importers are entering their annual maintenance windows, reducing immediate procurement urgency. Several buyers say they are sufficiently covered with on-site stocks to bridge the shutdown period and will rely on those inventories rather than lift new spot cargoes. That dynamic limits immediate demand even as feedstock costs and geopolitical risk keep upward pressure on offers.

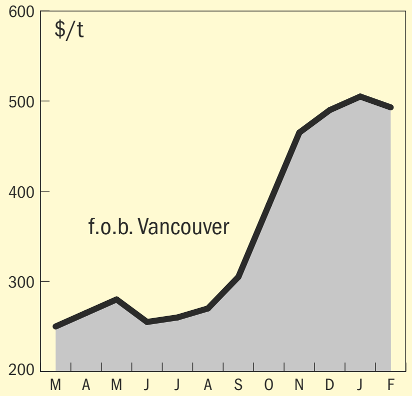
Sellers in Japan and Korea are reported to have only limited volumes available for new allocation, while China remains absent from spot exports. A handful of traders retain positions, but low acceptance rates among importers have left those parcels largely unsold. Physical flows through mid-February confirm the tighter backdrop. India imported around 67,000 tonnes of sulphuric acid to mid-February, with over 82% of that volume directed to CIL and the balance to FACT, according to vessel tracking data. With arrivals modest and bid acceptance weak, the market balance is fragile: limited spot liquidity and elevated offer levels leave importers reluctant to buy, yet any disruption to contracted flows could prompt rapid repricing.

END OF MONTH SPOT PRICES

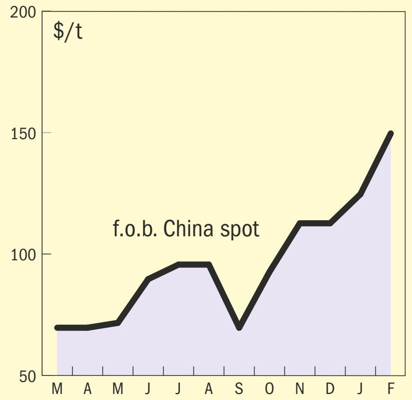
oil



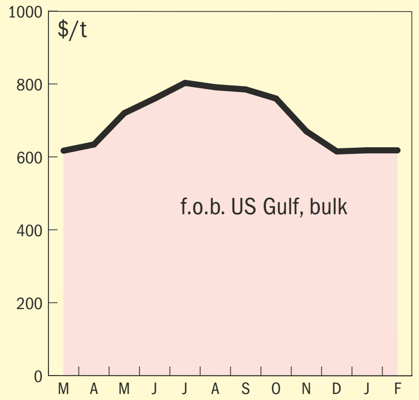
sulphur



sulphuric acid

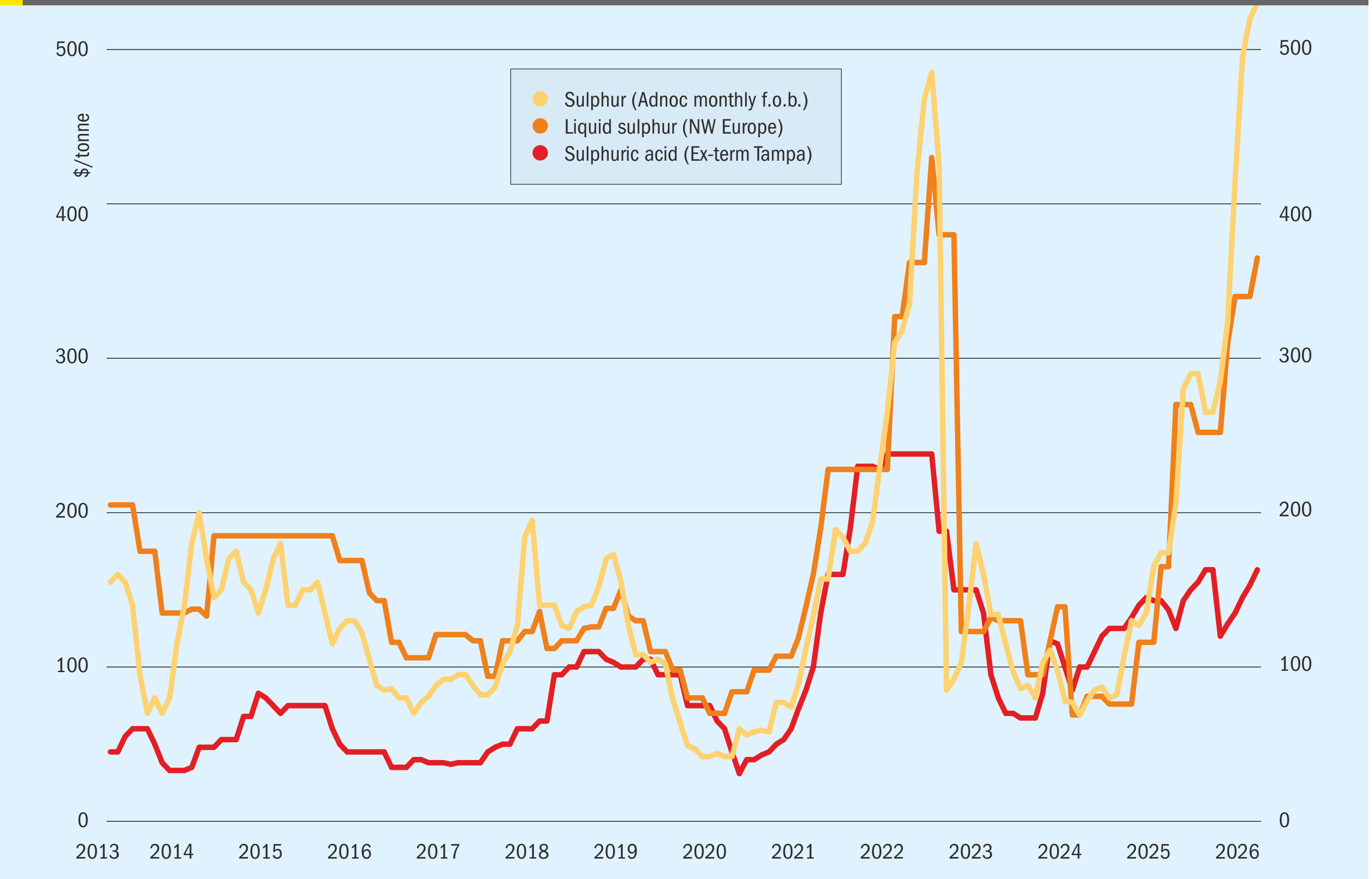


diammonium phosphate



Market Outlook

Historical price trends $/tonne



Source: CRU

SULPHUR

- Market sentiment has shifted decisively from bearish to bullish as the conflict in the Middle East has triggers a significant price rally.
- The sulphur market's direction is now dependant on the duration of the conflict in the Middle East. The current holding pattern is unsustainable, and the market is poised for a price increase as 48% of seaborne supply remains largely unavailable.
- A prolonged halt to operations would mean the loss of volumes that cannot be recovered from other origins, tightening the global balance and inevitably leading to demand destruction and upward pressure on the market. While production continues, the halt in shipping will also start to cause inventory build-up, with some producers facing imminent storage issues if exports remain blocked. The immediate lack of cargo availability is supporting prices.
- However, this support is fragile. If the flow of vessels through the Strait of Hormuz recovers in the short term, the release of this pent-up supply would likely cause prices to fall.
- Market sentiment is split between fears of demand destruction and concerns over supply security. One side argues that if phosphate producers cannot secure ammonia, sulphur demand will collapse. Conversely, other buyers are focused on the sulphur shortage itself, showing a willingness to pay a premium to secure product.

SULPHURIC ACID

- Looking ahead, the market remains clouded by significant uncertainty. In the near term, price direction will depend on the duration of the shipping disruption. With sulphur from the Middle East being significantly affected, there is growing market talk that China may potentially restrict its acid exports after April, opting to use the acid domestically as an alternative to buying expensive sulphur. While this currently remains just a rumour, such a policy shift would add significant upside risk to the seaborne market.
- Near-term prices will be influenced by the logistical reshuffling from the Maaden disruption, but the greater upside risk is the potential for China to extend its current export policy, which would fundamentally tighten the global market; the conflict in the Middle East has prompted speculation that China may extend its current sulphuric acid export policy beyond its expected April end date, in a bid to retain acid domestically as an alternative to expensive sulphur imports.
- For now, the market will remain thin and price discovery uneven. Importers on maintenance will keep demand muted, traders will hold back parcels unless pricing becomes compelling, and the impact of regional tensions will determine whether the next visible transactions reset the assessment higher or merely reflect isolated distressed volumes.

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Sulphur Industry News

KUWAIT

Contract awarded for sour oil field development

The Kuwait Oil Company (KOC) has awarded global oilfield services firm SLB a five-year integrated contract worth about $1.5 billion for the next phase of development at Kuwait's Mutriba oil field. The contract covers design, development and production management work and builds on SLB's existing subsurface studies of the Mutriba field. It includes development of high-pressure, high-temperature reservoirs with sour conditions, expanding SLB's scope as the project moves into more technically complex stages. SLB says that the award reflects its long-standing partnership with KOC and gives the company end-to-end responsibility for planning and execution as field development progresses.

The Mutriba field is an onshore oil development located in northwest Kuwait, in a previously undeveloped area covering more than 230 square kilometres. Commercial production began in June 2025 after KOC connected several wells to production infrastructure, marking it as one of the newest additions to the country's upstream portfolio. The field is technically challenging, with high-pressure, high-temperature reservoirs and ultra-sour hydrocarbons containing high levels of hydrogen sulphide, requiring specialised technologies and safety design

KAZAKHSTAN

NCOC seeks arbitration over sulphur fine

The North Caspian Operating Company (NCOC), which operates the huge Kashagan oil field in Kazakhstan, has said that it is seeking international arbitration to resolve its ongoing dispute with the government of Kazakhstan. Kazakhstan has imposed a swingeing $4.6 billion fine for alleged violations of sulphur storage regulations at the NCOC site. In December, a special administrative court in Astana turned down an appeal by NCOC, although it also granted leave to appeal in a higher court. NCOC, a partnership between Shell, Eni, TotalEnergies, ExxonMobil, China National Petroleum Corporation, Inpex and Kazakh state oil and gas company KazMunayGaz, continues to maintain that its sulphur handling operations have been conducted in compliance with Kazakhstan's laws and that it had the required permits in place.

"We consider that Kazakhstan's conduct in relation to the alleged permit violation for the storage of sulphur is not meeting the country's obligations under international investment treaties, including its obligation to afford fair and equitable treatment to their investors," NCOC said in a statement. "Despite disputing the allegations, and attempting to resolve these issues through dialogue, these efforts have not resulted in a solution. Therefore, the international shareholders have concluded that they have no choice but to initiate a request for arbitration under international treaties."

UNITED STATES

Devon and Coterra merger creates shale major

Devon Energy has signed a definitive merger agreement with Coterra Energy. The companies say that the combination will create a leading shale operator with a high-quality asset base anchored by a premier position in the economic core of the Delaware Basin. The combined company will be named Devon Energy and will be headquartered in Houston while maintaining a significant presence in Oklahoma City. The companies say that they have identified $1 billion in annual pre-tax synergies which, together with technology-driven capital efficiency gains and optimised capital allocation will drive near and long-term per share growth.

Under the terms of the agreement, Coterra shareholders will receive a fixed exchange ratio of 0.70 share of Devon common stock for each share of Coterra common stock. Based on Devon's closing price on January 30, 2026, the transaction implies a combined enterprise value of approximately $58 billion. Upon completion, Devon shareholders will own approximately 54% of the company and Coterra shareholders will own 46%. The transaction, unanimously approved by the boards of both companies, is expected to close in the second quarter of 2026, subject to regulatory approvals and customary closing conditions.

"This transformative merger combines two companies with proud histories and cultures of operational excellence, creating a premier shale operator," said Clay Gaspar, Devon's President and CEO. "We've now built a diverse asset base of high-quality, long duration inventory to drive resilient value creation and returns for shareholders through cycles. Underpinned by our leading position in the best part of the Delaware Basin, and a deep set of complementary assets, we expect to capture annual pre-tax synergies of $1 billion. This will drive higher free cash flow and greater shareholder returns beyond what either company could achieve alone."

The merger will create one of the world's leading shale producers, with pro forma third quarter 2025 production exceeding 1.6 million barrels of oil equivalent per day, including over 550 thousand barrels of oil per day and 4.3 billion cubic feet of gas per day.

OMAN

Duqm Refinery looking at further expansion

Following an increase in its processing capacity, Duqm Refinery is now looking at further expansion projects at the $9 billion refinery project located, in the Special Economic Zone at Duqm (SEZAD) on Oman's southeast coast. The refinery, which now has an expanded capacity of 255,000 bbl/d, is run by OQ8, a joint venture between Kuwait Petroleum International (KPI) and Oman's OQ Group. Speaking to local media, CEO Abdulla Al Ajmi said that OQ8 has now begun front end engineering design on a reformer unit to upgrade naphtha into high-octane gasoline components such as reformate, a critical step in producing finished, specification-grade fuels. In addition to the proposed reformer unit, Duqm Refinery is also exploring opportunities to enhance value creation from its refining by-products, notably sulphur and coke.

Al Ajmi said: "Other opportunities include sulphur and coke, and we have an MoU with a cement plant in Duqm that plans to use our coke by 2028. We are always on the lookout for projects that help us extract value from our outputs and by-

PHOTO: MAIRE

Opening ceremony for the refinery upgrade project.

products and contribute to the industrial ecosystem."

Duqm's sulphur unit includes three IPCO SG20 drum granulation units, with two operating at any given time. The units have a design capacity of 800 t/d each, but are currently run at 450 t/d to meet the refinery's daily production need of 900 t/d. This has been a major boost to Oman's sulphur production, which elsewhere runs at around 240 t/d, recovered primarily from gas processing operations at Petroleum Development Oman facilities, including Jebel Khuff and Taysir.

POLAND

Grupa Azoty adds new sulphur fertilizer to its range

Grupa Azoty has launched DuoS®, a new nitrogen–sulphur fertilizer. Its formulation is based on ammonium sulphate, ammonium nitrate and anhydrite and includes two forms of nitrogen – nitrate and ammonium; two sulphur sources – ammonium sulphate and anhydrite; and calcium to support crop resilience and the quality of produce. The new nitrogen–sulphur fertilizer with added calcium is designed to improve nutrient use efficiency and reduce leaching and other nutrient losses. It is recommended for pre-sowing and top dressing on winter and spring cereals, winter rapeseed, sugar beet, potatoes, legumes, grassland, as well as vegetables and fruit crops. Grupa Azoty says it is introducing DuoS® in the current season as part of a strategy to develop its fertilizer business and focus on specialty products.

"Developing more advanced fertilizer formulations is part of our focus on our key technological competences. We clearly see a trend towards products that increase nutrient use efficiency and reduce environmental losses. DuoS® responds to these needs by combining proven solutions with a precisely designed nutrient release profile," said Jacek Zaborowski, director, corporate trading department, AGRO Segment, Grupa Azoty.

The product's different rates of sulphur release should ensure availability during initial crop growth stages as well as later in the growing season. Its nitrogen-to-sulphur ratio, meanwhile, is designed to match crop nutrient uptake, and should therefore reduce the risk of overapplication, particularly in early spring and late autumn.

Grupa Azoty previously launched POLIFOSKA Multi S, a high-sulphur multi-nutrient fertilizer product, in February last year. This contains 7% nitrogen in ammonium form, 10% phosphorus, 20% potassium, 5% calcium, 1% magnesium, and 23% sulphur in sulphate form.

CROATIA

Completion of refinery upgrade

Maire Group subsidiary KT-Kinetics Technology says that it has completed work on the Rijeka Refinery Upgrade Project in Croatia, having completed the engineering, procurement and construction activities. The scope of work included a new delayed coking unit to process heavy residue and eliminate the production of fuel oil while increasing refinery efficiency capacity, the revamping of the process units and the utility network and the implementation of the latest solutions for coke handling and storage and sea jetty construction and shipping loading facilities.

The project was executed across a period marked by major global events, including the Covid-19 pandemic and the geopolitical developments related to the Russian-Ukrainian conflict. In this context, the works progressed thanks to a high level of flexibility, strong coordination and close cooperation among all stakeholders.

Speaking at the opening ceremony, Alessandro Bernini, CEO of Maire commented: "We are proud of this milestone, which marks an important step in strengthening Croatia's energy infrastructure as well as enhancing the efficiency and environmental performance of the Rijeka Refinery. We are also thrilled we were able to contribute a significant value creation for the Country by involving numerous Croatian companies, thus supporting the development of local capabilities that will benefit both the domestic market and export activities."

Also present at the opening ceremony were Ante Šušnjar, the Croatian Minister of the Economy, Zsuzsanna Ortutay, president of INA, József Molnár, CEO of MOL Group, and Levente Magyar, the Hungarian Deputy Minister of Foreign Affairs and Trade.

UNITED ARAB EMIRATES

New sulphur fertilizer plant opens at Jebel Ali

Amarak Chemicals FZC says that it has begun operations at an automated sulphur fertilizer facility in the Jebel Ali Free Zone. The company says that it will improve the availability of sulphur-based products for the agriculture sector by using Jebel Ali's integrated logistics. The facility, which will manufacture up to 60,000 t/a of sulphur bentonite and other sulphur-based products, was opened at a ceremony attended by Shri B. G. Krishnan, the Indian trade Consul, and Saoud Al-Awadhi, Director – Sales Jafza, and the Board of Directors of the Aries Group of Companies.

Dr. Rahul Mirchandani, Group Chairman of the Aries Group of Companies, said: "Our investment in Jafza reflects the Aries Group's long-term commitment to building world-class manufacturing capabilities in agricultural inputs and to becoming the preferred global supplier for quality, consistent, and innovative fertilizers. Amarak Chemicals FZC represents our belief that Indian manufacturing excellence, when combined with the UAE's enabling ecosystem, can successfully serve farmers and markets across the world."

Amarak has established long-term partnerships with leading sulphur suppliers in the UAE, ensuring raw material security, quality consistency and supply continuity. The project reflects growing India-UAE industrial collaboration, combining Indian process and product expertise with the UAE's infrastructure and logistics.

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JORDAN

JPMC to build new sulphuric acid plant

PHOTO: JPMC

Signing ceremony for the new sulphuric acid plant.

The Indo-Jordan Chemicals Company (IJCC), a wholly owned subsidiary of the Jordan Phosphate Mines Company (JPMC), has signed a $193 million strategic agreement with China's East China Engineering Science and Technology Company to construct a sulphuric acid plant in the Shidiya area. The new facility will have a capacity of 900,000 t/a of concentrated sulphuric acid, and is scheduled to be completed within 30 months, according to the company. The sulphuric acid produced will be used in phosphoric acid manufacturing as part of a new expansion phase, increasing IJCC's phosphoric acid production capacity from 330,000 t/a to 550,000 t/a.

Speaking at the signing agreement, JPMC Chairman Mohammad Thneibat said the project "reflects JPMC's commitment to expanding investments and developing operations in line with Royal directives and the Economic Modernisation Vision", noting that it "will enhance value-added production in Jordan's mining sector and create direct and indirect employment opportunities during construction and operation." It will also "ensure a stable supply of sulphuric acid to support phosphoric acid production, improving operational efficiency and strengthening competitiveness in regional and global markets."

East China Engineering CEO Meng Chenzhou expressed pride in the partnership, reaffirming his company's commitment to delivering the project to the highest standards and expanding long-term industrial cooperation with Jordan.

UNITED STATES

Itafos reports higher phosphates, acid production in 2025

US-based phosphate producer Itafos reported higher production in 2025, as well as higher sales prices, in preliminary operational results announced 11 February. In 2025, Itafos produced 352,851 tonnes P_2O_5 at its Conda facility in Idaho, up slightly from the 349,396 tonnes P_2O_5 produced in 2024. This was driven by higher MAP and super-phosphoric acid (SPA) sales volumes, offset by the discontinuation of ammonium polyphosphate (APP) and lower mono-ammonium phosphate with micronutrients (MAP+) volumes. The Q4 2025 output of 90,815 tonnes P_2O_5 was down from 97,307 tonnes a year earlier due to unplanned downtime.

Itafos finished mining at its Rasmussen Valley site and delivered first ore from its Husky 1/North Dry Ridge (H1/NDR) location after achieving mechanical completion of infrastructure, resulting in a seamless transition from the Rasmussen Valley Mine to H1/NDR, the company said. At its Arraias operations in Brazil, Itafos produced 124,712 tonnes sulphuric acid during 2025, compared with 112,785 tonnes in 2024, driven by higher customer demand with no plant turnaround downtime. Acid production for Q4 was down to 31,900 tonnes from 34,774 tonnes, due to higher acid consumption from fertilizer production and lower customer demand.

Arraias in 2025 produced 48,919 tonnes P_2O_5 of direct application phosphate rock (DAPR), partially acidulated phosphate rock (PAPR), and granulated partially acidulated phosphate rock (G-PAPR) compared with 18,147 tonnes P_2O_5 in 2024.

As previously reported, Itafos completed the sale of its Araxá Project in Brazil in 2025 Q1, generating nearly $43 million in pre-tax proceeds over the course of the year, and the company declared a special dividend associated with the sale.

Itafo recently completed an assessment of the Arraias Phosphate Project, and noted that the technical report, filed on 9 February 2026, defines high-grade phosphate rock layers at the mine that support plans for upgrades to the beneficiation circuit at the plant, which are expected to enable Itafos to produce SSP for sale to local markets. The assessment estimates sufficient resources to establish a 14-year life-of-mine plan, with SSP production and sales planned to begin in 2027.

Florence Copper project begins operations

Taseko Mines' Florence Copper project, featuring Metso's copper solvent extraction and electrowinning (SX-EW) technology, is ramping up its commercial operations in Arizona. The successful harvesting of the first copper cathodes at the end of February 2026 is an important milestone for Taseko Mines and Metso, marking the first new greenfield copper production in the United States since 2008. The project caters to the rapidly growing copper demand while supporting the transition towards more environmentally responsible copper production in North America.

Stuart McDonald, President & CEO of Taseko Mines commented: "This represents a landmark achievement for the Florence Copper team and a major milestone for Taseko, as we continue our journey to become a leading North American copper producer."

Metso's delivery to the Florence Copper project consists of a modular VSF®X solvent extraction plant and main process equipment for the electrowinning plant. Florence Copper has a nameplate capacity of 85 million lbs (40,000 tonnes) of LME Grade A copper cathode per year.

"We are excited to congratulate Taseko Mines and the Florence Copper team on this important milestone. It's an honor to support their success with proven Metso Plus technology designed to maximize resource efficiency and reduce environmental footprint. This aligns perfectly with our mutual dedication to sustainability and operational excellence," said Mikko Rantaharju, Vice President, Hydrometallurgy and Thermal Processing at Metso. "Moreover, this delivery is the first of its kind to the United States and holds tremendous value for Metso as we expand our offering and installed base in the region."

"Metso's nearby Mesa, Arizona service center and aftermarket team will work closely with the customer to ensure reliable, safe operation long after commissioning and maximize performance across the full equipment lifecycle," said Martin Karlsson, Vice President, Sales & Services, USA.

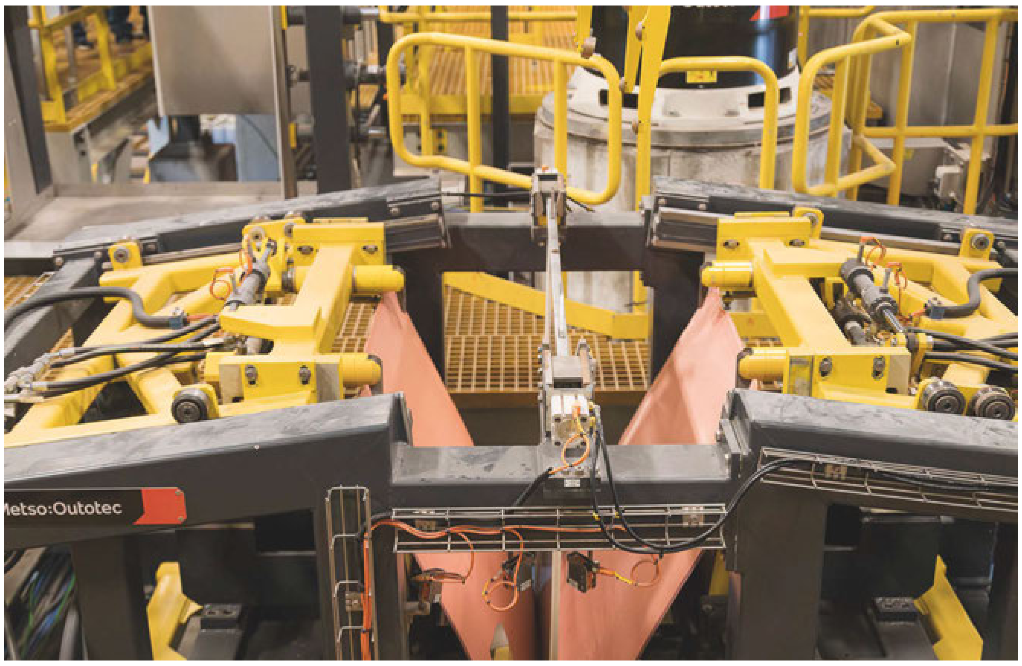

PHOTO: FLORENCE COPPER

Copper cathode stripping at Florence.

Nutrien and Mosaic under fire from USDA secretary

Stephen Vaden, the US Department of Agriculture (USDA) Deputy Secretary, has called Nutrien and Mosaic a "duopoly", saying they limit "fertilizer supply in this country" and "[drive] up the cost that farmers are paying", according to media reports. Vaden made the accusation against North America's two largest fertilizer producers during a 21st January webinar hosted by the National Agricultural Law Center.

The US fertilizer market is coming under increasing scrutiny. In February, two corn grower groups – the Texas Corn Producers Association (TCPA) and the Iowa Corn Growers Association (ICGA) – wrote to US Attorney General Pam Bondi requesting a formal status update on a Justice Department investigation into fertilizer pricing and market concentration. In December 2025, President Trump also signed an executive order instructing the Attorney General and the Chairman of the Federal Trade Commission to establish a Food Supply Chain Security Task Force. They were instructed to: "Take all necessary and appropriate actions to investigate food-related industries … and determine whether anti-competitive behaviour exists in food supply chains in the United States." The executive order specifically names fertilizers – alongside meat processing, seeds and equipment – as having "vulnerabilities to price fixing and other anti-competitive practices".

The eventual outcome of these federal investigations remains unclear. But, against the backdrop of vocal criticisms from USDA leadership and farmers groups, the market dominance of leading North American fertilizer producers is being questioned.

"While I remain cautious about the likelihood of any near-term structural shift in supply policy, pressure is clearly building from farm groups and grower associations focused on input costs and access to product," commented CRU's Justin Rackleff, Americas Lead, Fertilizer Value Chain, Intelligence & Prices. "And although legislative and trade processes tend to move slowly, the volume and consistency of that pushback is becoming increasingly difficult for producers to ignore," he added.

Nutrien is carrying out a strategic review of its entire phosphates business, with divestment being one option. A decision on this is due later this year.

Corey Rosenbusch, president and CEO of trade body The Fertilizer Institute (TFI), has argued that the very real pressures faced by US farmer have more to do with global market dynamics, not domestic decisions. He said geopolitics was "taking the headlines" when it came to fertilizer supply and demand.

"It's even harder for the American farmer right now than it was a few years ago when markets exploded. At least, back then, [agricultural] commodity prices were high. Right now, it's a perfect storm. Commodity prices are low, and input costs keep going up and up," Rosenbusch said in November. The US government's own policies, such as the on-off import tariff situation since April 2025 and longstanding countervailing duties (CVDs) on Russian and Moroccan phosphate imports, have arguably added to current fertilizer costs and supply issues.

Months of uncertainty ended in November when a presidential executive order finally exempted fertilizers from 'Liberation Day' tariffs. More recently, the legal basis for the use of these tariffs by the US President – under the International Emergency Economic Powers Act (IEEPA) – was itself struck down by the US Supreme Court in a 20th February ruling.

However, the White House immediately moved to counter this judgment by imposing a 15% global import surcharge under Section 122 of the 1974 Trade Act. These tariffs will be time-limited, though, and only apply for up to 150 days. Regardless, the imposition of Section 122 is not expected to have a direct impact on fertilizers anyway, due to their presence on an exemption list.

EGYPT

Xingfa sets sights on $2bn Egypt phosphate build as it lifts home-mine scale

China's Xingfa Chemicals Group is planning to invest $2bn in a three-phase project for phosphate ore exploration, extraction and downstream production in Egypt's Golden Triangle Economic Zone, according to Egypt's Ministry of Petroleum and Mineral Resources. The ministry said the project would progress once a memorandum of understanding is finalised, alongside technical exchanges and feasibility work.

Petroleum minister Karim Badawi said the proposed investment aligns with Egypt's push to expand value-added industries based on its mineral resources and attract technologically advanced companies. He also linked the initiative to a wider economic development agenda in which the energy sector, including mining, is positioned as a priority area.

Xingfa has also been strengthening its upstream phosphate position at home. In a Shanghai exchange filing dated 11 February 2026, the company said a wholly owned grand-subsidiary had completed a mining-rights change and secured updated mining documentation for the Qiaogou phosphate mine, lifting the mine's designed production scale to 2.8m t/y from 2.0m t/y, with the mining license valid until 22 June 2055.

In the same filing, the company said the change would "enhance… resource security" and "strengthen… the integrated industry chain", underscoring the supply-security logic behind its phosphate expansion plans.

INDIA

RCF plans to build $95m phosphoric acid unit at Thal

India's state-owned Rashtriya Chemicals and Fertilizers Ltd (RCF) has granted in-principle board approval to set up a new 300 t/day phosphoric acid plant at its Thal unit in Alibag, Maharashtra. The company put the investment at about INR 8.65bn ($95.36m), with funding planned through a combination of debt and equity. RCF said the proposed capacity addition is 300 t/d "on a 100% P_2O_2 basis".

In its 12th February Bombay Stock Exchange filing, RCF said the project is expected to take 24 months from the Letter of Intent and is intended to strengthen backward integration. The move is likely to reduce the company's need to procure phosphoric acid externally, with RCF's own tender trail showing it has sought third-party "supply and delivery of phosphoric acid and sulphuric Acid at the RCF, Thal unit" in a recent Expression of Interest process.

IFFCO expands acid capacity at Paradeep

Indian Farmers Fertiliser Cooperative Limited (IFFCO) has inaugurated its new, third sulphuric acid plant at its facility in Paradeep, Odisha. This expansion significantly boosts the site's total production capability from 750,000 t/a to 2.2 million t/a. The plant, dedicated by Union Minister Amit Shah, highlights a major increase in domestic capacity for India's fertilizer industry.

Coromandel starts trial operations at new acid plants

Coromandel International says that it has started trial production at its new sulphuric acid and phosphoric acid plants in Kakinada, Andhra Pradesh. The company says that this marks a crucial step towards transforming the unit into a fully integrated facility, significantly enhancing production capacity and diminishing reliance on imported raw materials for fertiliser manufacturing. The company is now focusing on a phased ramp-up. The new plants have of 2,000 t/d of sulphuric acid and 650 t/d of phosphoric acid, respectively. The integration of these acid plants is strategic, aligning with Coromandel's objective to strengthen backward integration in its fertiliser manufacturing value chain. By producing key intermediates in-house, the company aims to secure stable supplies, enhance cost efficiencies, and achieve greater self-sufficiency, thereby reducing dependence on imported raw materials. The project aims to replace over 50% of the Kakinada plant's imported acid requirements and mirror the integration levels seen at its Vizag and Ennore facilities.

RCF to build new phosphoric acid capacity

Rashtriya Chemicals and Fertilizers Limited (RCF) has received in-principle board approval to invest approximately $93 million in a new phosphoric acid plant with a planned capacity of 300 t/d at its Thal Unit in Alibag, Maharashtra. RCF sats that the investment aims to significantly strengthen the company's backward integration capabilities. The investment will be financed through a mix of debt and equity. The proposed plant is anticipated to be operational within 24 months of receiving a letter of intent.

INDONESIA

Indonesian nickel shutdown to cut sulphur/acid demand

Four Chinese-operated nickel plants at the Indonesian Morowali Industrial Park have temporarily ceased operations following a fatal landslide in February, in a development that will significantly reduce regional demand for sulphur and sulphuric acid. The shutdowns affect facilities run by China's GEM Co. and its partners, which together account for 30% of Indonesia's high-pressure acid leaching (HPAL) capacity. The move comes amid heightened regulatory scrutiny. The largest of the four plants, PT QMB New Energy Materials, could remain offline for up to three months.

The production halt will lead to a sharp reduction in the consumption of sulphuric acid, a key reagent in the HPAL process. PT QMB New Energy Materials has an annual acid requirement of 1.5 million t/a. The other three affected plants, PT ESG New Energy Material, PT Meiming New

PHOTO: INCITEC PIVOT

Phosphate Hill mine, Australia.

Energy Material, and PT Green Eco Nickel, consume 653,000 t/a, 620,000 t/a, and 530,000 t/a acid, respectively. Collectively, this is expected to remove around 260,000 tonnes of monthly acid demand from the market. Consequently, this will reduce upstream sulphur demand by an estimated 50,000 tonnes per month for the duration of the shutdown.

AUSTRALIA

Dyno Nobel sells Phosphate Hill to Mayfair

Dyno Nobel has signed a binding agreement for the sale of the Phosphate Hill plant in Australia to Ryowa II GPS Pty Ltd, a wholly owned subsidiary of Mayfair Australia Corporation, it announced 9 March. The purchase is for a nominal A$1.00 (US$0.70), with a deferred value of up to A$100 million payable to Dyno Nobel subject to certain conditions and performance hurdles. Phosphate Hill produces around 400,000 t/a DAP and 200,000 t/a MAP.

Mayfair is set to take over the operation from 1 April 2026. Dyno will provide approximately A$80 million of inventory at completion to support the continuity of operations. The deal secures employment for Phosphate Hill's roughly 540 employees and contractors, enabling continuity of operation for the North-West Queensland region, Dyno said.

Securing natural gas and sulphuric acid from Glencore's Mt Isa copper smelter is critical to Phosphate Hill, and the operation is a critical outlet for the smelter's by-product. Glencore said in July 2025 it had no choice but to start work on placing the loss-making smelter and Townsville refinery in Australia into care and maintenance until market conditions improve, and in October Canberra and the Queensland state government reached an agreement with Glencore for up to A$600 million of support, so that the smelter and refinery can operate for another three years. The deal concludes the separation of all fertilizers businesses and achieves the company's strategic objective of transforming into a "pure play global explosives leader".

Dyno announced last October that it would close Phosphate Hill by 30 September 2026 if it is unable to sell the asset, and the company noted it would still do so if this deal fails to go through. Dyno's sale of the Incitec Pivot fertilizers distribution business to Ridley Corporation Limited, which was agreed in May, was successfully completed on 30 September 2025. The deal did not include the acquisition of the Phosphate Hill site or the closure and remediation costs associated with the Gibson Island and Geelong manufacturing operations. Ridley also did not acquire Dyno Nobel's contract with Perdaman for the supply of 2.2 million t/a urea, which was sold to Macquarie Group's Commodities and Global Markets business. Consideration payments of up at A$145 million are subject to operational milestones for the project, which is expected to commence production in 2027.

BELGIUM

Prayon opens new Engis unit

Prayon has opened a new sodium hexametaphosphate (SHMP) production unit at its Engis complex in Belgium. The €30 million investment is designed to strengthen the company's position in the food and technical phosphates market. The new 10,000 tonnes per annum (t/a) capacity Engis unit complements Prayon's existing SHMP unit at its Les Roches-de-Condrieu site in France and will double the company's SHMP's output capabilities.

The new state-of-the-art SHMP plant is built to high environmental standards with, for example, a closed-loop water circuit that guarantees zero process water discharge. Prayon said the investment reaffirmed its commitment to "industrial performance, excellence in customer service and environmental responsibility", as well as a consolidating its role as a global leader in phosphorus chemistry.

"In a European environment with high energy and labour costs, we can't be a cost leader. With this new unit, we are strengthening our reliability for our customers and continuing our growth strategy in high value-added specialty phosphates," said Geoffrey Close, Prayon's CEO. "This objective is fully in line with our Solution Provider approach, which is centred on our customers, offering them not only greater reliability but also solutions that meet their needs for their specific applications."

Prayon's continuing investment in the region and its job creation efforts were praised by Pierre-Yves Jeholet, Vice-President and Minister for the Economy, Industry, Digital, Employment and Training.

"Excellent news to see Prayon strengthen its foothold in Wallonia. This industrial flagship represents 1,500 jobs worldwide, more than half of them in our region. We must continue to proactively support ambitious projects," Jeholet said. "With Wallonie Entreprendre, our strategic partner and 50% shareholder, we are proving that together, public authorities and companies can facilitate and accelerate investment, and seize opportunities to prepare for the future."

CANADA

Canadian government underwrites phosphate feasibility study

First Phosphate Corp. says that it has finalised an agreement for a C$16.7 million non-repayable contribution from the Government of Canada via Natural Resources Canada's Global Partnerships Initiative. The company says that the funding will accelerate the development of its phosphate project in Bégin-Lamarche by developing the technical and engineering parameters – including processing circuits and equipment – needed to validate the ability to produce a phosphate concentrate that meets the quality requirements of the lithium iron phosphate (LFP) battery market. The work will be conducted based on parameters established under the contract between First Phosphate and its definitive offtaker.

"Canada and our partners are putting real capital behind the secure and resilient critical mineral supply chains that our economies and defence industries rely on," said Tim Hodgson, Canadian Minister of Energy and Natural Resources. "By supporting companies like First Phosphate, we are helping deliver the minerals the world needs and the prosperity and security Canadians deserve."

"We welcome this investment from the Government of Canada which supports the continued progress of our project and its strategic role in the LFP battery supply chain," said John Passalacqua, CEO of First Phosphate. "Together, we are taking another step toward establishing an integrated phosphate-based LFP battery supply chain in Canada."

The Bégin-Lamarche demonstration and feasibility projects are part of a strategic plan by Canada to develop a domestic LFP battery value chain through the development of domestic capacity to process apatite (phosphate concentrate) into high-purity phosphoric acid. ■

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

Roeland Baan has informed the Board of Directors of Topsoe A/S of his decision to step down as President and CEO of Topsoe effective 31 May, 2026. The Board has appointed **Elena Scaltritti**, currently the company's Chief Commercial Officer, as the new President and CEO, from 1 June, 2026.

Scaltritti joined Topsoe in 2022 and has been responsible for building Topsoe's market position within low-carbon and renewable fuels, and growth in its conventional business.

Chairman of Topsoe A/S, Jeppe Christiansen, said: "We are very pleased to have a strong candidate for the CEO position internally. Elena is an exceptional leader, and she understands Topsoe's business and how to navigate the markets where we operate. The next couple of years will be defining for Topsoe. With large investments in innovative technologies and solutions, the company has a unique and strong technology platform ready to be scaled. This needs to be done while addressing the current market conditions and changing customer demands. We are fully confident that Elena is the right person to lead Topsoe through this next phase of development and growth."

PHOTO: TOPSOE A/S

Elena Scaltritti, Topsoe's new CEO.

He added: "Roeland was brought in to transform Topsoe. In six very decisive years for Topsoe, he has done so successfully. Roeland has transformed the company, positioning it as a recognized global leader in advanced technologies for the fuel transition and growing its revenue. He is a visionary, who gets the work done, and he has led Topsoe through major changes without losing sight of what makes this company special. We want to sincerely thank Roeland for his tremendous contributions and look forward to working with both Roeland and Elena over the coming months to prepare the transition."

Gazprom's board of directors has confirmed that CEO **Alexei Miller** will serve another five year term, beginning on May 31st 2026. An ally of Vladimir Putin since their days in the St Petersburg mayor's office, Miller has served as Russian Deputy Energy Minister and CEO of the OJSC Baltic Pipeline System. He has been at the helm of Gazprom since 2001. The company's valuation has tumbled in the past few years from $330 billion to $43 billion, much of that since the Russian invasion of Ukraine, as the company's gas exports to Europe have fallen from 180 billion cubic metres/year to only 10% of that.

Nutrien has appointed **Chris Reynolds** as Executive Vice President, Global Sales, to unify leadership across its wholesale and retail sales organisations. The company says that the appointment follows a planned leadership transition as **Jeff Tarsi**, who led Nutrien's global retail business through a period of significant growth and transformation, steps into an advisory role.

Calendar 2026

APRIL

13-15
CRU Phosphates+Potash Expoconference, PARIS, France
Contact: CRU Events
Tel: +44 (0) 20 7903 2444
Email: conferences@crugroup.com

13-15
World Copper Summit, SANTIAGO, Chile
Contact: CRU Events
Tel: +44 (0) 20 7903 2444
Email: conferences@crugroup.com

28-30
TSI Sulphur World Symposium 2026, VANCOUVER, Canada
Contact: The Sulphur Institute, Washington D.C., USA
Tel: +1 202 331 9660
Email: sulphur@sulphurinstitute.org

27 – MAY 1
RefComm Expoconference, GALVESTON, Texas, USA
Contact: CRU Events
Tel: +44 (0) 20 7903 2444
Email: conferences@crugroup.com

JUNE

5-6
49th Annual International Phosphate Fertilizer & Sulfuric Acid Technology Conference, ST. PETERSBURG, Florida, USA
Contact: Michelle Navar, AIChE Central Florida Section
Email: vicechair@aiche-cf.org
Web: www.aiche-cf.org

SEPTEMBER

14-18
Brimstone Sulphur Symposium, VAIL, USA
Contact: The Brimstone Group LP
Email: info@thebrimstonegroup.com
Web: https://www.thebrimstonegroup.com/symposium/

16-17
Oil Sands Expo, CALGARY, Alberta, Canada
Contact: Bruce Carew, EventWorx
Tel: +1 403 971 3227.
Email: marketing@eventworx.ca

NOVEMBER

3-5
CRU Sulphur & Sulphuric Acid Expoconference 2026, BERLIN, Germany
Contact: CRU Events
Tel: +44 (0) 20 7903 2444
Email: conferences@crugroup.com

Contents ISSUE 423 SULPHUR MARCH-APRIL 2026

Oil sands sulphur

With the decline of Venezuela's production, Canada's oil sands now represent 90% of all oil sands output, and a significant share of North America's sulphur production.

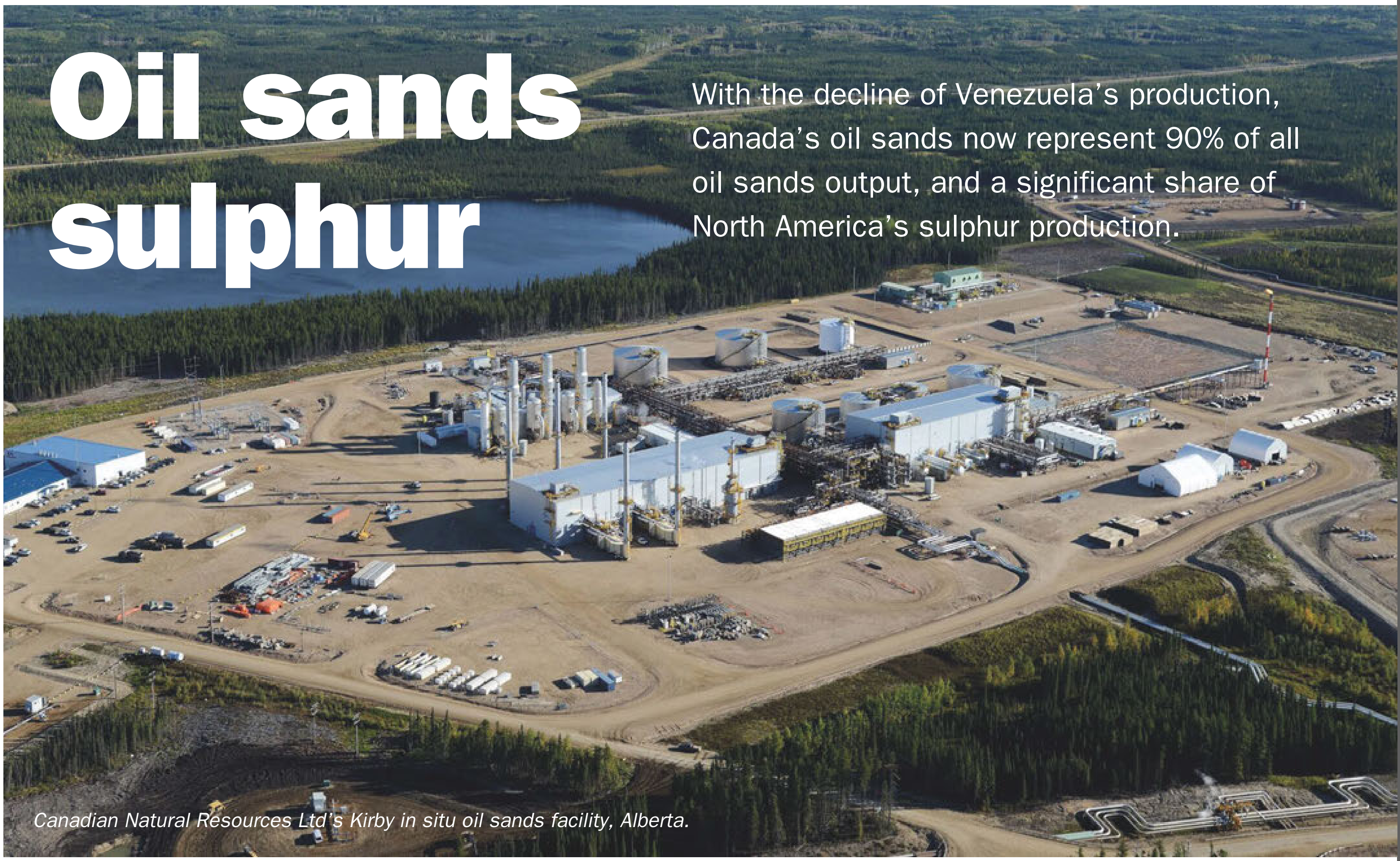

PHOTO: CNRL

Canadian Natural Resources Ltd's Kirby in situ oil sands facility, Alberta.

Proven global oil deposits total around 1.75 trillion barrels. Of this, around one quarter (470 billion barrels) are accounted for by oil sands deposits. Aside from some deposits in Siberia and Kazakhstan, the majority of this is found in two huge areas; the Faja Petrolifera del Orinoco (Orinoco Petroleum Belt) along the Orinoco river in Venezuela, and a long series of deposits on the eastern side of the Rocky Mountains in northern Canada.

While oil sands deposits are extensive, and represent 96% of Canada's and more than 90% of Venezuela's proved reserves, they are less easy to extract than conventional oil. The heavy, bituminous oil is trapped in a sandy layer close to the surface, and requires considerable energy to be supplied to liquefy it and make it pumpable, and further processing to break it down into lighter fractions suitable for refinery use. This raises the cost of production, and its energy intensity, making it a marginal play at times of low oil prices. Nevertheless, while oil sands production represents only about 4% of world oil output, because it has a high sulphur content (typically around 5%), it represents a correspondingly higher share of global sulphur production.

Venezuela

Venezuela's oil sands reserves there are estimated at 300 billion barrels, representing 90% of Venezuela's proven oil reserves and over 15% of all global oil reserves. Production expanded rapidly during the 1990s, the time of what was known as Venezuela's 'apertura' (opening). Much of the exploitation was via western oil majors such as Chevron, BP, Total and Repsol-YPF. However, the accession of populist president Hugo Chavez in 1998 led to an abrupt about-face in policy and part-nationalisation of the Faja, which caused most western countries to back out. Over the next decade and a half, corruption and mismanagement by political appointees and lack of investment in maintenance, coupled with the effect of US sanctions, led to steadily falling oil production, and under Chavez's successor Nicolas Maduro the decline has been even more marked, as Maduro purged the senior leadership of PDVSA and appointed his own political cronies. AS a result, Venezuelan oil production declined from 3.3 million bbl/d in 2000 to 650,000 bbl/d in 2021, with only 300,000 bbl/d coming from the Faja. Venezuelan sulphur output from oil sands production was estimated at just 30,000 tonnes in 2025.

The removal of Nicolas Maduro by the Trump administration leaves the future of Venezuela's oil sands in something of a limbo. President Trump has tried to encourage US producers to invest in Venezuela and held out the prospect of a removal of sanctions for a more pliable regime in Caracas, but as yet US oil majors have been somewhat indifferent to the prospect, with easier and safer plays to be found elsewhere.

Canada

The story in Canada has been very different. Like Venezuela, Canada's oil sands are in a remote and relatively inaccessible part of the country – in this case northern Alberta rather than the jungles of the Orinoco. The reserves are also of a similar size. However, Canada's oil sands exploitation has a longer and happier history than Venezuela's, and hence of the 5.3 million bbl/d of oil that Canada produced in 2025, about 4.1 million bbl/d or 75% was from oil sands production.

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There are three major producing basins in Alberta; Peace River, in the northwest of the province, and Athabasca and Cold Lake, which run along the eastern border with Saskatchewan. Production is split between conventional, open pit mines, and 'in-situ' production, the latter of which pumps steam down into underground deposits to melt the bitumen and then draws it back out. This so-called steam assisted gravity drainage (SAGD) method is increasingly popular as it is not only cheaper but uses less water and avoids the large-scale scarring of the landscape of open pit mining, which must then be remediated once extraction is complete. The mined deposits cluster in the north of the Athabascan deposit, around Fort MacMurray, where the deposits are less than 75m below the surface, with the SAGD projects running in a line south to Cold Lake.

The bitumen recovered is usually then either upgraded to produce synthetic crude oil ('syncrude'), or diluted with lighter fractions such as naphtha to produce a 'dilbit' (dilute bitumen) or with syncrude to create a 'synbit'. These are light enough to be pumped, and so can be exported by pipeline or rail. There are three major upgraders at Scotford, Redwater and Mildred Lake, with a total capacity of just over 1 million bbl/d. According to the Alberta Energy Regulator, roughly 25% of extracted bitumen is upgraded.

Table 1 shows current Alberta oil sands operations. The major operators are now Suncor, Cenovus, Canadian Natural Resources Ltd (CNRL), Syncrude and Imperial Oil. Some of the major oil companies such as Shell have moved out of oil sands production over the past decade (Shell retains only its Scotford upgrader) after a period of low oil prices in the late 2010s. Even so, production has continued to increase, as Figure 1 shows.

Exports

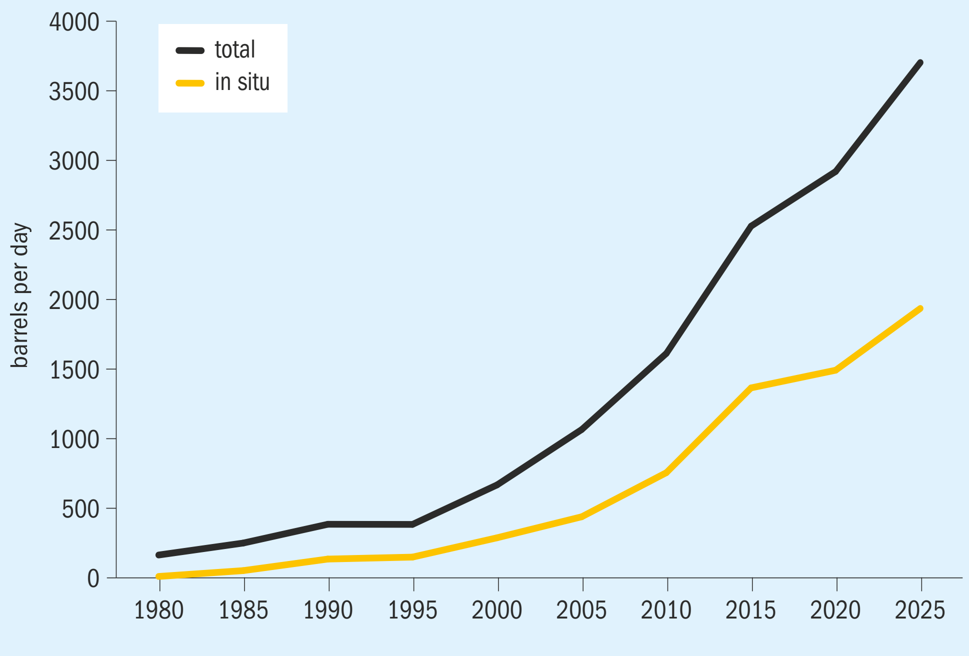
Canadian oil production from all sources ran at about 5.3 million barrels per day in 2025. Set against that, consumption totalled around 2.3 million barrels per day. The balance of 3.0 million bbl/d was exported, and by far the largest slice of this goes south across the border to the United States. After meeting domestic refining needs in Western Canada, Ontario and Quebec, roughly 95% of Canadian crude oil exports are to the US, due to proximity and Canada's limited access to alternative

Table 1: **Canadian oil sands production 2025**

Operator	Site	Capacity, bbl/d	Type
CNRL	Horizon	314,000	Surface mine
	Muskeg River	183,000	Surface mine
	Jackpine	145,000	Surface mine
	Kirby	80,000	In situ
	Primrose/Wolf Lake	140,000	In situ
	Jackfish 1/2/3	120,000	In situ
	Peace River	12,500	In situ
	Horizon Upgrader	250,000	Upgrader
Cenovus	Christina Lake	260,000	In situ
	Foster Creek	180,000	In situ
	Sunrise	69,000	In situ
	Christina Lake North	113,000	In situ
CNOOC	Long Lake	70,000	In situ
	Long Lake Upgrader	58,500	Idled
ConocoPhillips	Surmont	136,000	In situ
Imperial Oil	Kearl	280,000	Surface mine
	Cold Lake	190,000	In situ
	Aspen	75,000	In situ
NW Redwater	Sturgeon Refinery	50,000	Upgrader
Shell	Scotford Upgrader	328,000	Upgrader
Suncor Energy	Millennium	120,000	Surface mine
	Steepbank	180,000	Surface mine
	Fort Hills	194,000	Surface mine
	Firebag	215,000	In situ
	MacKay River	38,000	In situ
	Upgrader 1 & 2	350,000	Upgrader
Syncrude	Mildred Lake	180,000	Surface mine
	Aurora North	225,000	Surface mine
	Mildred Lake & UE1	350,000	Upgrader
Others	Various	229,000	Various

Source: Oilsands Magazine

Fig. 1: **Canadian oil sands production, thousand barrels per day**



Source: Alberta Energy Regulator

trade partners, and an integrated oil infrastructure built over decades. This is a net figure – Canada actually exported 4.5 million bbl/d of oil to the US last year, mostly in the west from Alberta, with US oil flowing north to feed Canadian refineries in the east of the country.

Most of the exports (85%) are via pipeline. After some years of environmental opposition, many of the major trans-border pipelines such as Keystone are now completed, and transport infrastructure also includes the Aurora, Enbridge Mainline, Express, Milk River, and Trans Mountain pipelines.

Carbon content

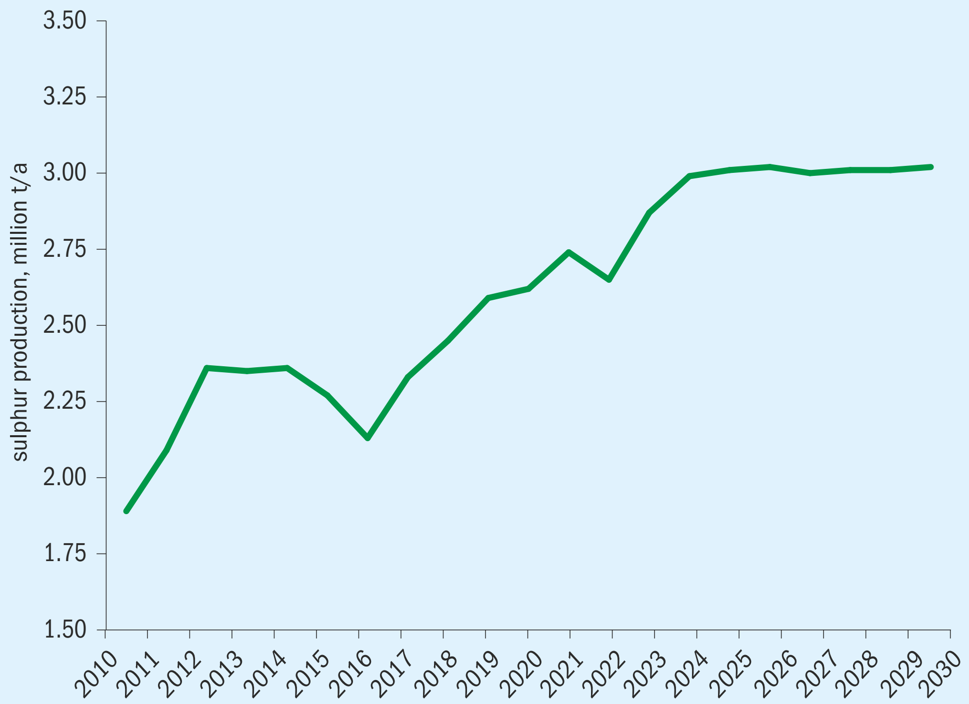
One of the major criticisms of oil sands production is its environmental footprint. The surface mines are unsightly, though companies perform remediation work once the area is mined out. But of increasing concern is the carbon footprint of oil sands crude, due to the heat that must go into melting the bitumen and the carbon cost of the hydrogen required to break the large molecules up into smaller, more desirable ones during upgrading. Oil sands extraction and processing is about 50% more carbon intensive than that for more conventional grades of oil, almost comparable to coal, and represents around 10% of Canada's total carbon dioxide emissions, according to figures submitted to the UN.

The oil sands industry has pledged to make its onsite operations carbon neutral by 2050. Some modifications to existing operations can reduce carbon intensity by around 25%, including using solvent rather than steam for SAGD operations, and processing to dry tailings rather than using tailings ponds which may emit methane. Partial upgrading of bitumen and dilbit can also reduce emissions through more efficient conversion of bitumen and use of diluent. A number of facilities are also looking at carbon capture and sequestration or use. The government of Alberta is also targeting a C$30/tonne carbon price to be applied to oil sands facilities in order to drive towards reduced emissions and carbon competitiveness.

Sulphur from oil sands

Canada was the world's sixth largest producer of sulphur in 2025, at 4.7 million t/a. More importantly, it was the third largest exporter, behind only the UAE and Saudi Arabia, with a total of 4.57 million t/a of sulphur exported. In spite of falling volumes being recovered from declining sour gas fields, increased recovery from oil sands production have so far by and large balanced this. Oil sands sulphur production within Canada totalled 3.0 million t/a in 2025, representing 63% of Canadian sulphur output.

Fig. 2: **Global oil sands sulphur production, 2010-2030, million t/a**



Source: CRU

Canada continues to represent the lion's share of all sulphur produced from oil sands, almost 98%, so the future of Canadian oil sands production is closely tied to how much sulphur is produced. Figure 2 shows world oil sands sulphur production over a 20 year period. Having grown slowly but steadily with Canadian oil sands output, there is at present no prospect of any major increase in this in the short term, although a period of sustained higher oil prices may encourage new investment back into Canada, and Venezuela remains a wild card in the longer term, depending on future relations with the US. Overall, oil sands-based sulphur production is expected to stabilise at around 3.0 million t/a from 2025 to 2030.

There is one additional corollary of this – if 3.7 million barrels per day of oil sands bitumen is being extracted, at an average sulphur content of 5%, that represents in theory a total of 8.3 million t/a of encapsulated sulphur that is being extracted. However, only the bitumen that is processed or upgraded in Alberta shows up in the Canadian figures of 3.0 million t/a of sulphur produced. The remaining sulphur will be extracted where the syncrude is delivered and processed, mainly on the Gulf Coast of the US. A shift to more processing within Canada could therefore increase domestic sulphur production while US refineries might need to source sour crude elsewhere.

Sulphur storage

The other factor in Canadian oil sands production is stocks of sulphur. The logistics of moving sulphur from northern Alberta to the port of Vancouver has been difficult and relatively expensive, meaning that in the early days of oil sands operations much sulphur was poured to long term storage in blocks. Since there has been a sustained run of higher sulphur prices, there are signs that some of this is now being recovered and remelted. Canadian sulphur inventory declined throughout 2025, prompted by a high price environment, and this trend is expected to continue into 2026. There plans to increase re-melting capabilities in Canada with new capacity commissioning by the end of 2026. A net figure of around 1.5 million tonnes of Canadian sulphur is expected to be remelted and sold in the period 2025-2030.

The Iran war and sulphur markets

The US and Israel attacks on Iran and the Iranian response have thrown commodity markets into chaos, with sulphur and sulphuric acid particularly affected.

The strikes, which began on February 28th, have led to retaliation from Iran, initially striking at bases and petrochemical facilities in neighbouring Gulf states, before beginning to concentrate on shipping, especially around the strategically vital Strait of Hormuz. The length of the campaign remains uncertain on both sides, but for the time being the Strait are effectively closed, with no seaborne cargoes transiting and maritime insurance unavailable. Iran has warned of attacks on any vessels passing through the Strait of Hormuz, adding that "not a single litre of oil will be exported to hostile parties or their partners until further notice". IRGC Navy official Mohammad Akbarzadeh said the Strait of Hormuz was under "full control" of the Revolutionary Guard's naval forces on 4th March. The UK Maritime Trade Operations (UKMTO) says that it has received 17 reports of incidents affecting vessels operating in and around the Arabian Gulf, Strait of Hormuz and Gulf of Oman between 28 February and 11 March. A cargo ship has caught fire in the Hormuz Strait and three vessels were hit by 'unknown projectiles' on 11 March.

LNG

One of the major effects has been on LNG cargoes. The strike at the Ras Laffan facility in Qatar has shut down production there, and QatarEnergy has declared force majeure and shut down LNG operations. Even if all hostilities were to end tomorrow, Qatari LNG shipments would not be able to resume for 5-6 weeks. One rapid knock-on effect of this was that India invoked emergency measures to cut natural gas supplies to its fertilizer industry, forcing the sector to operate at approximately 70% of recent capacity, according to a 9 March government order. Under the new regulation, fertilizer plants have been designated a "second priority" and will receive 70% of their average gas consumption over the past six months. Top priority is given to households and transport fuel, which will receive 100% supply.

The impact has been felt in gas markets worldwide, with gas prices for April delivery on the Dutch TTF hub reaching €50/MWh. To rein in energy price rises, the European Union is considering a natural gas price cap or subsidies, the European Commission President Ursula von der Leyen told MEPs in Strasbourg on 11 March.

Oil

The International Energy Agency said it will release 400 million barrels of emergency oil stocks held by its members – the largest release in its history and about a third of total public emergency reserves. Brent crude and European natural-gas prices climbed, despite the news, with Brent increasing to near $93/barrel. Lost production via Hormuz is around 15 million barrels/day, according to some estimates, and the IEA release amounts to about 5 million barrels/day through March.

On the other hand, Iran is exporting more oil through the Strait of Hormuz than before the war, according to the Wall Street Journal, citing Kpler data. Over the week to March 11th, tankers have loaded a daily average of 2.1 million barrels of Iranian oil, higher than the 2 million barrels/day Iran exported in February.

With storage rapidly filling up, oil production is being curtailed in Iraq, Kuwait, Bahrain and the UAE. If the current logistical situation persists, around 10-11 million bbl/d of potential oil supply (crude and refined products) will be prevented from reaching world markets.

Sulphur

CRU's sulphur price forecast has been revised radically higher to reflect the unprecedented supply shock caused by the conflict in the Middle East. While the disruption is expected to be short-lived, the immediate paralysis of a region responsible for 48% of global seaborne trade has created extreme upside risk in the near term.

The immediate reaction saw Middle East producers roll over March contract prices, while buyers, already pushing back against poor affordability, retreated to the sidelines. This initially resulted in a frozen physical market, with limited spot activity to guide price discovery.

The metals industry, particularly nickel producers, has much stronger margins and is expected to drive prices higher to maintain operations. In contrast, the phosphate industry has very limited capacity to absorb these higher costs and will be forced into significant demand destruction. Furthermore, buyers in Indonesia and southern Africa likely have two to three months of inventory, allowing these consumers to avoid rushing into the spot market. The eventual peak of the market will therefore be determined by the price the metals sector is willing to pay.

When shipping through Hormuz resumes, the market will have to contend with a massive volume of pent-up supply. With Middle East producers currently accumulating an estimated 40,000 t/day of inventory, the downward pressure on prices will be immense. While logistical challenges will temper the speed of this correction, producers will be keen to reduce stocks, likely leading to a sharp price drop once trade flows normalise.

Despite the overwhelmingly bullish narrative, a few bearish developments are providing very minor relief. In Indonesia, the temporary shutdown of four nickel plants following a fatal landslide is expected to cut sulphur demand by an estimated 50,000 t/month, weakening a key demand sector.

Additionally, some minor supply relief is expected, but it will not be enough to balance the market. The end of Russia's export ban on 31 March should add around 100,000 t/month, a fraction of the Middle East's lost volume, and this supply carries its own infrastructure risks. Compounding the tightness, severe Baltic Sea ice is also slowing exports from Russian ports, a bottleneck that will ease as the weather warms.

In China, the country is expected to rely heavily on its substantial port inventories of more than 1.7 Mt, effectively largely withdrawing as a major buyer from the international spot market in the near term. While this demand destruction will not be enough to halt the global price surge driven by the metals sector, the absence of the world's largest importer will act as an additional drag on the market.

Interest has naturally turned to alternative supply sources, particularly North America, but buyers are finding limited relief. Producers in both Canada and the US Gulf are reportedly well-committed for March and April loading, leaving little-to-no spot availability to meet the sudden surge in new enquiries. This lack of a viable alternative supply outlet is a key factor supporting the extreme upward price forecast, as it removes a potential escape valve for the market.

Sulphuric acid

The primary market impact from the Middle East conflict has been logistical. Rerouted cargoes originally destined for Saudi Arabia's Maaden have created unexpected prompt availability, putting a temporary ceiling on any intense price surge. While the sulphur crisis is prompting some to look to acid as an alternative, overall acid supply is limited to solve the larger potential sulphur deficit, giving major buyers little incentive to enter the spot market. It is also expected that Morocco will not return to buy large acid volumes in response to the sulphur shortage, as availability is tight.

Looking ahead, significant bearish pressure is building in Indonesia. Following a fatal landslide, four Chinese-operated nickel plants have ceased operations, including the 1.5 million t/a PT QMB facility. The shutdowns are expected to remove around 260,000 t of monthly acid demand from the market for up to three months, creating a significant pocket of weakness in the Asian seaborne market.

The long-term supply landscape is set to shift significantly with the anticipated return of several major smelter operations in H2. Increased output from facilities, including Freeport's Manyar smelter (1.6 million t/a), the Gresik operation (1.2 million t/a), and Amman Mineral's Sumbawa smelter (900,000 t/a), is expected to add an estimated 0.5-0.7 million tonnes of additional by-product acid supply in the second half of the year alone. This increase in domestic production will lower the country's import requirements.

Escalating disruption across Middle East shipping routes is beginning to feed through into sulphur supply chains, with implications for sulphuric acid availability into southern Africa and elevating near-term risk to DRC SXEW acid supply. While sulphur production may continue, constrained logistics can still translate into delayed arrivals, tighter spot availability and a higher probability of operational disruption for consumers that depend on imported sulphur and sulphur-derived acid.

Copper production in the DRC is particularly exposed to sulphur availability because a large share of its acid supply is generated via sulphur burning. An estimated 3.6 million t/a of sulphur-burned acid production is reliant on imported sulphur flows, which are heavily linked to trade in the Middle East.

The realised impact depends on how long disruption persists versus inventory cover, how intermittent the disruption is (partial flow versus full stoppage), and the availability of mitigation options such as alternative imports, domestic/by-product acid and logistics flexibility. It is estimated that there is 600–800,000 tonnes of elemental sulphur in the regional chain (~60% at ports), implying about two to three months' stock on paper. However, consumers need to begin replenishing within one to two months to avoid tightening.

Zambia's exposure profile differs. From a copper-output perspective, it is typically less directly exposed to sulphur import disruption as a large portion of its copper production is derived from sulphide ores through the smelting of concentrates. Moreover, the country is a net exporter of sulphuric acid, with flows primarily into the DRC. This trade linkage creates a second layer of risk for the DRC. If Zambian exports tighten, the DRC loses an important regional balancing source of acid.

Phosphates

The Strait of Hormuz closure removes supply from Saudi Arabia, the source of around a fifth of global traded DAP/MAP supply. China had already temporarily halted DAP, MAP, and NP exports until August 2026, suggesting even tighter global P_2O_5 availability in 2026, when the country's P_2O_5 exports increased despite exceptionally low DAP/MAP volumes. As sulphur prices are set to remain high and limit potential for decreases in domestic Chinese phosphates prices, exports from China are now only expected to return around September, with only around 1 million tonnes of DAP/MAP exports expected, down from 5.4 million t/a last year, which was already a 12-year low.

Tight availability and high prices for raw materials may also lead to production constraints in other regions. Morocco's OCP is also heavily reliant on raw materials from the Middle East.

Where now?

At the moment it remains unclear as to how long the war and associated disruption will last; will it be a short-lived disruption, a longer, deeper disruption, or could there be wider regional escalation? At present the single most likely outcome is a de-escalation in the next few weeks, as domestic political pressure on president Trump builds as higher oil prices feed through to pump prices, and he chooses to end airstrikes (probably declaring that military objectives have been reached). However, there are serious risks of disruption continuing for longer. Even if president Trump decides to end military action, ending disruption to shipping through Hormuz is not immediately within his control. Either Israel or Iran may seek to continue action.

The probability of further escalation – with energy infrastructure severely damaged on both sides – has probably reduced somewhat, with Iran stating over the weekend that it will no longer attack the infrastructure of its neighbours, and with a wind-down of US military operations looking more likely. However, this risk – and the associated risk of Iran collapsing or disintegrating as a state – have not disappeared.

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

Safe handling of H_2S

The US Chemical Safety and Hazard Investigation Board (CSB) has released its final investigation report into the fatal release of hydrogen sulphide at the PEMEX Deer Park Refinery in Texas in October 2024.

PHOTO: PEMEX

The Deer Park refinery, Texas.

The report notes that two contract workers died as a result of exposure to H_2S, and 13 others were transported to local medical facilities, with dozens more treated at the scene. In total, 13 ½ tons of hydrogen sulphide gas were released during the incident, and a shelter-in-place order was issued for two neighbouring cities.

The release occurred at approximately 4:23 p.m. on October 10, 2024, during maintenance activities in the refinery's amine unit, when contract workers mistakenly opened a flange on piping that contained pressurised hydrogen sulphide. The workers had been supposed to open a different flange on piping that was located approximately five feet away. One worker was fatally injured when the gas was released. The hydrogen sulphide vapor subsequently travelled downwind into an adjacent unit, where a worker employed by another contractor inhaled the toxic gas and was also fatally injured.

The release continued for nearly one hour until refinery emergency responders reassembled the leaking flange and stopped the discharge. Because of the release, local officials in the neighbouring cities of Deer Park and Pasadena, Texas, issued shelter-in-place orders that remained in effect for several hours. Although the refinery did not sustain physical structural damage, the company reported approximately $12.3 million in property damage related to loss of use of the amine unit and downstream processes.

In the report, CSB Chairperson Steve Owens commented: "Two people died and the surrounding community was put at risk because of a completely preventable mistake. Companies must ensure that hazards are clearly identified and that effective procedures are in place to protect workers in facilities like this and the people who live and work nearby."

The CSB's final report concludes that the incident resulted from the failure to positively identify the correct equipment before mistakenly opening the piping that contained hydrogen sulphide instead of the piping that had been clear of the toxic gas. Contributing to the severity of the incident, says the CSB, was the refinery's failure to adequately assess the hazards of conducting pipe-opening activities in an active unit next to an area where numerous other workers were present. The investigation also found that deviations from established policies and procedures contributed to the event.

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

Key findings

Positive Equipment Identification: the CSB found that the refinery lacked an effective method to clearly identify the correct piping flange before work began. Drawings and flange lists were insufficient to distinguish nearly identical segments, and the identification tag for the correct flange was placed out of view. Without reliable identification, workers searched for unlocked flange devices similar to what they had seen elsewhere in the refinery. The CSB noted that accidental releases from opening the wrong equipment are common in the chemical and refining industries and that no industry-wide standard currently addresses this issue.

Work Permitting and Hazard Control: the refinery issued a broad work permit covering multiple jobs with varying hazards and without clear hold points. Workers overlooked a written instruction to stop work and obtain an operator's presence before opening the hydrogen sulphide piping. The permit also failed to address the hazard of opening piping in an operational unit upwind of other contractors.

Turnaround Contractor Management: On the day of the incident, workers were reassigned from a shutdown unit to a partially operational unit containing hydrogen sulphide. This change, combined with the proximity of the units, led workers to believe they were still working in the shutdown environment, and they were not specifically informed of the risks in the operational unit.

Conduct of Operations: The CSB identified gaps between written procedures and actual practices at the facility. While the refinery's policies aligned with industry standards, management and operations personnel often misunderstood or deviated from them, contributing to failures in work permitting and hazard evaluation.

According to CSB Investigator-in-Charge Tyler Nelson: "Opening hazardous process piping is a common maintenance activity that can be performed safely with effective equipment identification and work permitting practices. This tragic incident underscores the critical importance of equipment identification methods that are clear, consistent, and verified by both facility operators and contract workers before equipment is opened. Strong equipment marking practices, effective work controls, and disciplined operations are essential to preventing deadly releases like this one."

Recommendations

The report issues several safety recommendations to Pemex Deer Park Refinery and the American Society of Mechanical Engineers (ASME). Firstly, it recommends Pemex Deer Park label all piping in the relevant unit at the refinery in accordance with ANSI/ASME A13.1. It also recommends that the company implement procedures to ensure that workers reassigned to units in "positive isolation status" are clearly informed of associated hazards and safeguards before beginning work, and that they establish a comprehensive conduct of operations system consistent with the Centre for Chemical Process Safety's guidance on operational discipline, including enforceable performance metrics and routine audits.

Separately, the CSB recommended that ASME develop written guidelines establishing a standard practice for marking equipment prior to opening, including clear identifiers and requirements for removing markings after work is complete.

Sulphuric acid in South America

While Brazil is the largest consumer, trade in acid in South America has been dominated by Peru and Chile.

South America is a relatively small part of the overall sulphuric acid market, consuming about 19 million t/a of acid, or 6% of all production, split roughly evenly between Brazil's phosphate fertilizer industry and the copper industries of Chile and Peru. However, Chile's considerable need for acid for copper leaching operations makes it one of the largest importers of acid worldwide, and makes the continent a significant factor in global acid trade.

As Table 1 shows, the major producers are Brazil, Chile and Peru. However, there is considerable difference in how that acid is generated. Brazil only has around 300,000 t/a of smelter acid production, and relies upon sulphur burning acid plants to produce all of the acid for its phosphate plants. Chile and Peru, conversely, generate most of their acid from copper smelting. Chile imports large volumes of acid, mainly from neighbouring Peru, as well as Japan, South Korea, China and Mexico.

Brazil

Brazilian phosphate demand continues to climb, and with it phosphate production and demand for sulphuric acid. Most Brazilian acid production is fed from imported sulphur. Brazil imported 2.3 million t/a of sulphur in 2025, 95% of it to manufacture single superphosphate (SSP) and mono- and diammonium phosphate (MAP/DAP) fertilizer production. Sulphur 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-March 2024, and it was expected to reach full output by the end of 2025. The facility will add an additional 330,000 t/a of sulphur consumption to Brazil. Growing demand is expected to maintain import growth throughout the rest of the decade, with Brazilian sulphur imports reaching 2.9 million t/a in 2030, feeding total acid production of 9.6 million t/a in that year. Imports of sulphur are forecast to climb in 2026, despite an expected slower rate of demand in 2026 Q1.

PHOTO: JOSE LUIS STEPHENS/SHUTTERSTOCK

Copper cathodes at an SX/EW plant, Antofogasta, Chile

Chile

Chile's acid position is dominated by the copper market. Chile holds the world's largest share of known copper reserves, at 21.3%, according to the United States Geological Survey (USGS). Chile also represents about 25% of global copper

Table 1: **Sulphuric acid production and consumption in South America, 2025 (million t/a)**

Country	Production	Consumption	Imports	Exports
Argentina	0.4	0.5	0.2	0
Brazil	8.1	8.7	0.5	0
Chile	4.5	8.4	3.8	0
Peru	1.9	0.8	0.2	1.1
Others	0.2	0.4	0.1	0.1
Total	**15.1**	**18.8**	**4.8**	**1.2**

Source: Xxxxx

output, mainly in the north of the country. Copper markets, although volatile, have generally been buoyant over the past few years with prices high, assisted by supply disruptions among major producers (including Chile) and a weak US dollar. Copper prices of around $12,000/t have been seen at the end of 2025 and into 2026. Copper demand is expected to grow 2.6% annually out to 2030, outpacing supply growth of 2.4%, mainly due to Chinese demand, particularly for electric vehicles, leading to projected deficits forecast for remainder of the decade. However, part of the reason for this mismatch between supply and demand has been falling copper production from Chile. Copper cathode production in Chile has actually declined over the last decade, from 1.8 million t/a in 2015 to 1.2 million t/a in 2025 – a 3.8% annual fall. Much of this has come from ageing mines and falling ore grades. News that Codelco and Glencore will partner on a new smelter and cathode refinery in the Antofagasta region is a positive for Chilean refined copper production, although with construction not expected to start until 2030, it sits beyond the medium term forecast.

In spite of this fall in output, Chile's sulphuric acid consumption has remained broadly stable at an average of 8.2 million t/a. This is due to an increase in the consumption ratio from acid leaching projects, which has risen from an average 4.5 tonnes of acid being required to generate each tonne of copper in 2015 to 6.9 tonnes of acid per tonne of copper in 2025, as ore grades fall. Continued growth in acid demand has thus become increasingly reliant on the start-up of new, high acid consuming projects, as well as the extension of existing assets with high acid demand rates.

Overall Chilean sulphuric acid demand in 2025 was down slightly on the 2024 figure, falling from 8.3 to 8.2 million t/a due to some maintenance shutdowns at existing operations. This is expected to recover in 2026 to 8.4 million t/a, driven by a rebound in demand at the Radomiro Tomic and Mantoverde projects, although the closure of the Mantos Blancos site will partially offset overall copper performance, and there will be a continued decline in demand from existing copper operations. The reduction of these will be recorded from the Centinela and Chuquicamata project, with a total 300,000 t/a of acid demand being lost, while acid consumption at Radomiro Tomic is expected to rebound by 200,000 t/a. Looking forward, the project landscape is composed of a mix of restarts or extensions of existing assets, and projects deploying alternative leaching technologies. Extensions are planned at Spence and El Abra, for example, although this will only serve to maintain acid demand at its current level.

Chilean acid consumption is set to continue increasing throughout 2030. The Marimaca project, expected to start operations by 2028, will add 400,000 t/a of acid consumption. Additionally, the sulphide leaching at Gaby (expected to start in 2029) and the Collahuasi bioleaching project (anticipated to come online in 2028) are forecast to add 100-200,000 t/a of new acid consumption by 2030. Region II (Antofagasta) is expected to increase acid consumption to 7.50 million t/a by 2030 from 6.77 million t/a in 2025. Supply in Region II is also expected to climb, but at a slower rate, with output up from 2.53 million t/a in 2025 to 3.13 million t/a in 2030.

Supply will also increase more generally. In part this will be due to the start of the proposed Marimaca sulphur burner but also an anticipated increase output at smelters. The unplanned outages at the Altonorte (2025 Q2) and Potrerillos (2025 Q3) smelters cut a total of around 300,000 tonnes of acid supply last year. The Altonorte issue triggered buyers to commit to new imports, which pushed 2025 Q2 arrivals to a 6-year high. Total imports for 2025 reached 3.8 million tonnes, representing a 10% increase year on year. Smelter availability is expected to recover in 2026 once the supply disruptions ease, which will reflected in lower import requirements. Supply is also expected to increase in central Chile with production recovery expected at Codelco's Caletones smelter in Region 6. However, long-distance imports will still be required in the country, as supply is only anticipated to grown moderately. The result is that the requirement for imports is expected to increase, with a combination of European and Asian volumes necessary to meet demand needs. At the same time, Peruvian volumes available for the Chilean market are expected to decline with the start-up of the Tia Maria project, which will consume around 600-700,000 t/a of acid from 2028 (see below).

Peru

Like Chile, Peru's acid industry is dominated by copper extraction. Peru is the world's second-largest copper producer, with production approximately 2.8 million t/a in 2025, supported by major operations like Cerro Verde, Antamina, and Las Bambas. While output increased 1.6% across 2025, production faces a plateau due to a lack of new, large-scale projects and declining ore grades. However, there is positive news on the horizon, with the long-delayed Tia Maria mine expected to be commissioned in late 2027. The project is expected to add 800,000 t/a of acid demand, accounting for 60% of Peru's total consumption. Other demand is expected to decline as existing mines reduce output and cut acid consumption by 2030.

Peruvian smelter acid production will remain broadly stable though the medium term, and will be sufficient to meet increasing domestic demand. The ramp-up of the PetroPeru facility will add around 100-200,000 t/a of supply by 2026, increasing exports in the short term. But once Tia Maria starts up, export volumes are expected to fall to around 700,000 t/a from 2028. This will reduce Peruvian supply into Chile. While the long-running relationship between Peruvian acid surplus and Chilean consumers will remain intact, the scale of demand that Peru can serve will fall. Peru is also expected to remain a minor acid import destination with the Mina Justa operation currently engaged in around 300,000 t/a of international trade.

Argentina

The sulphuric acid market structure in Argentina has been mainly focused on single superphosphate manufacture and some industrial-based consumption, with an annual demand of around 500,000 t/a. However, new copper-based consumption is expected to double Argentina's acid demand by 2030. The start-up of McEwen's Los Azules copper project will significantly boost acid demand in the country. Construction is expected to begin in 2026, with a target for initial production by 2030. Acid demand from the project is anticipated to reach 400,000 t/a, doubling the country's total acid consumption in 2025. The project is expected to include a sulphuric acid plant at peak consumption, sourcing 800,000 t/a from the burner. Therefore, acid needs are expected to be largely met by local acid availability, with a minor impact on the traded market.

SulGas® Mumbai 2026

The 8th SulGas® Mumbai sulphur recovery and gas treating conference and exhibition, organised by Three Ten Initiative Technologies LLP, took place on 5 and 6 February 2026. We report on some of the key topics on the agenda.

PHOTO: THREE TEN INITIATIVE TECHNOLOGIES

Attendees of SulGas® Mumbai 2026

SulGas® 2026 returned to the Holiday Inn, Mumbai for this year's event, bringing together public-sector oil companies, private refiners, licensors, engineering companies, solvent and column equipment manufacturers, as well as control and instrumentation companies. This year saw participation from over 155 attendees representing more than 68 companies across various areas of sulphur handling and gas processing.

The conference's agenda featured ten sessions covering:

- Amine unit performance and energy optimisation
- Liquid treating
- Gas dehydration
- SRU controls and upset management
- SRU oxygen enrichment
- Innovations in carbon capture
- SRU thermal integrity and safety
- Sulphuric acid technologies
- SRU modelling
- Tail gas and degassing.

The conference featured 26 speakers in interactive technical sessions, fostering maximum technical exchanges among participants. Each session concluded with a detailed panel discussion, sparking valuable dialogue between the audience and speakers.

An additional valuable feature of 310i's knowledge forums is the open house session that allows unhindered discussion on any topic of interest to the audience, including plant problems, follow up questions with speakers, and experience sharing from all the stakeholders.

Some of the topics discussed at the conference are highlighted below.

Optimising the energy demand of an amine reboiler

Amine plants play an important role in protecting the environment. They remove H_2S and CO_2 from sour gas and liquid hydrocarbon streams, allowing them to be safely burned, vented to the atmosphere, or sold into households. A well operated amine system will make sure that the treated gas stream meets the strict specifications. However, if not fully understood, the amine plant can be very inefficient, using far more energy than necessary. On the other hand, over-optimisation of the energy consumption can adversely affect the system, potentially leading to corrosion issues.

When regenerating the amine, it is critical to first and foremost prevent acids (H_2S and CO_2) from entering the reboiler in large enough quantities that they will cause corrosion, and secondly the amine must be regenerated enough such that each absorber in the system meets the specification for its treated gas stream.

Ben Spooner of SGS Amine Experts discussed how to determine the optimal energy input needed in the amine reboiler and recommended the following steps:

- Optimise the amine circulation rate to each absorber.
- Set the heat duty to the reboiler as a ratio with the total amine arriving at the regenerator.
- Fine-tune the ratio set point with the regenerator overhead temperature measurement.
- Doublecheck the ratio and overhead temperature readings are correct by calculating the ratio of the flow rates of reflux water to amine.
- Use a simulator to verify that:
- The amine increases in temperature from the moment it enters the regenerator.
- 95% of acid gases are stripped from the amine before it enters the reboiler.
- In the vapour return line from the reboiler to the regenerator there less than 0.5 mol% H_2S and CO_2.
- If there are heat stable amine salts present these must be input into the simulation or the last two points will not be accurate.

Instrumentation solutions for reliable and safe operation of the SRU

In refinery processing, maintaining instrumentation for sustainable and reliable operation of the sulphur recovery unit and the tail gas treating units can be difficult due to frequent choking, sulphur deposition and corrosion issues.

Due to stringent emission control norms and environmental regulations, the reliability, safety and efficiency of the SRU and TGTU have become a primary focus at BPCL Bina Refinery, which operates an SRU with three trains with a capacity of 3 x 243 t/d, commissioned in 2010.

Nirmalya Nandi of Bharat Petroleum Corporation Limited shared the methodologies and innovative solutions implemented by the instrument team at BPCL to address the challenges of frequent choking and instrument failure, aimed at ensuring continuous safe operation.

The methodologies employed focused on:

- Process monitoring enhancement: Upgrading physical instrumentation to monitor pressure profiles and flame intensity.
- Logic and interlock upgrades: Converting trip logic from 1oo1 (one out of one) to 2oo3 (two out of three) to prevent spurious trips and enhance reliability.
- Automation schemes: Developing stoichiometric calculation schemes for air demand and auto-loading configurations for dispatch.
- Physical hardware modifications: Implementing purging arrangement and steam jackets to combat sulphur solidification and deposition.

Collectively, through the strategic implementation of these solutions the SRU and TGTU at BPCL Bina Refinery have transitioned from being potential bottlenecks to highly reliable units with an operation availability of more than 95%.

The hybrid optimised SRU

Ayan Dasgupta of Fluor Daniel India Pvt. presented a case study for a hybrid sulphur recovery unit design, which integrates acid gas enrichment with high level oxygen-enriched operation, to deliver an optimal balance of cost, efficiency and reliability. The case study demonstrated that these systems can operate seamlessly while achieving energy and cost savings, maintaining environmental compliance, and improving plant uptime.

By adopting a smart, flexible oxygen-enrichment strategy, modern gas processing plants and refineries can achieve higher sulphur recovery rates, lower emissions and enhance operational reliability driving both performance and profitability in sulphur recovery operations.

Technical benefits such as higher thermal efficiency, elimination of spare trains and reduced energy consumption combined with operational advantages like flexibility and resilience, enable facilities to manage throughput variability and maintenance downtime without flaring or capacity loss. This approach is particularly valuable for plants with space constraints or those seeing to revamp existing units for increased capacity and performance.

Simulation for amine treatment of hydrocarbon liquids

Liquid extraction is widely used in the refining and natural gas industries for a variety of applications, including to strip sulphur compounds, mainly H_2S, COS and mercaptans from LPGs and NGLs. Yet despite its wide use, designing these units with confidence has remained elusive due to the complete lack of commercial models. In practice, engineers often rely on ideal-stage calculations supplemented by anecdotal estimates for tray efficiency or HETP values. This approach takes no account of how the treater's actual internals, dispersed phase selection, flow rate it handles, or the composition and temperatures of the streams feeding it affect its performance.

Dr. Anand Govindarajan of Three Ten Initiative Technologies reported on a new mass transfer rate-based liquid treater model, which allows engineers, for the first time, to be able to analyse and predict the performance of trayed and packed treaters in acid-gas liquid hydrocarbon service with the same reliability that rate-based simulation of gas treatment using amines has provided for the past 30 years.

The simulation's calculations include the Sauter mean diameter of the dispersed-phase droplets (which helps set the interfacial area and hydraulics within and outside the droplets), as well as tray-by-tray and packed segment-by-segment interfacial compositions and fluxes. These results provide insight into the operating regime, specifically whether the separation is limited by phase equilibrium or by mass transfer, and which phase is limiting. Interfacial area and interfacial tension are also calculated. Simulations are predictive and not reliant on empiricism.

Until now the effect of tray details such as sieve hole size and tray spacing, and packing details such as type, material and size on treater performance has remained largely unknown. Even the effect of amine type and strength on the removal of sulphur compounds from LPGs has remained unexplored. Rate-based simulation is a game changer allowing the effect of all relevant parameters to be quantified.

Addressing the safety concerns of oxygen enrichment

The benefits of oxygen enrichment in sulphur recovery units are well known, oxygen provides a useful debottlenecking solution for hydraulically limited SRUs, allowing substantial increases in capacity for revamped plants and reducing the size of greenfield oxygen-based SRUs. Replacing air with oxygen in a Claus combustion chamber reduces the gas volume to be heated, eliminating the need for preheaters, which lowers investment costs, plot space and complexity. Higher combustion chamber temperatures as a result of oxygen enrichment improve the destruction of impurities like BTX or NH_3. Many refineries and gas processing units dealing with lean acid gas face a challenge in maintaining the required reaction furnace temperature for effective contaminant destruction. Traditionally, the solution has been co-firing with natural gas, which is an expensive fuel source that generates Scope 1 CO_2 emissions. Oxygen enrichment naturally elevates the adiabatic flame temperature by eliminating the nitrogen heat sink, achieving high operating temperatures without the need for supplemental fuel gas.

Despite these benefits, the adoption rate of oxygen enrichment in the industry has often been held back by industry reluctance regarding oxygen usage due to the risks of internal ignition or combustion. Alexander Haenel of Air Liquide Global E&C Solutions addressed some of the most common concerns in his presentation, expressing that oxygen is not a hazard, rather it is a utility that requires respect and proper engineering. The risks are manageable. The primary hazards, often caused by inappropriate velocities, improper material selection, or weak protective barriers, can be effectively mitigated through a rigorous, risk-based design approach. Safety should be managed by strictly adhering to ignition prevention strategies and consequence mitigation, ensuring that oxygen systems are designed according to proven guidelines and standards. When treated with the correct engineering discipline, oxygen transforms from a safety concern into a powerful tool for operational flexibility.

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The secrets of successful sulphur strategies

Efficient sulphur recovery is essential for modern refineries to meet stringent environmental regulations and support sustainability goals. **Debopam Chaudhuri**, **Pranay Veer Singh** and **Vaneet Garg** from Fluor examine the key design considerations, smart design strategies and flexible sulphur block configurations that are essential in achieving an overall optimised design. Together, these strategies enhance efficiency, reduce emissions, improve reliability, and provide flexibility for changing crude qualities, ensuring compliant and economically robust refinery operations.

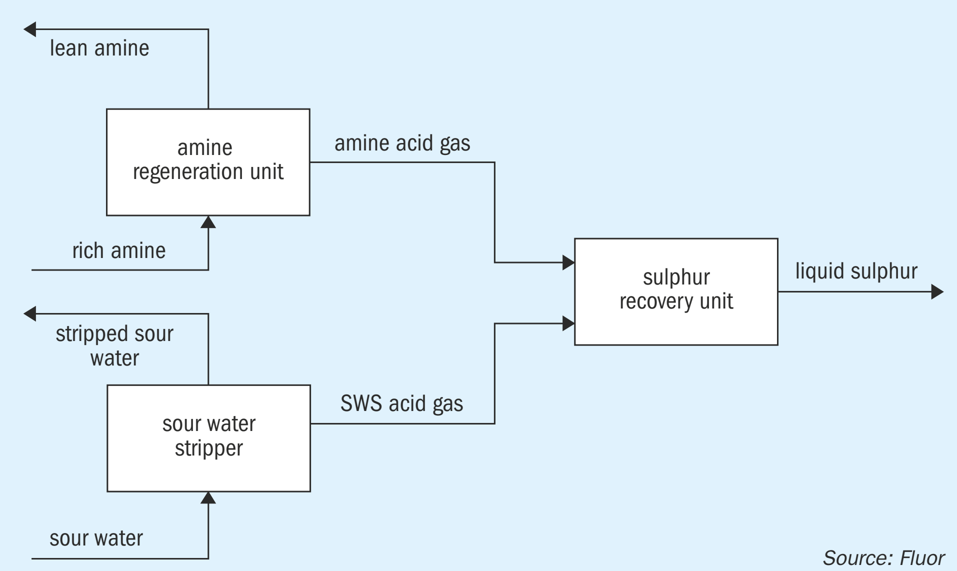
Sulphur recovery is a cornerstone of modern refining and gas processing, driven by stringent environmental regulations and the growing need to minimise emissions. Compliance with these regulations is not optional, it is a critical requirement for refineries and gas plants to operate responsibly and sustainably. Beyond regulatory obligations, efficient sulphur management plays a vital role in protecting air quality, reducing environmental impact, and supporting global sustainability goals.

This article explores strategies for integrating three key units: the amine regeneration unit (ARU), sour water stripper (SWS), and sulphur recovery unit (SRU) – collectively forming the sulphur block. Each of these units performs a distinct yet interconnected function. The ARU regenerates the circulating amine by removing absorbed acid gases such as hydrogen sulphide (H_2S) and carbon dioxide (CO_2) from rich amine streams to generate lean amine. The SWS treats sour water streams, stripping ammonia (NH_3) and H_2S to produce acid gas for further processing while generating stripped sour water for reuse. These streams converge at the SRU, where the Claus process converts H_2S into elemental sulphur, eliminating SOx emissions, ensuring compliance with emission standards and minimising environmental impact.

Efficient sulphur management is achieved through the integration of these three units, which collectively form the backbone of refinery operations for sulphur management. This synergy not only optimises sulphur recovery but also reduces energy consumption and enhances reliability across the entire process chain. By converging these systems, refineries adopt a holistic approach to sulphur handling, effectively reducing operational bottlenecks and improving overall plant efficiency. Such integration is critical for meeting sustainability goals while maintaining economic viability in an increasingly competitive industry.

As environmental standards become more stringent and the demand for cleaner fuels grows, the importance of robust sulphur recovery systems will continue to rise. While the need to be more efficient in operation and design will continue to mandate a 'leaner' sulphur block for the facilities. The strategies discussed in this article aim to transform sulphur recovery from a compliance-driven necessity into a value-added process that supports operational excellence and long-term profitability.

Fig. 1: **Simplified block flow diagram of the sulphur block**



Source: Fluor

The sulphur block

The sulphur block comprises three primary units, the ARU, SWS, and SRU, working together to recover sulphur and meet environmental norms. It is a critical configuration in refinery operations, designed to efficiently manage sulphur compounds and ensure compliance with environmental standards. Each unit plays a distinct yet interconnected role in the overall sulphur management process. Fig. 1 shows the very high level interaction between these three units.

Amine regeneration unit

In refinery hydroprocessing units, hydrogen sulphide is removed from hydrocarbon streams using amine solvents, most commonly a hindered tertiary amine such as methyldiethanolamine (MDEA). The amine solution, now rich in absorbed H_2S, is regenerated in the ARU in a regenerator column, releasing H_2S gas and producing lean amine for reuse. This closed-loop system enables continuous H_2S removal from multiple refinery streams. The liberated H_2S-rich gas is routed to the sulphur recovery unit.

Sour water stripper unit

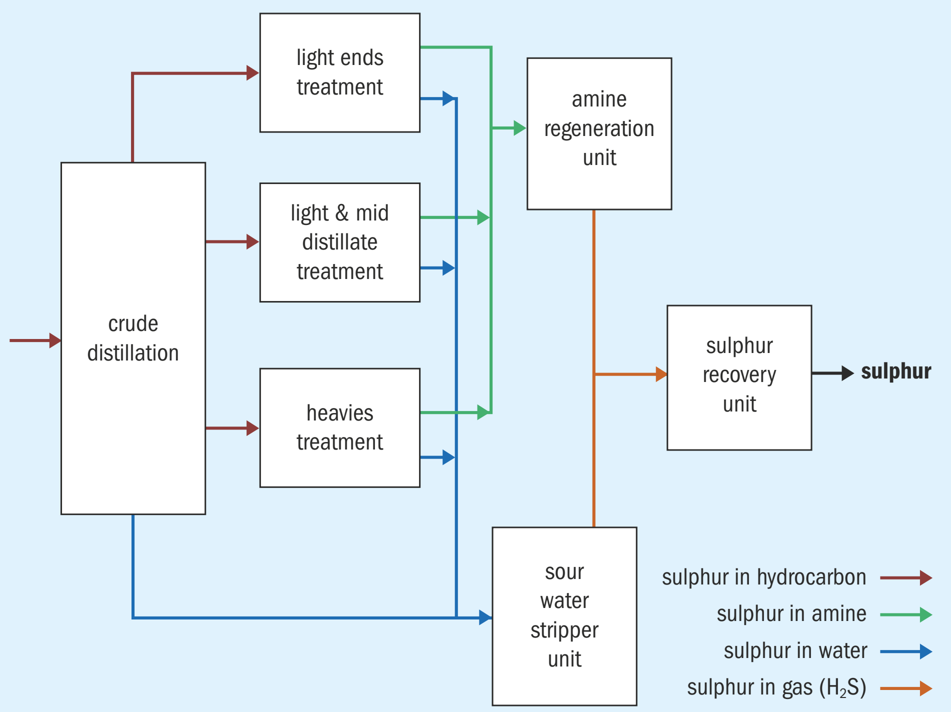
Various process units generate sour water containing dissolved H_2S and ammonia. The SWS unit strips these contaminants, producing an acid gas stream rich in H_2S and NH_3. This stream is also sent to the SRU. The presence of ammonia adds complexity to SRU design, as it can lead to undesirable byproducts if not properly managed, thus requiring additional check points in designing of the sulphur block.

Sulphur recovery unit

The SRU processes combined H_2S-rich gases from the ARU and SWSU, converting H_2S into elemental sulphur for storage, transport, or sale. Most typically the modified Claus process is implemented to convert the H_2S to elemental sulphur, complemented by a reduction-absorption-regeneration based (amine based) tail gas treatment unit (TGTU). The modified Claus process implements the thermal stage followed by a catalytic stage for the conversion of H_2S to elemental sulphur. A sulphur degassing block to purify the product sulphur, and a thermal oxidiser stage to incinerate any unrecovered H_2S completes the configuration of the SRU.

Together, the ARU, SWSU, and SRU form a critical subsystem in refinery operations. By integrating these units into a cohesive sulphur block, refineries streamline operations, minimise bottlenecks, and enhance overall efficiency. This synergy not only ensures regulatory compliance but also supports sustainability objectives, making the sulphur block an essential component of successful refining operations.

Fig. 2: **The sulphur map**



Source: Fluor

Understanding synergy strategies

Design basis for the sulphur block

The sulphur block in a refinery is designed based on the amount of sulphur present in the crude oil and how it is distributed across different process streams. Correctly estimating this sulphur load is essential for determining the optimum capacity (size) of the ARU, SWS and SRU. At the same time, it is important to understand the overall refinery operational reliability for the design of the sulphur block – in particular the train configurations for each of the units. Fig. 2 shows a bird's-eye view of the sulphur movement across various processing units in the refinery starting from the crude oil and ending up finally in the SRU.

There are two main design approaches: backward integration and forward integration.

Backward integration starts with the SRU, calculating its capacity based on total sulphur recovery needs. From there, the ARU and SWS capacities are determined. This approach ensures compliance with environmental regulations and sulphur recovery targets.

Forward integration begins with upstream process units, estimating acid gas and sour water generation to size ARU and SWS first, then the SRU. Forward integration often results in oversized equipment because peak loads in upstream units rarely occur simultaneously – a non-coincident peak scenario.

An optimised design balances these approaches, considering variations in upstream processes to avoid unnecessary costs while maintaining reliability. Proper integration of these units ensures efficient sulphur handling, reduced emissions, and sustainable refinery operations.

A simple case study data is shared on how the sulphur load of a refinery is estimated using the backward integration method to determine the SRU capacity. This case study considers a refinery expansion project to increase its crude processing capability to 15 million t/a. The design case of the refinery operation with respect to the maximum sulphur load is based on processing a mix of high sulphur crude (Basra Light) and low sulphur crude (Bonny Light) and generating a mixture of fuels and hydrocarbons for downstream processes. A mix of Basra Light and Bonny Light in a ratio of 80-20 is considered for sulphur balance as the worst feed with respect to

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the sulphur content. Based on the actual mathematical sulphur recovery capacity (971 t/d), the real capacity of the sulphur recovery may be selected by adding a margin. The margin typically is 10% or 15% over the calculated plant capacity thus the total expected plant capacity would have been 1,100 t/d in case this would have been a greenfield refinery project.

Since the example cited in Table 1 is for a refinery revamp, the new sulphur plant capacity depends on the existing and available sulphur handling capacity of the refinery. And this refinery already had an installed total sulphur handling capacity of 495 t/d (two non-identical trains – an old 195 t/d train and a more recent 300 t/d train), thus the additional sulphur handing capability that was demanded after the revamp was 476 t/d. Taking an additional design margin of 10%, the required capacity is fixed at 520 t/d. But while considering the SRU design capacity the old train was not considered and hence the required capacity was finalised at 720 t/d. And to accommodate operational variations, the new SRU train configuration was fixed at 2 X 360 t/d. This configuration allowed for maximum flexibility in the refinery operation and had minimum impact on the refinery throughput with one SRU train becoming unavailable.

The new ARU and SWSU capacities were based on the sulphur load and considering the additional details from the various processing units. For the ARU, the peak simultaneous sulphur load and the amine circulation rates were considered for the plant capacity, considering non-concurrent design loads always lead to overcapacity. And similarly for the SWS unit, the sour water stripping load was based on the concurrent sour water effluent loads from the process units.

Determining the SRU inlet pressure

The inlet pressure of the sulphur recovery unit is an important design factor that influences both process performance and general equipment size of the unit. This pressure is mainly controlled by the operating conditions of upstream units such as ARU and SWS unit. Choosing the right pressure ensures smooth operation and proper integration within the sulphur block.

Higher SRU inlet pressure has certain benefits and drawbacks. On the positive side, it reduces the size of SRU equipment, which lowers capital costs and saves space. However, it also increases the demand for low-pressure steam in the ARU and SWS reboilers, leading to higher energy consumption. On the other hand, operating at lower pressure reduces steam requirements but results in larger SRU equipment, which can increase costs and footprint. Hence it is imperative that the units within the sulphur block synergise to find the sweet spot of plant operation.

Industry practice recommends a column-top pressure of around 1 barg as it balances energy efficiency and equipment sizing, reducing steam demand while maintaining operability. Finalising this pressure requires careful consideration of upstream conditions and process constraints to ensure reliable, cost-effective, and efficient sulphur recovery.

This pressure also plays an important role in revamp projects which translates to very small increase in sulphur loads which does not demand any major revamp or modification in existing unit designs. A small increase in sulphur operation loads can be met by making small changes in the SRU, and the higher process gas then would translate to slightly higher pressure drops in the unit, demanding a higher unit battery limit pressure. In such cases the operating pressures of the ARU and SWSU columns are increased to the limit of their operations, allowing a higher battery limit pressure at SRU.

SRU capacity control

Managing capacity in a multi-train sulphur recovery unit setup is crucial for maintaining stable and efficient operations in refineries. Typically, these configurations include several SRU trains working in parallel to handle varying acid gas loads. The muti train concept is mainly to manage the refinery operations such that the availability of the SRU is maintained and planned shutdowns of the SRU are linked to planned turnarounds of the overall refinery.

Under such configurations, all but one SRU train run at a fixed load, with only one train 'floating' with the acid gas header pressure. There is a master pressure measurement and controller on the main acid gas header. The signal form this pressure controller is fed to one of the flow controllers of the SRU acting as the master – cascade control loop, such that all changes in pressure due to variations in the acid gas generation rate from the upstream unit is managed by fluctuating the acid gas flow into that train of SRU. The other trains operate on a fixed flow, while the flexibility in design is available allowing

Table 1: **Sulphur balance**

	Tonnes/day	Sulphur (ppmw)	Tonnes/day of sulphur
Feed			
Basra Light	36,000	28,300	1,018.8
Bonny Light	9,000	1,500	13.5
Total feed sulphur			**1,032.3**
Products			
Naphtha	589	177.2	0.10
Jet fuel	91	1,685.9	0.15
Kerosene cut	2,079	1,685.9	3.50
Motor Spirit – BS IV	5,251	40	0.21
Motor Spirit – BS V	1,215	8	0.01
Diesel – BS IV	19,950	40	0.80
Diesel – BS V	7,253	8	0.06
Light diesel oil	93	2,667.1	0.25
Bitumen	661	47,265.7	31.24
SHC pitch	724	23,080	16.71
Internal fuel oil	798	4,851.2	3.87
Coke burnt FCC - 1	133	5,182.4	0.69
Coke burnt FCC - 2	130	27,679	3.60
Total product sulphur			**61.20**
Balance for plant capacity			**971.1**

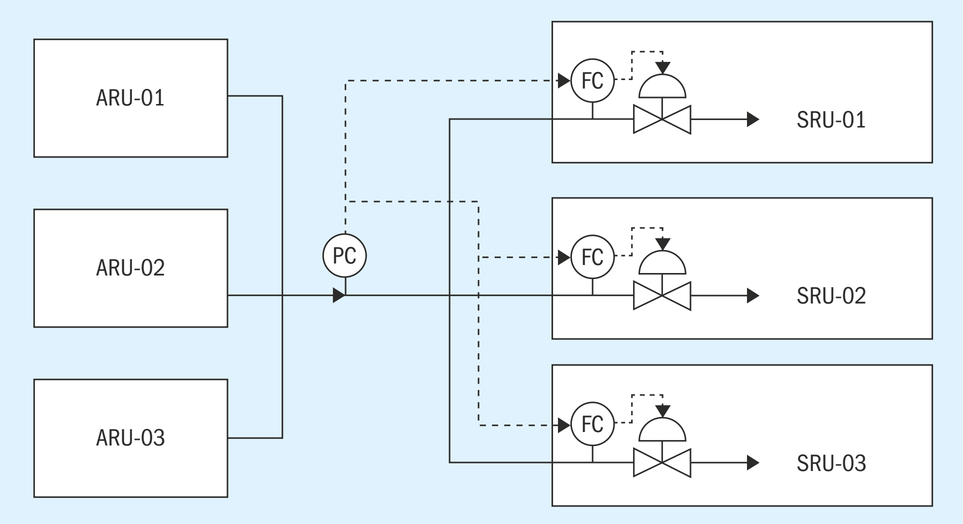
Source: Fluor

operator to choose any train of the SRU as the 'floating' train. This is applied for both the acid gas system – amine acid gas from the ARU and SWS acid gas from the SWS unit. This floating train absorbs acid gas fluctuations, but robust control logic and alarms are essential to prevent overload. This approach ensures that most trains run under steady conditions, reducing complexity and improving predictability (Fig. 3).

The floating train plays a key role as a buffer. It adjusts automatically to changes in acid gas flow from upstream units – ARU and SWS unit. By responding to header pressure, it absorbs fluctuations without disturbing the fixed trains. However, this flexibility comes with a trade-off – only the floating train is exposed to operational variations, a small overall variation enunciates a larger variation as only one train gets exposed to the entire deviation. This makes the floating train more susceptible to process upsets and requiring robust control systems.

This method strikes a practical balance between reliability and adaptability. It prevents all trains from continuously adjusting, which could lead to instability and higher operator interventions. Effective implementation requires precise control logic and monitoring to avoid overloading the floating train. When applied correctly, this strategy optimises sulphur recovery, minimises downtime, and ensures smooth operation in multi-train SRU configurations, with minimum operator involvement.

Fig. 3: **SRU capacity control**



Source: Fluor

ARU and SRU – common solvent

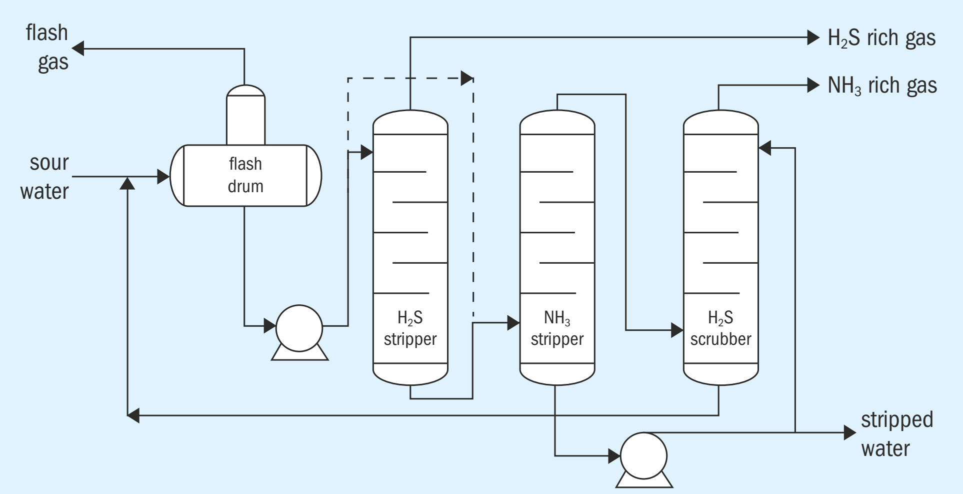
Using a common amine solvent for both the amine regeneration unit and the sulphur recovery unit is a practical possibility as theoretically the amine-based solvent used in the ARU and the TGTU section of the SRU are both designed to selectively absorb H_2S from the acid gas streams. And using a common solvent definitely offers significant potential for cost savings and operational efficiency. By standardising the solvent across these units, refineries can simplify processes and reduce complexity in handling and storage.

One of the major benefits of this approach is the possibility of using a shared regenerator, which minimises equipment duplication and lowers capital expenditure, while adding a little complexity in the piping system to cover for both the amine system. Additionally, managing a single solvent system reduces the need for multiple tanks, pumps, and associated infrastructure, leading to streamlined operations and reduced maintenance requirements. This is a more practical approach as the amine tank is typically used only for inventorying and solvent make-up periods, and is mostly not used or kept empty.

However, implementing a common solvent system is not without challenges. The main challenge is linked to the differences in lean/rich loading for the ARU and the TGTU of the SRU. The design basis for the amine solvent system for the ARU and TGTU differs due to variations in rich and lean amine loading. The ARU typically handles higher acid gas concentrations, thus the amine design in most cases are rich-pinched; while the SRU requires a much leaner lean solvent concentration and precise control to ensure optimal sulphur recovery, and the design of the amine solvent system is lean-pinched. And thus to achieve the required leanness in many TGTU designs the amine solvent has certain additives or is formulated for an efficient design – requiring lesser steam for stripping.

Although it is not impossible to design a common amine solvent, these differences in design concepts must be carefully addressed during design to avoid operational constraints. Successful adoption of this concept requires thorough evaluation of process conditions, solvent characteristics, and regeneration requirements. When properly engineered, this strategy can deliver substantial economic and operational benefits without compromising system performance or reliability. For example, even when the steam demand for the common regenerator is higher than the added steam demands for the ARU and TGTU regenerator, there are benefits which might compensate for this higher operation and capital costs.

Fig. 4: **SWS configuration**



Source: Fluor

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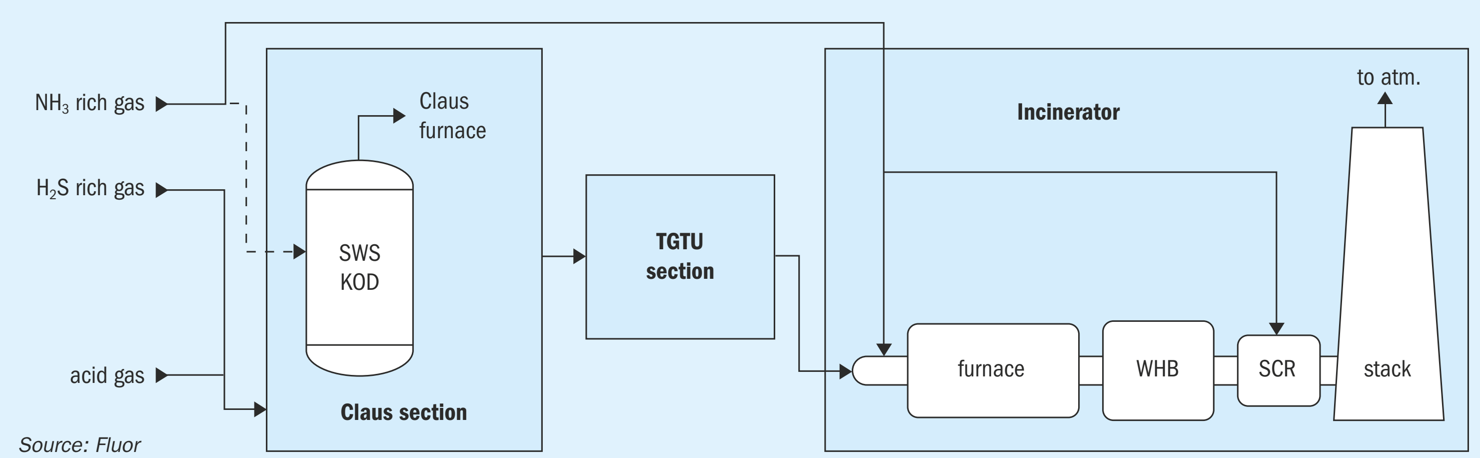
Fig. 5: **SRU design for management of sour gases from SWS**



Source: Fluor

SWS configuration

Optimising the sour water stripper design is critical, especially when processing high-nitrogen crudes and/or when the refinery is designed to operate with a diverse crude slate varying from low nitrogen to high nitrogen. In such cases, a two-stage SWS configuration offers significant advantages by efficiently separating hydrogen sulphide and ammonia from sour water streams. This approach enhances operational flexibility and reduces downstream challenges in sulphur recovery and SRU designs.

Refineries handling high nitrogen crudes can yield a total acid gas stream – mixed acid gas stream from ARU and SWSU – containing very high proportions of NH_3, such that processing of such gas streams becomes a challenge in the Claus section of the SRU. One key opportunity for the two-stage SWS system as shown in Fig. 4 is the fact that it generates an NH_3 stream separate to the H_2S stream. Instead of routing ammonia through the Claus reaction furnace, it can now be directed straight to the incinerator. This bypass strategy simplifies the Claus section, minimises operational risks, and improves reliability. Additional design modifications in the incinerator are necessary to manage the potential of high NOx problems due to burning high amounts of ammonia. The simplest solution for such issues is to include a selective catalytic reduction (SCR) unit and use a slip stream of the same ammonia in a SCR to manage the NOx. Alternatively, the recovered ammonia can be utilised as a valuable byproduct in certain applications, further enhancing process economics, if the market is available, thus even increasing the economic viability of the overall sulphur block.

The two-stage SWS design, shown in Fig. 4, exploits the differences in solubility and affinity for water between H_2S and NH_3. H_2S is considerably less soluble in water than NH_3. Therefore, the first column (the H_2S stripper) operates at higher pressure so that almost the entire H_2S load is removed, leaving NH_3 in the aqueous phase to be treated in the second column (the NH_3 Stripper). The second column must operate at much lower pressure to release NH_3 from the aqueous phase. As shown in Fig. 4, an additional H_2S scrubber column may be included to limit H_2S slip into the NH_3-rich gas stream, primarily to reduce SOx emission issues in the downstream SRU incinerator.

Case study data are presented for a refinery designed to operate on a diverse crude diet: Crude “A” – high sulphur, low nitrogen; and Crude “B” – low sulphur, high nitrogen. Table 2 shows how varied the acid-gas composition can be if a conventional single-stage SWS unit is used. The design implemented in this case study uses a two-stage SWS unit, with an SCR installed in the SRU incinerator. Fig. 5 shows the SRU design and how it manages the H_2S- and NH_3-rich streams. The H_2S-rich stream is routed to the front end (the Claus section) of the SRU for sulphur recovery, while the NH_3-rich stream is routed to the rear of the unit to the thermal incinerator, where it is burned off and released to the atmosphere. To meet NOx emission limits, a portion of the NH_3-rich stream is routed through the catalytic converter (SCR).

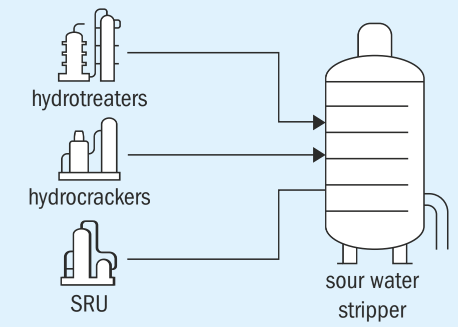
The two-stage SWS can also be operated as a single-stage unit, as shown by the dashed line in Fig. 4, allowing refiners to manage both low nitrogen and high nitrogen crudes with the same installed unit. By adopting a two-stage SWS design and optimising NH_3 management, refineries can achieve better sulphur recovery performance, reduce maintenance issues, and improve compliance with environmental standards.

Table 2: **SRU feed gas compositions**

	Crude A		Crude B	
Parameter	Acid gas from ARU	Acid gas from SWS	Acid gas from ARU	Acid gas from SWS
Flow, kg/h	6,200	1,090	970	1,350
H_2S, kmol/h	171.3	17.7	24.5	24.4
NH_3, kmol/h	0.1	17.4	0	27.7
Capacity, t/d S	145		38	
$(NH_3) : (NH_3 + H_2S)$, %	8.5		36	

Source: Fluor

Fig. 6: **Sour water route**



Source: Fluor

Sour water from the SRU

The major sources of sour water are the refinery's secondary process units — the hydrotreaters, the hydrocrackers, and the thermal crackers such as the FCC and DCU. Small sour-water streams are also generated by the SRU and the ARU, and these contribute to the facility's overall sour-water balance (Fig. 6). During early design, the sour-water flows from the SRU and ARU may not be available for finalising the SWS unit capacity. Therefore, it is prudent to use reference project data or other databases to estimate the sour-water volumes produced by the SRU and ARU. Although these streams are small in volume, they are significant to the overall sour-water system design: they are typically low in H_2S and have very low to negligible NH_3, but can represent roughly 10% of total sour-water generation, thus impacting the hydraulic design of the overall sour water system.

For design optimisation, it is essential to account for the normal purge rate from the SRU rather than peak values. Multiple sources generate sour water in the SRU, but many are intermittent. The routine sour-water purges from the quench-water system and the regenerator-reflux system of the TGTU should be included in the normal sour-water balance. Overestimating peak flows by considering the intermittent and emergency sour water flows can lead to oversized sour water stripper units, increasing capital costs without adding real operational benefits. By focusing on typical purge conditions, refineries can achieve a balanced design that ensures reliability while minimising unnecessary investment.

Lean acid gas system

Handling lean acid gas streams, particularly those with high CO_2 content, requires a specialised approach to maintain efficiency and reliability. These streams typically originate from renewable unit integrations or gasification processes, where acid gas composition differs significantly from conventional sources. The challenge lies in the low H_2S concentration, which impacts sulphur recovery performance in standard SRU configurations.

A practical solution is to design a separate train configuration for the ARU, SWS, and SRU dedicated to lean acid gases. This segregation ensures optimised treatment without affecting conventional trains.

A revamp case study is presented in which, for cost-effectiveness, only one of the existing SRU trains was upgraded for lean-gas handling by incorporating design enhancements to achieve high-level oxygen enrichment. Alternatively, in the absence of oxygen enrichment, fuel-gas co-firing provides a route to manage lean gas in the SRU. These modifications improve combustion stability and sulphur recovery efficiency despite the low H_2S content.

The case study in Table 3 shows that, after the revamp, co-processing all the lean gas with some rich acid gas from the existing ARU and SWS increases the hydraulic acid-gas load while producing lower sulphur quantities and reducing sulphur handling requirements. Therefore, high-level oxygen enrichment was included in the design to manage lean feed-gas processing in the SRU. Implementing oxygen enrichment allowed the unit to operate with the revised feed-gas composition even when processing appreciable quantities of lean acid gas. The advantages of implementing high level oxygen enrichment were:

- Minimum revamp needed – existing equipment (burner and furnace) replaced in situ and no impact on plot area
- Operational flexibility – unit able to operate over a wide range of feed gas compositions by managing the level of oxygen enrichment.
- No impact to the unit beyond the existing Claus furnace – operating capacity post revamp well below design values.

By isolating lean acid gas processing and applying targeted upgrades, refineries can avoid overdesigning all SRU trains while maintaining operational flexibility. This approach minimises capital expenditure, enhances energy efficiency, and supports integration with emerging renewable and gasification technologies.

Table 3: **Case study**

	Amine acid gas	TGTU recycle	SWS acid gas	Lean acid gas
Component, mol-%				
H_2S	90	30	33	11
NH_3	0	0	33	0
CO_2	5	65	0	81
H_2O	4	5	33	2
Balance	1	0	1	6
Total	100	100	100	100
Flow rate, Nm³/h				
Base (design case)	4,300	320	1,500	0
Post revamp	2,400	380	1,350	4,100
Sulphur production, t/d				
Base (design) case	150			
Post revamp	110			

Source: Fluor

Key takeaways

Designing and operating sulphur management systems requires a holistic approach to achieve efficiency, compliance, and flexibility.

First, optimised design considerations are essential to avoid overdesign, which can lead to unnecessary capital costs and operational complexity. Implementing rational strategies ensures that systems are right sized for actual process requirements.

Second, integrated environmental compliance plays a critical role in minimising emissions and pollutants. Proper synergy between units reduces SO_2 emissions, NH_3 slip, and water contamination, helping refineries meet stringent environmental regulations and avoid penalties.

Third, enhancing reliability through strong interface management prevents cascading upsets across interconnected units. Robust control strategies and communication between units are key to maintaining stability.

Finally, strategic flexibility for crude variability ensures adaptability to changing feedstock compositions and rate swings. Well-defined interfaces allow quick adjustments without compromising compliance or profitability.

These principles collectively support sustainable operations, cost efficiency, and regulatory adherence, making them indispensable for modern refinery design and operation.

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Sulphur plant tail gas incineration options

Sulphur recovery units in petroleum refineries and natural gas processing plants utilise incineration as a final treatment step for tail gas, ensuring that residual sulphur compounds are converted to less harmful emissions. **Elmo Nasato** of Nasato Consulting Ltd provides a comparison of the two sulphur plant incinerator options – thermal incineration and catalytic incineration – including key considerations for policymakers, businesses, and environmental advocates.

The treatment of sulphur-containing emissions is critical to environmental compliance and operational efficiency in sulphur recovery plants. Incineration is employed to oxidise hydrogen sulphide (H_2S) and other sulphur species into sulphur dioxide (SO_2), which can then be released under controlled conditions. The choice between thermal and catalytic incineration has significant implications for plant operations, emissions control, and overall cost-effectiveness.

This article compares two primary incineration techniques – thermal incineration and catalytic incineration – in terms of efficiency, environmental impact, operational costs, and practical applications. The sulphur recovery industry has primarily utilised thermal incineration due to the flexibility of operation. The choice between thermal and catalytic incineration has significant implications for plant operations, emissions control, and overall cost-effectiveness.

Sulphur tail gas incineration

The primary function of a sulphur tail gas oxidiser is to eliminate hydrogen sulphide, a highly toxic gas even at low concentrations. Typical emission limits for H_2S from an oxidiser range between 5 and 10 ppmv. In many applications, carbon monoxide (CO) emissions are also regulated.

In a tail gas Incinerator, essentially all the sulphur compounds in the incinerator feed stream(s) are incinerated to SO_2 by the high temperature oxidising atmosphere created inside the incinerator:

$$H_2S + 3/2O_2 \rightarrow SO_2 + H_2O$$
$$S + O_2 \rightarrow SO_2$$
$$COS + 3/2O_2 \rightarrow SO_2 + CO_2$$
$$CS_2 + 3O_2 \rightarrow 2SO_2 + CO_2$$

Heat is provided to the incinerator by combustion of fuel gas in the burner, and the fuel gas flow rate is adjusted to maintain the furnace temperature at a high enough temperature to ensure complete incineration of the sulphur compounds in the feed to the incinerator typically 1,200 to 1,400°F (650 to 760°C).

In recent years, much attention has also focused on other contaminants found in sulphur plant tail gas, such as carbon monoxide, nitrogen oxides, and hydrocarbons (particularly aromatic hydrocarbons). These contaminants often require higher incinerator temperatures to ensure adequate destruction (typically > 1,400°F (760°C)).

In a forced-draft incinerator, the incinerator temperature is also controlled by adjusting the fuel rate, but the combustion air is provided by combustion air blowers, which make it easier to maintain the proper amount of excess oxygen in the vent gas, thus ensuring complete destruction of all combustibles in the feed stream(s) to the incinerator and very importantly, minimising fuel gas consumption. Optimised operation reduces fuel gas consumption thus reducing operating costs and also minimises CO_2 emissions.

It is also important to monitor the oxygen concentration in the incinerated vent gas. Too little oxygen (or no oxygen) may result in incomplete destruction of the sulphur compounds and hydrocarbons entering the incinerator.

Hydrogen sulphide and organic sulphur compounds such as carbon disulphide (CS_2) and carbonyl sulphide (COS) are an odorant pollutant of toxicity. The tail gas burning process utilises either thermal incineration or catalytic incineration. The thermal incineration method is carried out with excess oxygen at temperatures typically around 1,200 to 1,400°F (650 to 760°C). These elevated temperatures place thermal stress on the incinerator and stack. Catalytic incineration can oxidise hydrogen sulphide, sulphur vapour, carbon disulphide and carbonyl sulphide in the tail gas to sulphur dioxide at a lower temperature of 570 to 1,100°F (300 to 600°C). Although the output-to-investment ratio of thermal incineration is about 10% higher than that of catalytic incineration, catalytic incineration reduces energy consumption and operating costs by nearly 50%, enabling it to satisfy both environmental protection and energy-conservation objectives.

Thermal incineration

Process overview

Thermal incineration involves the high-temperature oxidation of sulphurous compounds, typically operating at temperatures above 1,200°F (650°C). The process ensures complete combustion of H_2S and other hydrocarbons, converting them into SO_2, CO_2 and water vapour. Compared to CO, H_2S is significantly easier to combust. The H_2S autoignition temperature is 530°F

PHOTO: NASATO CONSULTING LTD

Thermal incinerator.

(275°C), while CO requires a much higher temperature of 1,170°F (630°C) to ignite. For this reason, oxidiser manufacturers generally do not guarantee CO emission performance unless the unit operates at temperatures above 1,400°F (760°C). As with all combustion systems, increasing the operating temperature generally results in lower CO emissions – but it can also lead to higher nitrogen oxides (NO_2) emissions.

It is important to distinguish between low-NOx burners used in fired heaters and the burners used in thermal oxidisers, as they are often mistakenly considered the same. Thermal incinerator burners can operate as either natural draft or forced draft systems, depending on the desired turndown ratio and the presence of downstream waste heat recovery equipment. Forced draft systems offer more precise air control and improved energy efficiency but come with higher capital costs.

Advantages of thermal incineration include:

- High destruction efficiency (>99.9%).
- Simple design and reliable operation.
- Handles a wide range of feed compositions.
- Design options
  - Natural Draft
    - Lower capital cost
    - Less efficient
  - Forced Draft
    - Higher capital cost
    - More precise control (more efficient)
    - Option to add waste heat recovery.

Disadvantages of thermal incineration include:

- High fuel consumption due to extreme operating temperatures.
- Risk of elevated NO_2 and SO_3 emissions.
- Higher thermal stress on incineration equipment and stack.
- Increased operational and maintenance costs.

Catalytic incineration

Process overview

Catalytic incineration uses a catalyst to promote oxidation at significantly lower temperatures, typically 570 to 1,110°F (300 to 600°C). This process converts H_2S and other sulphur compounds to SO_2 with improved energy efficiency.

Advantages of catalytic incineration include:

- Lower operating temperatures reduce fuel consumption.
- Lower NO_2 emission and SO_3 compared to thermal incineration.
- Extended equipment lifespan due to reduced thermal stress.

Disadvantages of catalytic incineration include:

- Catalyst deactivation over time, requiring periodic replacement.
- Susceptibility to poisoning by impurities in the tail gas.
- Higher initial capital costs for catalyst installation.

Comparative analysis

In sulphur recovery units (SRUs), the incinerator serves as a critical end-of-pipe unit designed to oxidise residual reduced sulphur compounds (e.g., H_2S, sulphur vapour, COS, CS_2) and unconverted hydrocarbons to meet environmental discharge limits converting all sulphur species to SO_2 before release to the atmosphere.

Given the wide variety of sulphur plant configurations including the number of Claus stages, types of tail gas treatment units (TGTUs), and operating scenarios, the design and simulation of incinerators must be adaptable and precise. The list of considerations is provided below with an overall summary of comparison of a thermal versus catalytic incineration operation.

The incinerator ensures:

- Complete oxidation of residual H_2S, sulphur vapour, COS and CS_2 to SO_2.
- Destruction of any unburned hydrocarbons or ammonia.
- Compliance with stack emission regulations (SO_2, NO_2, CO, etc.).

The performance of the incinerator is closely tied to what the feed stream is from upstream, which varies based on the number of Claus stages and the type and efficiency of the TGTU.

In addition, the number of Claus stages directly affects the residual sulphur species content in the tail gas entering the

PHOTO: NASATO CONSULTING LTD

Catalytic incinerator.

incinerator:

- Fewer Claus stages:
  - Lower sulphur recovery efficiency.
  - Higher H_2S and other sulphur species in the tail gas.
  - Incinerator must handle a higher sulphur load.
- More Claus stages:
  - Improved conversion of H_2S to sulphur.
  - Lower tail gas sulphur species, reducing incinerator duty.

A simulation is based on the number of Claus stages which affects both fuel gas requirement and oxygen demand in the incinerator to achieve full oxidation. The incinerator's thermal rating and residence time must be adjusted accordingly.

The type of TGTU significantly alters the composition of gases entering the incinerator:

- No TGTU:
  - Tail gas contains high levels of H_2S, sulphur vapour, SO_2, COS, CS_2, and potentially hydrocarbons.
  - Incinerator design must prioritise high destruction efficiency (>99.9%).
- Amine-based TGTU (e.g., SCOT-type reduction/amine):
  - Converts sulphur species to H_2S, which is recycled to the feed of the SRU.
  - Tail gas to incinerator is lean in sulphur, mostly containing inert gases and small H_2S slip.
- Direct oxidation or sub dewpoint:
  - Either converts H_2S to sulphur directly in the tail gas unit or increases the Claus efficiency through sub dew-point operation.
  - Overall sulphur recovery is typically in the range of 98.5 to 99.2%.
  - Incinerator sees more H_2S, less fuel requirement for further oxidation.

Incinerator oxygen demand, combustion air ratio, and stack gas composition are highly dependent on TGTU efficiency and type.

Sulphur plants operate under a wide range of scenarios, each requiring distinct simulation cases:

- Normal operation: Moderate tail gas sulphur levels, balanced fuel-to-air ratios.
- Start-up/shutdown: High variability in tail gas composition, requiring transient simulation.
- Turndown: Lower flow rates, reduced heat input, potential for flame instability.
- Emergency bypass (e.g., Claus or TGTU failure): Incinerator must treat high H_2S streams temporarily.

Simulation and design tools must support:

- Dynamic behaviour (especially during transitions).
- Safety margin analysis for oxygen and temperature profiles.
- SO_2 emission modelling under worst-case scenarios.

There are many proven sulphur plant simulation packages that provide steady state thermodynamic based calculations and the use of computational fluid dynamic (CFD) simulation tools that assist with reactor design. Some of the software packages and platforms include the following design packages and considerations:

- Aspen HYSYS, ProMax, ProTreat, or CFD tools for combustion modelling.
- Custom combustion reaction models for:
  - $H_2S + O_2 \rightarrow SO_2 + H_2O$
  - COS, CS_2 oxidation pathways
  - CO and hydrocarbon oxidation
  - NO_2 formation under high-temperature conditions.

Key outputs:

- Stack gas composition: SO_2, CO_2, O_2, H_2O, NO_2.
- Flame temperature.
- Combustion air/fuel gas demand.

- Destruction efficiency.
- Heat recovery potential (e.g., waste heat boiler downstream)

The environmental and operational constraints and regulations typically limit, but are jurisdictional specific:

- SO_2 emissions (e.g., <250 ppmv).
- NO_2 and CO formation.
- Visible plume control (SO_3 or acid mist formation).

Incinerator simulations must also evaluate:

- Sulphuric acid dew point corrosion risk.
- Heat integration (e.g., with waste heat boilers).
- Stack dispersion modelling (for environmental permitting).

Effective simulation and calculation of sulphur plant incinerators depend on a comprehensive understanding of the entire sulphur recovery process, upstream Claus units, downstream TGTUs, and the specific operating scenarios involved. Tailoring incinerator design and operation to these variables ensures not only optimal sulphur destruction but also environmental compliance and operational flexibility. In summary the overall comparison of thermal versus catalytic incineration is shown in Table 1.

Environmental and regulatory considerations

Environmental regulations increasingly favour lower NO_2 and greenhouse gas emissions, making catalytic incineration an attractive option for reducing the overall carbon footprint of sulphur recovery operations. However, the choice between the two methods often depends on the specific sulphur content in the feed gas, the availability of clean combustion air, and the economic feasibility of installing and maintaining catalytic systems.

Key design considerations

The end objective of thermal or catalytic incineration is to ensure destruction of trace sulphur species to meet regulatory requirements. However, each option has unique features that can be attributed to the unique features associated with burner design considerations versus catalytic reactor designs. The principles of reaction kinetics and reactor design are common to both thermal and catalytic incineration but there are key differences as described below.

Thermal incinerator design for sulphur plants

A key focus is safety, specifically the evaluation of NFPA 86 guidelines regarding purge requirements and how these guidelines can be applied to oxidiser restarts.

Designing a thermal incinerator for sulphur recovery requires a careful balance between efficient oxidation of sulphur compounds and preventing corrosion due to acid gas formation but also the additional thermal stress due to the elevated thermal incineration operation. As with any burner system the burner management system for ignition is critical but the logic tied into the SRU cause and effect is also a critical consideration. This involves precise control of temperature, oxygen levels, and gas mixing. Key design and operational considerations are outlined below:

Combustion and mixing

Excess air or superstoichiometric operation: Operate the thermal incinerator with excess air conditions to ensure complete oxidation of all trace sulphur compounds to comply with regulations and to satisfy the excess oxygen permit requirement.

Enhanced mixing: Use intensive mixing devices – such as choke rings, or checker walls – to ensure thorough blending of flue gas with incinerator waste stream tie-in(s). This prevents gas stratification and promotes complete reactions.

Temperature management: Maintain consistent temperature distribution, particularly near the burner, to avoid hot spots that could damage internal components and to ensure complete combustion of sulphur compounds.

Material selection and corrosion prevention

High-temperature refractory: The high thermal stress of elevated thermal incinerator operation must be considered in the selection of refractory linings (brick or castable) that are resistant to high temperatures and corrosive sulphur species. Refractory materials must be evaluated for durability under the excess air operating conditions.

Dew point control: Ensure the steel shell remains above the acid gas dew point (typically 300 to 350°F or 150 to 175°C) to prevent sulphuric acid condensation and corrosion.

Flue gas management & emissions control

Vent stack design: Design of the stack for effective dispersion of flue gases. Stack height and placement must avoid interference with plant operations and comply with regulatory emission limits for SO_2 and TRS.

Control systems and monitoring

Automated control systems: Implement control systems to maintain consistent operating conditions—regulating temperature, air-to-fuel ratio, excess air and mixing efficiency – to achieve safe, stable, and repeatable performance.

Emissions monitoring: Integrate real-time monitoring systems to track sulphur emissions (SO_2 and TRS) and other operational parameters, ensuring environmental compliance and process efficiency.

A structured approach: This structured approach ensures that the thermal incinerator operates safely and efficiently while meeting emissions regulations and maximising sulphur recovery.

Catalytic incinerator design for sulphur plants

Designing a catalytic incinerator for sulphur recovery units requires detailed consideration of feed gas characteristics, thermal and reaction conditions, catalyst selection, and environmental discharge. The

Table 1: **Comparison of thermal versus catalytic incineration**

Parameter	Thermal incineration	Catalytic incineration
Operating temperature	1,200°F (649°C)	570 to 1100 °F (300 to 600°C)
Fuel consumption	High	Low
NO_2 and SO_3 emissions risk	High	Low
Efficiency	>99.9%	>99.5%
Maintenance costs	Moderate to high	Moderate (catalyst replacement)
Suitability	Broad feed composition	Requires cleaner feed

Source: Nasato Consulting

system must ensure complete conversion of total reduced sulphur (TRS) compounds to sulphur dioxide (SO_2), maintain regulatory compliance, and operate safely with automated controls.

The primary function of the SRU catalytic incinerator is to promote the oxidation reactions associated with conversion of Claus tail gas sulphur species to SO_2. Additional considerations include the oxidation of other SRU tail gas species such as CO and H_2. Regardless of the catalyst selection, the catalytic incinerator reactor must employ the principles of chemical reactor design that stipulate maximum residence time distribution of all reactants, plug flow behaviour in temperature distribution, pressure distribution and flow distribution.

The most important design parameter used in sizing the catalyst beds is superficial gas space velocity, but it is critical to distribute the gas equally over the entire catalyst bed to maximise performance for all modes of SRU operation which include startup, shutdown, turndown, normal operation and, where applicable, tail gas unit bypass. Additionally, the reactor inlet deflectors must be designed to prevent gas impingement and/or flow patterns that can cause catalyst displacement. Catalyst is vulnerable to displacement but with proper gas distribution the displacement issue can be avoided. The space velocity is a measure of the volumetric flow rate of gas (at standard conditions) per volume of catalyst.

Designing a catalytic incinerator for sulphur recovery requires a careful balance between efficient oxidation of sulphur compounds and thermal excursions but with the benefit of lower thermal stress due to the lower catalytic incineration operation. This involves precise control of temperature, oxygen levels, and gas mixing. Key design and operational considerations are outlined below.

Feed gas and process conditions

Robust SRU front-end air control: During normal operation, the SRU receives amine acid gas and, where applicable, sour water stripper off-gas and converts H_2S and other sulphur compounds into high purity sulphur. The combustion air flow to the Claus burner must be controlled accurately at all times for the proper extent of combustion of H_2S. It is recommended to accomplish this through the feedforward ratio control in combination with the feedback air demand analyser signal control; the combination of feedforward/feedback defines the air control system. The design intent of the feedforward/feedback system is to optimise the control of the H_2S to SO_2 ratio to maximise sulphur recovery and to ensure adequate stability to respond to upset conditions that include change in feed rate and/or feed composition. The design intent of the decoupled feedforward/feedback system is to optimise the control of the H_2S to SO_2 ratio to maximise sulphur recovery, and to ensure adequate stability to respond to upset conditions that include change in feed rate and/or feed composition in order to protect the catalytic incinerator from thermal excursions.

Feed composition: The performance of the catalyst depends heavily on the concentration of TRS compounds such as hydrogen sulphide (H_2S), carbonyl sulphide (COS), and carbon disulphide (CS_2) as well as other contaminants like hydrocarbons, which can inhibit catalytic activity.

Operating temperature and residence time: Optimal catalyst performance requires maintaining specific temperature ranges. The incinerator must ensure sufficient residence time to achieve complete oxidation of TRS compounds.

Catalyst selection: Catalysts must be selected based on their ability to withstand contaminants in the feed gas while maintaining high oxidation efficiency. A robust, poison-resistant catalyst is essential for long-term performance. Additional considerations include the oxidation of other SRU tail gas species such as CO and H_2.

Incineration efficiency and performance

TRS to SO_2 conversion: The primary function of the catalytic incinerator is to oxidise H_2S, sulphur vapor (where applicable), COS, CS_2 and, where applicable, sulphur vapour into SO_2. Efficient conversion minimises environmental impact and maximises compliance.

Performance optimisation: Efficient operation depends on maintaining target temperatures, ensuring proper catalyst function, and tightly controlling process parameters. Routine monitoring and catalyst maintenance are key to sustained performance.

Safety and control systems

Automated control system: A fully integrated control system is required to monitor catalytic incinerator feed combustion parameters such as temperature, air-to-fuel ratio, and flame stability. Real-time control helps ensure safe and reliable operation.

Fuel gas and air management: Automated systems should adjust fuel and combustion air to maintain optimal operating temperatures and safe burner performance.

Exhaust management and environmental compliance

Vent stack design: The exhaust stack must be properly designed to disperse SO_2 emissions safely and prevent adverse effects on nearby structures, equipment, or personnel.

Regulatory compliance: The incinerator must meet all applicable environmental regulations, including limits on ground-level SO_2 concentrations and total sulphur emissions.

Air emissions: The primary exhaust components are nitrogen and sulphur dioxide. Final emissions must be monitored and reported to ensure environmental compliance and permit adherence.

Conclusion

In a changing world, two major strategies have emerged to tackle rising greenhouse gas emissions: carbon reduction and carbon capture. While both aim to lower atmospheric CO_2 levels, they differ significantly in approach, impact, and feasibility.

Both thermal and catalytic incineration play crucial roles in sulphur plant emissions management. Thermal incineration remains the preferred choice for high-load applications requiring robust processing capabilities, while catalytic incineration offers significant fuel savings and reduced CO_2 and NO_2 emissions for plants that can accommodate cleaner feed conditions. The selection between these technologies should be based on operational needs, cost considerations, and environmental compliance requirements. ■

Reference

1. "Operational and safety considerations for SRU shutdowns due to tail gas thermal oxidizer trips: A case study from Motiva Port Arthur Refinery" Brimstone 2025 Sulphur Symposium, R. Pitman, M. Harrelson, R. Vilce, G. Tidwell MOTIVA, Port Arthur, TX, R. Heflin, G. Tanda, K. Wesselowski ZEECO, Tulsa, OK.

Indian refinery case: TopClaus® in the lead

Worley Comprimo has carried out an evaluation of technologies allowing 99.8+% sulphur recovery for an Indian refinery case. The TopClaus process was compared to alternative technologies, focussing on modern technical challenges, investment operation and maintenance costs, as well as CO_2 considerations.

Eric Roisin, Adriaan Roux, Gerrit Bloemendal, Marco van Son (Worley Comprimo)

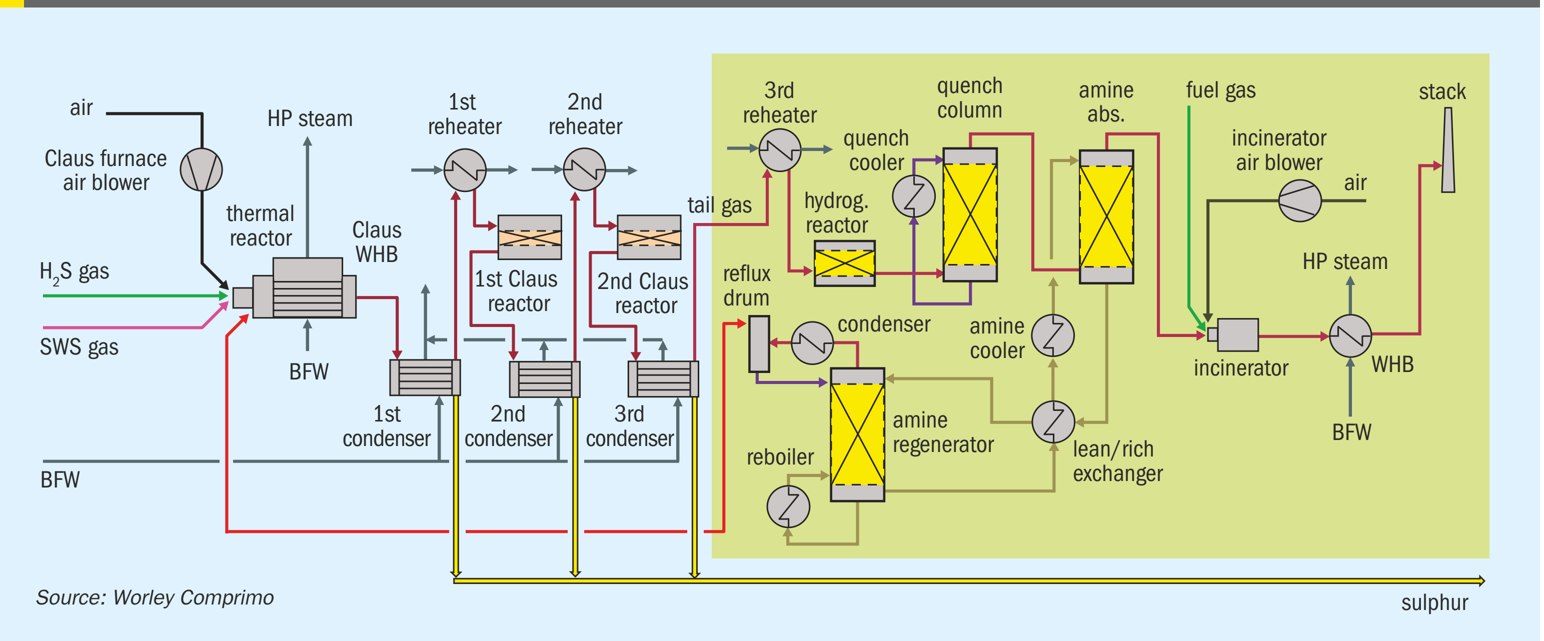
To better protect public health and the environment from toxic and odorous sulphur dioxide emissions, maximum allowed sulphur content in refined oil products and natural gas globally decreased over the past decades, despite regional variations in regulation. In parallel, increasingly stringent limits have been imposed on sulphur dioxide emissions from industrial stacks. In response to these regulatory developments, sulphur recovery processes have progressively evolved towards higher recovery efficiencies.

Contemporary sulphur recovery units predominantly employ the modified Claus process in conjunction with tail-gas treatment technologies. The simplest processes, such as SUPERCLAUS®, employ a direct oxidation reactor stage to partly oxidise hydrogen sulphide in the Claus tail gas to sulphur. To maximise overall sulphur recovery efficiency, BSR and lookalike processes hydrogenate the sulphur-containing species in the Claus tail gas. The resulting H_2S is subsequently removed via amine absorption and recycled to the feed of the sulphur recovery unit (Fig. 1). Advanced amine solvents with enhanced selectivity for H_2S have been developed, increasing the energy efficiency of the process by limiting the recycling of carbon dioxide. The amine-based tail gas treatment processes using the most selective solvents is often regarded as the best available technology.

Direct conversion of Claus tail gas to sulphuric acid represents a potentially attractive alternative to BSR technology, offering the prospect of improved economic performance and a technically robust solution for the treatment of feedstocks with high ammonia content. This approach is supported by the broader industrial context in which the vast majority of the elemental sulphur produced globally is ultimately oxidised into sulphuric acid – the most produced chemical worldwide – serving as a key intermediate for fertiliser production, metallurgical processing, and the manufacture of a wide range of products, including detergents, dyes, explosives, rubber and tyres.

Notwithstanding these advantages, practical implementation of a Claus tail gas-to-sulphuric acid route is constrained by logistical considerations that limit its applicability in many installations. Consequently, elemental sulphur remains the preferred product in most sulphur recovery applications.

Fig. 1: **Simplified BSR process flow diagram**



Source: Worley Comprimo

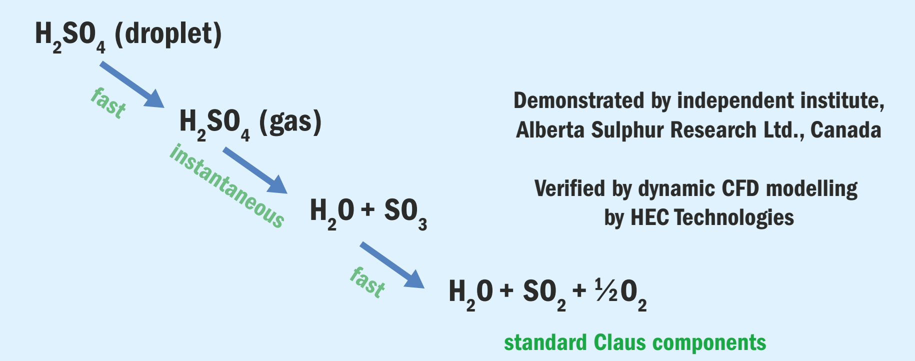
Worley Comprimo and Haldor Topsøe have developed the TopClaus® process[1], based on established industrial technologies, in which sulphuric acid generated in a wet sulphuric acid (WSA) tail gas treating unit (TGTU) is recycled to the Claus thermal reactor, so that only elemental sulphur is produced. The proposed configuration reduces the number of required equipment items and therefore the installation cost. In addition, favourable overall energy balance results in lower operating costs. Collectively, these attributes position the TopClaus® process as a preferable alternative to currently implemented process schemes.

This article describes the TopClaus® process and compares it to the most used alternative technologies.

TopClaus® process development

A typical sulphur recovery unit of a refinery comprises a Claus plant with two catalytic sections, followed by a BSR tail gas treatment unit, in which the sulphur containing species present in the Claus tail gas are hydrogenated to H_2S, which can then be extracted from the process gas using a selective amine and recycled back to the feed to the Claus section. The treated off gas from the BSR unit, which still contains trace amounts of H_2S and COS, is typically routed to a thermal oxidiser, where these residual sulphur species are converted to SO_2 prior to release to the atmosphere.

Fig. 2: **Claus thermal reactor chemistry – Fate of recycled sulphuric acid**



Source: ASRL

This technology was first patented by the Ralph M Parsons Company in 1971 and then other companies quickly followed suit.

Incremental improvements have been apparent throughout the years, including development of amine formulations more selective towards H_2S and advanced hydrogenation catalysts that can operate at lower temperatures, but the process scheme remains unchanged.

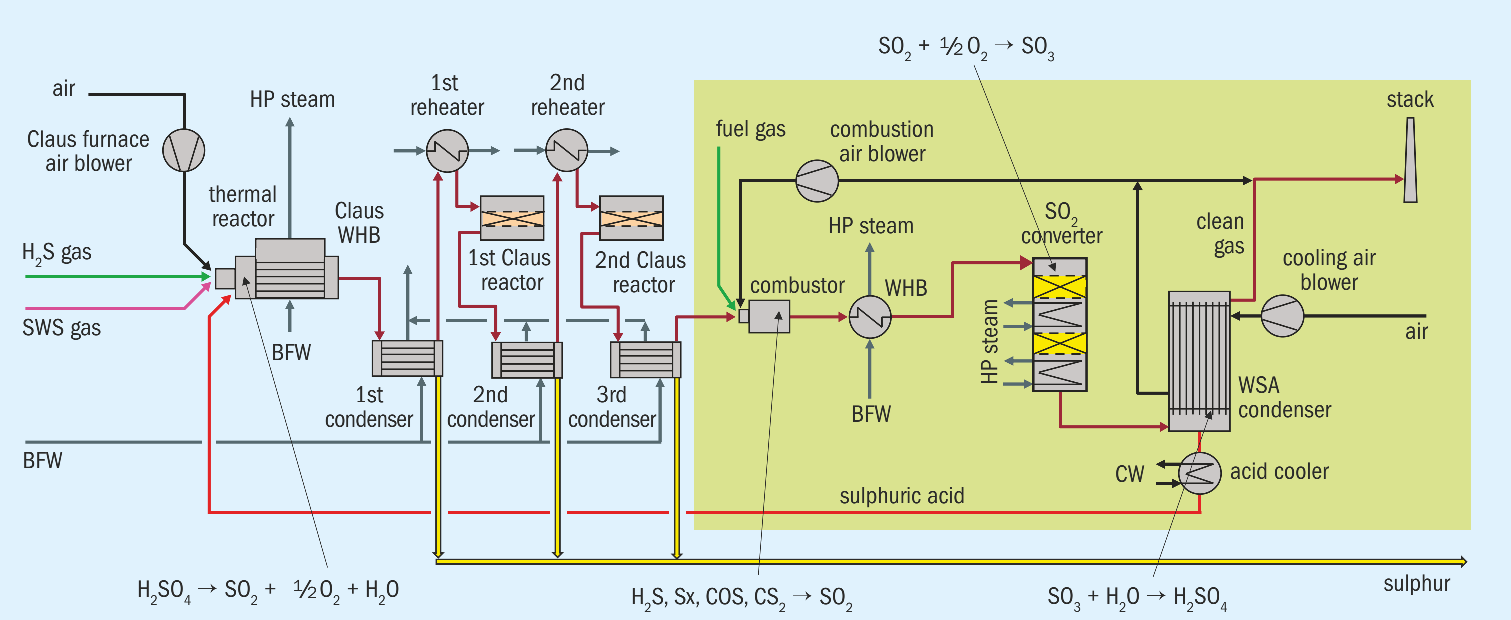
The process is quite energy intensive, mainly because of the amount of heat required for the regeneration of the amine. Sulphur recoveries can exceed 99.9% but at the cost of high capital (capex) and operating expenditures (opex), and it is the last few percentage points where energy requirements escalate, accompanied by CO_2 emissions growing exponentially. In order to reduce the contribution of sulphur recovery units to overall CO_2 emissions, especially in large natural gas applications[2], some authors have even advocated relaxing SO_2 stack emission specifications[3].

Topsoe's Wet Sulphuric Acid (WSA™) process offers an alternative tail gas treating technology. The WSA™ process dates back to 1980 and around 165 units have been licensed. However, as discussed in the introduction, the handling of sulphuric acid as a secondary product within the sulphur recovery block is generally considered undesirable. This raises the question of whether the sulphuric acid can instead be recycled to the thermal stage.

Alberta Sulphur Research Ltd[4] and HEC Technologies have both investigated the decomposition behaviour of sulphuric acid within the combustion chamber. Their findings, summarised in Fig. 2, demonstrate the technical feasibility of this approach.

The TopClaus® technology (Fig. 3), using Topsoe's WSA™ tail gas unit with

Fig. 3: **Simplified TopClaus® process flow diagram and key chemical reactions**



Source: Worley Comprimo

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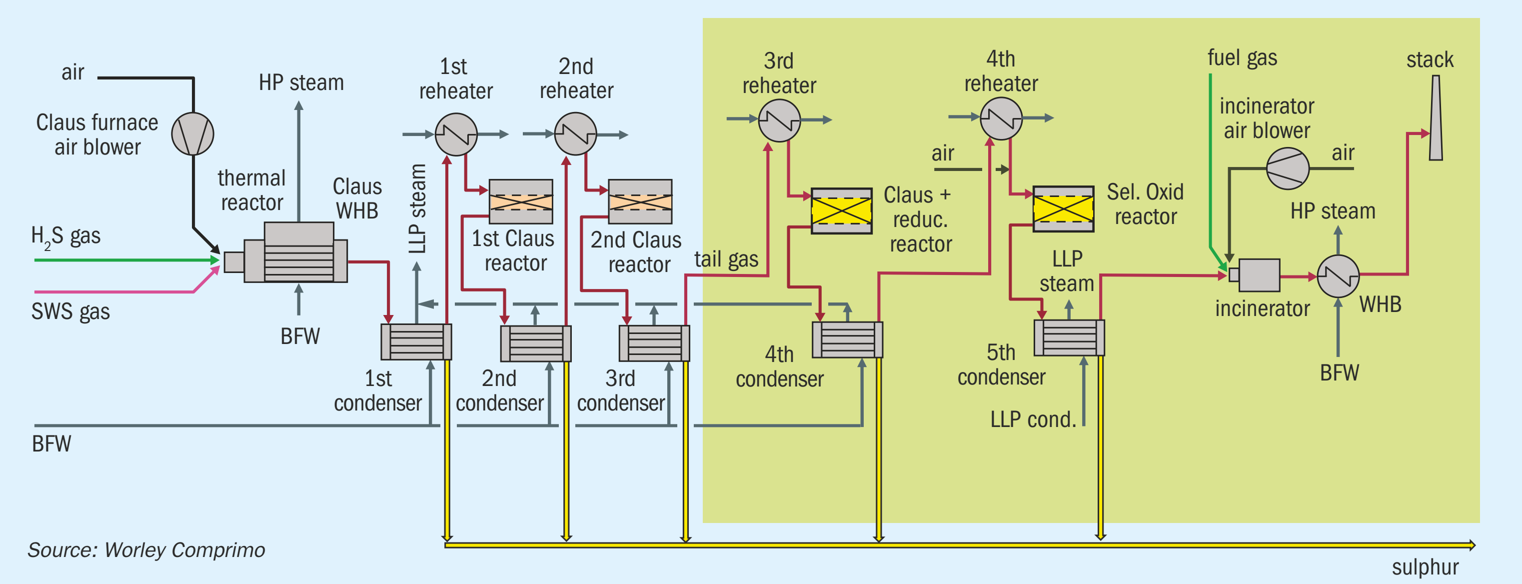
Fig. 4: **Simplified EUROCLAUS® process flow diagram**



Source: Worley Comprimo

acid recycling, reduces energy intensity, but still maintains the sulphur recovery in excess of 99.9%.

Because less heat is released by the combustion of H_2S to SO_2, and because the vaporisation and dissociation reactions of sulphuric acid are endothermic, recycling sulphuric acid to the thermal stage obviously leads to a temperature reduction in the combustion chamber. Consequently, appropriate engineering measures may be required to ensure that the reactor temperature remains above the minimum threshold, especially above 1,250 °C when ammonia is present.

Recycling sulphuric acid results in the reduction of oxygen/air demand of around 15% in comparison to Claus and processes based on direct oxidation and of around 20% in comparison with amine-based TGTUs. Another comparison with a conventional amine-based TGTU is that there is no CO_2 in the recycle stream to the furnace. Both these factors contribute to a capacity increase in the Claus section.

In summary, TopClaus® can achieve a sulphur recovery equivalent to the conventional BSR design. The Claus unit itself will be smaller due to the oxygen carrying capacity of the recycled sulphuric acid, which may help increasing the capacities of existing units in brownfield applications. Although the integrated process has not yet been implemented as a complete commercial installation, its constituent elements – the Claus process, the WSA™ process, and sulphuric acid atomisation – are all widely applied in the industry.

Additional benefits for double stage sour water strippers

Two-stage SWS systems are sometimes used in refinery applications, especially when renewable feedstocks are used. The process encounters a high-pressure stripper column to remove an H_2S richer gas compared to single stage SWS, followed by a low-pressure column where ammonia is stripped. In this configuration, an alternative for processing SWS off gas with a TopClaus® configuration becomes apparent, in which the NH_3-rich gas feeds the combustor in the WSA™ section, so that the risk of accumulation of ammonium salt deposits in the Claus section is eliminated.

The NH_3-rich gas is burned in the combustor of the WSA™ section with excess air. This leads unavoidably to some formation of NOx, which is removed again in the SCR reactor, located after the waste heat boiler. A small fraction of the ammonia-rich gas sent to the combustor effluent after the waste heat boiler to provide enough ammonia to react with the formed NOx over the catalyst installed in the SCR reactor. The results of the reaction are nitrogen and water vapour.

Economical comparison of available technologies

To assess the economic advantages of the TopClaus® process, this study compares this technology with several well-established sulphur recovery technologies, which are described in the following sections. Each of these reference technologies is capable of removing more than 99.5% of the sulphur contained in the feed

Worley Comprimo's alternatives based on direct oxidation

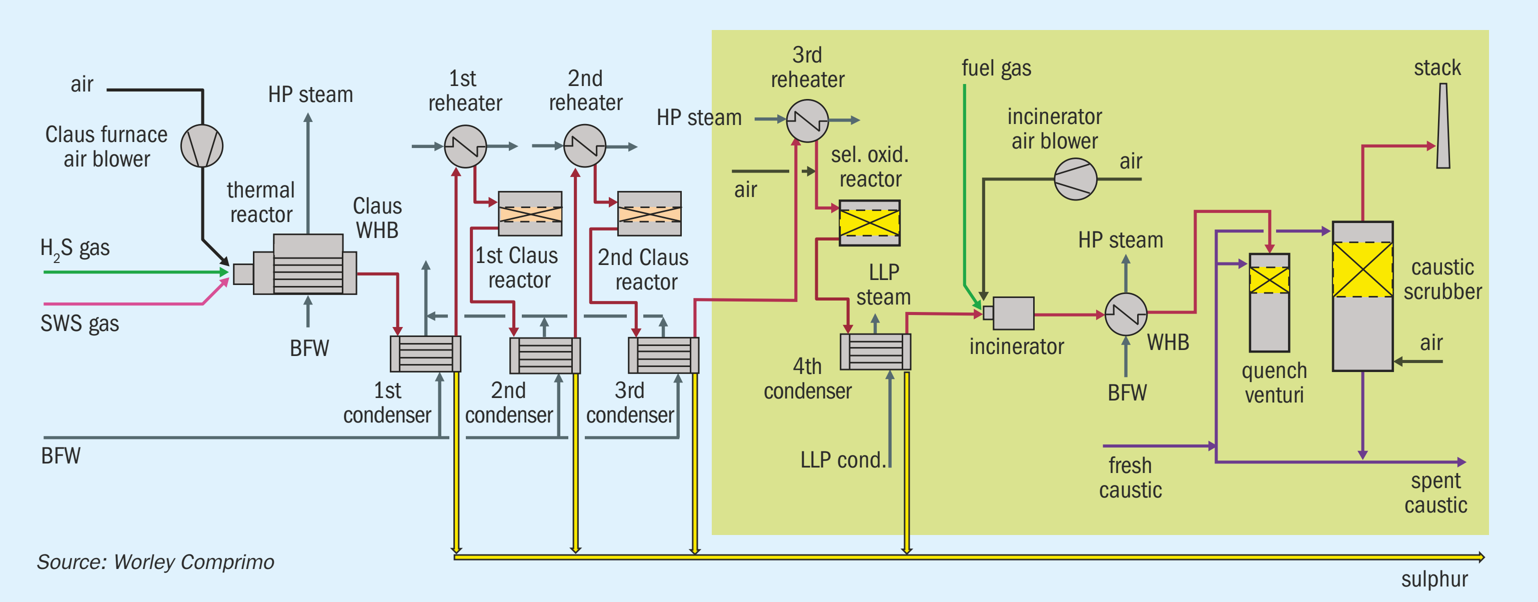
The SUPERCLAUS® process is based on the catalytic oxidation of the H_2S contained in the tail gas of the Claus section into elemental sulphur. This process typically allows recovering 99% of the sulphur present in the feed to the SRU. The first industrial application started up in 1988 and more than 250 units have been licensed to date with capacities ranging from 3 to 1,500 t/d of sulphur per train.

EUROCLAUS® is an improvement of the SUPERCLAUS process that was introduced to the market in 2000. In this configuration (Fig. 4), SO_2 is first reduced into H_2S over a thin hydrogenation catalyst layer installed at the bottom of a third Claus reactor, before the direct oxidation takes place in the last catalytic reactor. The integration of this additional Claus reactor and this reduction step typically increases the overall sulphur recovery efficiency to approximately 99.5%.

In order to meet the tightest specifications on SO_2 stack emissions, a caustic scrubber can be installed downstream both these processes (Fig. 5). Unrecovered sulphur is combusted to SO_2, which then oxidises to sulphate ions in the caustic solution. This solution is especially suited to relatively low sulphur plant capacities, and typically, but not exclusively, to refinery plants with sulphur capacities below 300 t/d sulphur. Extremely low SO_2 stack emissions can then be reached, although the system is typically designed to reach a few tens of ppmv.

The liquid effluent discharged from the scrubber, typically containing approximately 10 wt-% sodium sulphate, may be disposed

Fig. 5: **Simplified SUPERCLAUS® + caustic scrubber process flow diagram**



Source: Worley Comprimo

of either directly to the sewage system or, more commonly, routed to the refinery wastewater treatment facility. Although the chemical composition of the spent caustic stream generally does not present significant treatment challenges, it is advisable in revamp projects to verify that the existing wastewater treatment plant has sufficient hydraulic capacity to accommodate the additional liquid load resulting from the installation of such a scrubber.

For a technical and economic comparison with TopClaus®, the EUROCLAUS® and SUPERCLAUS® + scrubber configurations were selected. Their main features are summaried in Table 1.

Equipment count

A high-level indication of the potential capex of the different configurations can be obtained by comparing the equipment count, as listed in Table 2.

Note that only the equipment located in the green area of the aforementioned simplified process schemes is included in Table 1, the equipment count of the Claus section being the same for all options).

The processes based on direct oxidation have the lowest equipment counts.

Hence, the SUPERCLAUS® + scrubber configuration is likely the lowest-cost installation capable of meeting the most stringent stack-emission specifications. For the two processes based on the recycling of sulphur containing species back to the thermal reactor, TopClaus® requires thirteen equipment items less than BSR. Specifically, removal of the three columns (quench column, amine absorber and amine regenerator) results in important savings both on capex and plot space.

Refinery case study – 300 t/d sulphur

To compare the capital expenditure (capex) and operating expenditure (opex) associated with the different process configurations, a reference case was defined consisting of a new sulphur recovery unit (SRU) to be installed at a refinery located in India. The feed gas comprises a mixture of 75 vol-% amine acid gas and 25 vol-% sour water stripper gas (generated by the most conventional single stripper column design), corresponding to a total sulphur processing capacity of 300 t/d. In accordance with local environmental regulations, the SO_2 concentration in the stack gas is limited to a maximum of 250 ppmv, normalised to an oxygen content of 3 vol-%.

Table 1: **Main features of the studied process configurations**

	EUROCLAUS	SUPERCLAUS + caustic scrubber	BSR amine-based TGTU	TopClaus®
SO_2 at stack, ppmv	500 to 1,000	<100	100 to 250	100 to 250
Sulphur recovery efficiency	99.5 %	99.1 %	99.9 %	99.9 %
Plot space	Base - 50%	Base - 35%	Base	Base -10%
Installation cost	Base -15/35%	Base -15/30%	Base	Base -8/20%

Source: Worley Comprimo

Table 2: **Equipment count comparison**

Equipment type	EUROCLAUS	SUPERCLAUS + caustic scrubber	BSR amine-based TGTU	TopClaus®
Furnace / burners	1	1	1	1
Columns	0	1	3	0
Reactors / converters	2	1	1	2
Vessels	0	0	4	2
Tanks / sumps	0	2	2	1
Heat exchangers	9	7	10	8
Blowers*	1	1	1	2
Pumps*	0	2	6	1
Filters	0	0	3	0
Package units*	0	0	0	1
TOTAL	**13**	**15**	**31**	**18**

Source: Worley Comprimo ** Excludes installed spares*

Air and acid gas preheat were included in all process configurations. All reheaters are supplied with saturated high pressure (HP) steam. Pump capacities were determined by applying a 10% design margin to the calculated hydraulic duties.

Based on these assumptions, a Class 4 factored cost estimate was developed, considering only facilities within the SRU, defined as inside battery limits (ISBL). Costs associated with offsites and common facilities, such as site preparation, were excluded.

The estimated capex costs for the different process configurations are:

EUROCLAUS®: $76 million
SUPERCLAUS® + caustic scrubber: $78 million
BSR using conventional MDEA: $97 million
TopClaus®: $86 million

A gas blower was included in the TopClaus® design to provide sufficient pressure for the tail gas to pass through the WSA™ section. In addition, some limited amount of natural gas was co-fired at the Claus thermal stage to maintain the required furnace operating temperature.

Utility costs were based on the following assumptions:

HP steam:	45 $/t
LP steam:	38.50 $/t
Boiler feed water:	5.60 $/t
Cooling water:	0.50 $/$m^3$
Natural gas:	0.55 $/kg
Electric power:	0.12 $/kWh
Caustic soda:	410 $/t
Sulphur:	135 $/t

Tables 3 and 4 show utility production/consumption values which have then been monetised to give capex and opex over 20 years.

Table 3: **Refinery case study – Utility values**

	EUROCLAUS	SUPERCLAUS + caustic scrubber	SRU + BSR amine based	TopClaus®
Consumption per hour				
Boiler feed water, t	47.4	47.4	46.7	51.8
Electric power, kWh	866	934	1,000	1,081
Natural gas, kg	687	666	523	738
HP steam, t	7.07	6.11	6.52	5.13
LP steam, t	1.00	1.00	6.12	1.00
Cooling water, m^3	0	0	0	14
Caustic soda, t	0	0.20	0	0
Production per hour				
HP steam, t	42.5	41.9	39.7	45.1
LP steam, t	10.9	10.5	12.5	10.7
Sulphur, t	12.44	12.39	12.50	12.50

Source: Worley Comprimo

Table 4: **Refinery case study – Operating costs**

	EUROCLAUS	SUPERCLAUS + caustic scrubber	SRU + BSR amine based	TopClaus®
Consumption per hour				
Boiler feed water, kUSD	2,258	2,255	2,225	2,467
Electric power, kUSD	891	961	1,029	1,112
Natural gas, kUSD	3,212	3,114	2,445	3,450
HP/MP steam, kUSD	2,703	2,337	2,495	1,960
LP steam, kUSD	327	327	2,002	327
Cooling water, kUSD	0	0	0	60
Caustic soda, kUSD	0	685	0	0
Total consumption, kUSD	9,390	9,679	10,196	9,376
Production per hour				
HP/MP steam, kUSD	13,568	13,701	12,690	15,279
LP steam, kUSD	3,225	3,093	2,079	3,167
Sulphur (delta to BSR), kUSD	-72	-129	0	0
Total production, kUSD	16,721	16,665	14,769	18,445
Balance, kUSD	**7,331**	**6,986**	**4,574**	**9,069**

Source: Worley Comprimo

TopClaus® consumes more utilities than any of the other processes, but this is more than offset by the largest HP steam production, resulting in the highest net yearly income. Compared to BSR the yearly result is $4.5 million higher.

A more detailed examination of the results reveals the following observations:

- The higher HP steam consumption associated with the EUROCLAUS® configuration, compared with the SUPERCLAUS® plus scrubber arrangement, is explained by the presence of an additional catalytic stage and its corresponding HP steam reheater. Conversely, EUROCLAUS® exhibits higher HP steam production owing to the reducing activity of the reduction catalyst, which permits operation of the thermal stage at a higher air to acid gas ratio. The increased natural gas demand at the thermal incinerator stage of the EUROCLAUS® configuration is a consequence of the lower sulphur concentration in the tail gas.
- The BSR configuration displays the lowest natural gas consumption, primarily due to the reduced flow rate of process gas entering the incinerator. This reduction results from the removal of a substantial fraction of the water content by condensation in the quench column.
- The highest natural gas consumption is observed for the TopClaus® configuration, reflecting the requirement for natural gas cofiring in the thermal stage to maintain the combustion chamber temperature at approximately 1,250°C, as necessary to ensure effective ammonia destruction. The highest electrical power consumption is also estimated for the TopClaus® configuration, due to the tail gas blower being considered.

As shown in Fig. 6, the operating income potential is strongly influenced by the valuation of HP steam. In this respect, the TopClaus® configuration provides a distinct advantage, as its higher HP steam generation positively affects overall operating income. Assuming all other parameters remain constant, including the cost ratio between HP and LP steam, the operating income reaches a breakeven point at an HP steam value of approximately \$16/t for the TopClaus® process, compared with approximately \$31/t for a sulphur recovery unit equipped with a BSR amine based tail gas treating unit.

Advantage of TopClaus® over 20 years

Considering capex and integration of 20 years of operating and maintenance costs, SRU + BSR clearly is the most expensive technology, showing the highest installation costs, the lowest operating income and the highest maintenance costs (Table 5). TopClaus® is in the lead, with a cost benefit of more than \$100 million over 20 years in comparison to the SRU + BSR configuration, often referred to as the best available technology. The advantage of TopClaus® would be even higher if a 2-stage SWS configuration was considered.

Over 20 years, the SUPERCLAUS® + scrubber configuration allows saving 80 million USD over the amine-based technology. This technology being already well proven, it is clearly an interesting alternative to SRU + BSR to meet the most stringent limitations of SO_2 stack emissions.

Of course, these conclusions, in terms of absolute figures, depend on the cost of utilities, that may differ significantly from one project to another. However, the economic ranking and the order of magnitude of capex and opex savings are consistent with previously published results for refinery cases[5,6].

CO_2 emission aspects

The case study can illustrate the impact on the environment in terms of CO_2 emissions/savings of the different processes considered in this article.

The CO_2 and hydrocarbons present in the amine acid gas and sour water stripper off-gas feeding the SRU were disregarded since it is constant for all processes. Instead, the focus was on determining the CO_2 impact of natural gas feeding the incinerator, the RGG or co-fired at the thermal stage, and the net steam generation (part of scope 1), as well as the consumed electricity (part of scope 2).

The combustion of natural gas results into the emission of 2.65 kg of CO_2 per kg of natural gas.

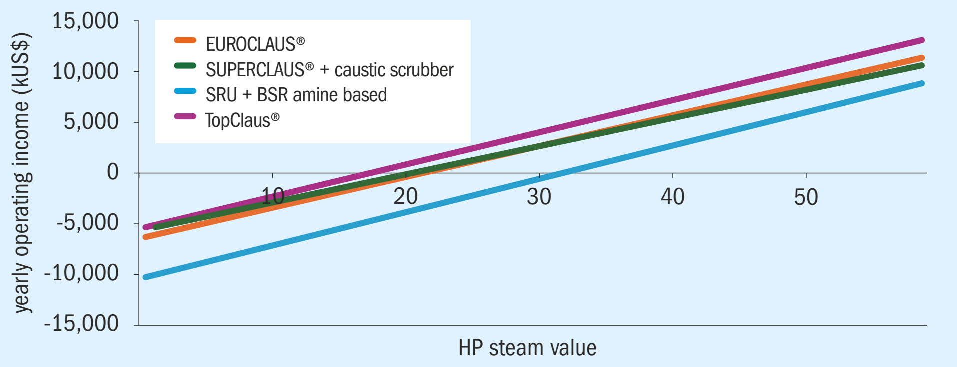
SRUs are usually exporters of steam that can be used outside the SRU facility. Typically, steam is generated in a boiler using the heat produced from burning natural gas. If all the steam exported from the SRU is consumed outside the facility it represents a saving in equivalent CO_2 emissions. The CO_2 emission factor for steam generation is calculated assuming a boiler efficiency of 85% and natural gas utilised as fuel, which results in a CO_2 equivalent emissions factor of 0.20 kg CO_2e/kWh.

It is assumed that the electrical power required to operate the various blowers, pumps, and air coolers is supplied by the national electricity grid. The associated carbon intensity is therefore country specific and depends on the prevailing energy mix: while the emission factor is expected to be close to zero in countries where electricity is predominantly generated from renewable sources or nuclear power, it is relatively high in regions where electricity production is dominated by coal-fired power plants.

In the case of India, the CO_2 emission factor for electricity generation has been reported in 2024 to be 0.707 kg CO_2e/kWh[7].

The results presented in Table 6 indicate that all the evaluated configurations contribute to the avoidance of net CO_2 emissions, consistent with their status of net energy exporters for the considered refinery case. Among the assessed options, TopClaus® achieves the highest level of CO_2 savings, with approximately 25% greater net avoided emissions compared to the BSR configuration.

Fig. 6: **Variation of the operating income as a function of the HP steam value**



Source: Worley Comprimo

Table 5: **Refinery case study – Overall costs**

	EUROCLAUS	SUPERCLAUS + caustic scrubber	SRU + BSR amine based	TopClaus®
Capex estimate, kUSD	76,000	78,000	97,000	86,000
Operating income, kUSD/year	7,331	6,986	4,574	9,069
Maintenance*, kUSD/year	1,520	1,560	1,940	1,720
Catalysts and amine, kUSD/yr	220	200	110	270
Cost over 20 years, kUSD	**-35,816**	**-26,524**	**46,529**	**-55,580**

Source: Worley Comprimo   ** Maintenance costs are estimated to be 2% of the capex pa.*

Table 6: **Refinery case study – CO_2 emissions/savings**

	EUROCLAUS	SUPERCLAUS + caustic scrubber	SRU + BSR amine based	TopClaus®
CO_2 emissions per year				
Electric power, t CO_2e	5,204.2	5,612.9	6,009.5	6,496.3
Natural gas, t CO_2e	16,058.6	15,567.8	12,225.1	17,250.8
HP steam, t CO_2e	11,858.9	10,254.5	10,949.3	8,601.3
LP steam, t CO_2e	1,516.5	1,516.5	9,276.7	1,516.5
CO_2 saved per year				
HP steam, t CO_2e	71,390.2	70,369.8	66,630.5	45.1
LP steam, t CO_2e	16,463.6	15,850.9	18,911.3	10.7
Balance, t CO_2e	**-53,215**	**-53,269**	**-47,081**	**12.50**

Source: Worley Comprimo

1 47 2 48 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

In certain regions, these CO_2 emission reductions may be monetised through carbon pricing mechanisms, with tariff levels reaching up to \$140/t CO_2. Under such conditions, the additional CO_2 savings associated with the TopClaus® and SUPERCLAUS® plus scrubber configurations would translate into a further economic advantage over the most commonly used amine-based processes.

Conclusion

The recently developed TopClaus® process is based on routing Claus tail gas to Topsoe's WSA® section, followed by recycling the generated sulphuric acid to the Claus thermal reactor. This configuration enables the production of elemental sulphur without generating any by-product and meets the requirement for sulphur recovery efficiencies exceeding 99.9%. Relying on the integration demonstrated by Alberta Sulphur Research Ltd of well proven technologies, the process is characterised by simplicity, robustness, and high efficiency. It is applicable to both greenfield and brownfield installations and offers particular advantages in revamp scenarios, where it can facilitate debottlenecking of existing sulphur recovery units.

The thermal efficiency of TopClaus® outperforms other available technologies, while requiring a lower capital investment than amine-based tail gas treating processes. This combination establishes TopClaus® as a highly cost-effective option for sulphur recovery from acid gas streams. An additional benefit is the significant reduction in net CO_2 emissions, primarily driven by the large export of high-pressure steam associated with the process.

In addition, the possibility for the operator to divert the sulphuric acid flow, for example to an alkylation unit, provides the operator with some options for flexibility.

Among the alternative technologies capable of achieving sulphur recovery efficiencies above 99.9%, the SUPERCLAUS process followed by a caustic scrubber represents the most competitive option, with the second best economic results. This configuration has proven to be reliable through numerous industrial applications

By contrast, amine-based tail gas treating configurations rank lowest in the economic comparison, owing to both higher capital costs and substantially greater energy consumption. Consequently, the widespread classification of such processes as "best available technology" warrants critical reconsideration.

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