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Number 399

March | April 2022

SULPHUR

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HPAL and acid demand

The 2022 price shock

Simplified sulphur recovery

Integrated acid plant design

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REGULARS

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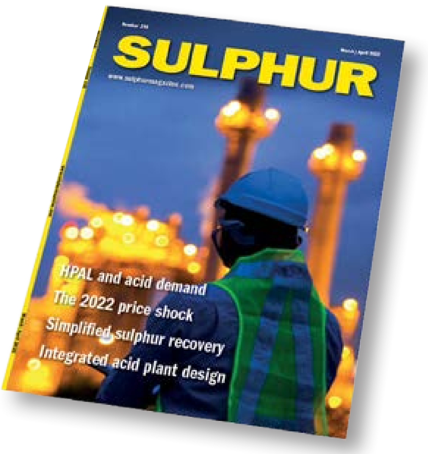
BCInsight

A shake of the kaleidoscope



> "Russia's move has already changed the world in ways which will not be easily changed back..."

It was supposedly Lenin who said that there were "weeks when decades happen", and the past few weeks have felt very much like that. The outbreak of conflict in Ukraine has sent shockwaves across the world and may have changed it permanently.

As terrible as the pictures coming from the conflict zone are, and the plight of millions of refugees, displaced both internally and externally, for most of us, in the short to medium term the way that this war will affect us is economically. As we discuss in the article elsewhere in this issue, the wide-ranging and indeed unprecedented sanctions that have been imposed on Russia will severely disrupt commodities markets, in most of which Russia is a significant net exporter. Sulphur is one of course, but so are related markets like phosphates, ammonia, nickel, copper, wheat and of course oil and gas. While none of these goods fall directly under international sanctions, and there has already been a push by South American nations, led by Brazil, to exempt fertilizers from any restrictions to avoid undermining food security, the ejection of Russia from the SWIFT inter-bank payment system makes actually paying for Russian commodities much more difficult, and a throttling back of exports more likely.

And of course, all of this comes at a time when there had already been a supply crunch in several markets simultaneously, with European gas prices at record levels and ammonia and phosphate markets tight. While some Russian product will find a home - China, India and Brazil are not part of the sanctions regime and will no doubt keep buying – we are still in the early stages of a supply shock that will be every bit as damaging as the covid pandemic. Nor has covid gone away – China has begun locking down cities again as the omicron variant spreads rapidly. A year or so ago I suggested that, with the demand shock caused by covid-19, we might have already seen peak global oil production. Demand destruction caused by the current oil supply shock makes that all the more likely.

At time of writing there were some hopeful signs that negotiations between the Russians and Ukrainians were making a limited form of progress. However, even if there is a settlement of some kind – and there will have to be eventually – Russia's move has already changed the world in ways which will not be easily changed back. The exodus of western companies from Russia that began with BP and Shell but which has now expanded to include virtually all oil and gas majors is unlikely to be reversed, especially if the Russian government proceeds with its threats to expropriate the assets of companies which leave. This will have a long term effect on the oil and gas exploitation that currently accounts for 60% of Russia's GDP.

In a way this marks the end of a process which had already been in train for some time. In the years after the fall of the Soviet Union, there was a shifting of geopolitical tectonic plates that had frozen the world as it was in 1945 for more than four decades. With that came the hope, at least in western countries that there would be a major shift towards liberalisation, leading the countries of eastern Europe and Russia to westernise, globalise and democratise. Russia itself was seen as a major destination for oil and gas investment, to modernise its creaking infrastructure and develop its huge energy reserves. But while this has largely come to pass for eastern Europe, Russia slid instead into crony capitalism and a suspicious, hardening nationalism that has now manifested as military adventurism. This feels for those of us who remember it very much like a return to the days of the Cold War.

In October 2001, in the aftermath of 9/11, British prime minster Tony Blair said that; "the kaleidoscope has been shaken, the pieces are in flux, soon they will settle again." This year feels like one of those pivotal moments in world history, but possibly one that marks an end to the globalised world that we have come to take for granted.

Richard Hands, Editor

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Price Trends

MARKET INSIGHT

Meena Chauhan, Head of Sulphur and Sulphuric Acid Research, Argus Media, assesses price trends and the market outlook for sulphur.

SULPHUR

Russia's invasion of Ukraine has propelled the sulphur and wider commodity markets to new levels of uncertainty. The potential threat of a significant shortage of sulphur availability from the Russian and Central Asian region has led global prices to even higher levels. Middle East prices increased by 8% at the time of writing after two weeks of conflict, up by $22-25/t to a range of $333-340/t f.o.b. on 3 March. This range was expected to see further significant increases in the short term, based on offer prices and market sentiment.

The range of financial and other trade sanctions now imposed on Russia in response to its actions is extensive and unprecedented. At the sanctions' core has been the exclusion of Russian banks from the Swift international payment system. As the conflict continued a slew of European buyers including Italy's Eni and Saras, Norway's Equinor and Finland's Neste withdrawing from purchases of Russian crude. Shell and BP are also stepping away from new oil contracts or deals with Russian entities.

Adnoc set its March official sulphur price for liftings to the Indian market at $335/t f.o.b. Ruwais, up by $15/t from the February price of $320/t f.o.b. The Middle East – East Coast India freight rate for a 30,000-35,000t shipment was assessed at a minimum of $50/t at the start of March, implying a delivered price of $385-387/t c.fr. Kuwait's KPC set its March sulphur lifting price at $343/t f.o.b., up by $28/t from the February price. Muntajat set the March Qatar sulphur price at $333/t f.o.b. Ras Laffan/Mesaieed, up by $18/t from the February QSP of $315/t f.o.b. These increases came on the back of the rapid rise in spot prices following the shock to the market of the Russian conflict. Climbing bunker prices also lifted freight costs globally, and this is adding support to further increases for delivered sulphur prices.

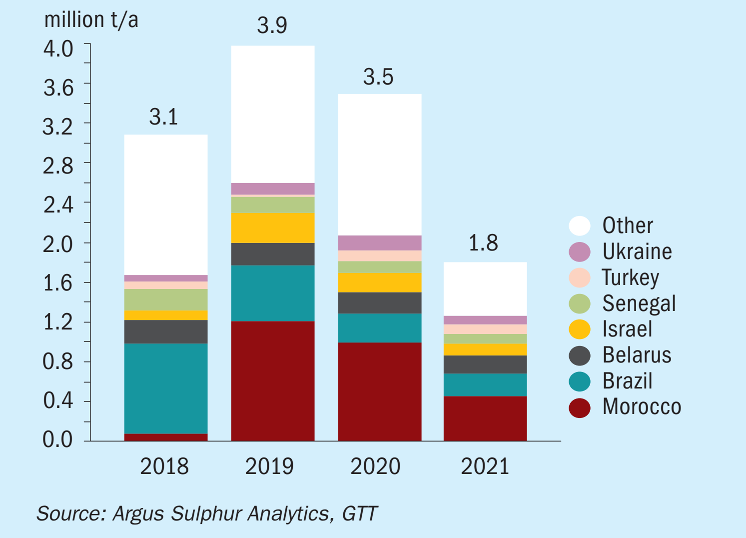
Russian sulphur exports totalled 1.8 million t in 2021, down by 48% on 2020 levels and well below exports in recent history, usually over 3 million t/a. The drop came because of a decrease in production as well as an increase in domestic demand in the processed phosphates sector. The main market for Russian sulphur tonnage in 2021 was Morocco followed by Brazil, together these two markets represented 38% of Russian exports. The two markets would be the most exposed to a drop in trade. For Morocco, Russian supply represented the fourth highest supplier in 2021, or 11% of its total imports, this was a significant decrease on 2020 levels because of the rise of supply from the UAE and Kazakhstan. Over in Brazil, Russian supply represented 8% of its imports while Kazakhstan was its leading supply source at over 800,000t.

Sulphur supply from Kazakhstan is also at risk because of the conflict. According to trade statistics, Kazakhstan exported 3.9 million t of sulphur in 2021, with 3.6 million t of this going via Russia. Disruption to this trade route would impact numerous markets reliant on these volumes. There is concern around how a shortfall of sulphur from Russia, as well as product in other neighbouring markets that moves via Russian rail, will be met.

There is increasing focus on Middle East sulphur supply growth potential in the short term and whether this would offset potential losses from Russia and Kazakhstan. We expect production in the Middle East to rise by 1.2 million t in 2022 on a year earlier, which falls short of the total export losses from the conflict. Kuwait's Al Zour was to begin commissioning with a gradual start-up of operations from March. While full sulphur capacity of 600,000 t/a is not expected this year, there is potential to see partial capacity in the months ahead. The Clean Fuels Project in the country is also adding supply this year, with Kuwait's exports expected to double in 2022. New supply is also expected in Saudi Arabia. Saudi Aramco has been gradually commissioning its newest refinery, a 400,000 bbl/d complex at Jizan. We expect sulphur output to slowly ramp up through 2022-23.

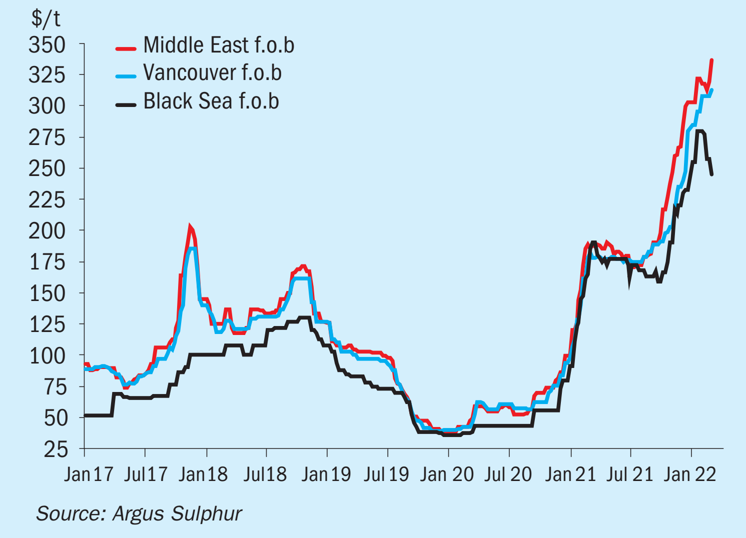
Other factors to consider are on the demand side, with little clarity yet on how the processed phosphates sector will be impacted. Ammonia exports have been affected and this in turn will affect buyers of the raw material in the production of processed phosphates. This raises questions around how sulphur consumption will fare. Prior to the conflict, we had been forecasting global sulphur demand to rise by 2.1 million t in 2022. Around 19% of this was expected to come a rise in phosphoric acid production. Without clarity on how exports of Russian finished fertilizers will be impacted or procurement plans for raw materials in key markets such as Brazil and Morocco it is difficult to assess potential sulphur con-

Fig. 1: **Russian supply import history**



Source: Argus Sulphur Analytics, GTT

Fig. 2: **Monthly Middle East sulphur producer prices**



Source: Argus Sulphur

sumption losses. Meanwhile nickel prices have accelerated to unprecedented levels in the wake of recent events, providing strong support to nickel HPAL projects in markets including Indonesia. Sulphur demand for nickel is expected to rise by around 900,000 t in 2022 to just under 3 million t, supporting trade in this sector.

SULPHURIC ACID

Global sulphuric acid prices have been more stable since the start of the year with some ranges easing slightly. There is concern in the market over the implications of military action taken by Russia although the acid market is not exposed in the same way as sulphur because acid is largely produced for captive use in the country.

The NW European export benchmark increased at the start of the year but has since remained stable at an average price of $235/t f.o.b. The elevated price has been underpinned by the tight supply fundamentals and the upcoming turnaround schedule at European smelters was expected to keep the market tight through the first half of 2022. Supply losses from planned maintenances at smelters and sulphur burners are expected to total over 700,000t, with some plants yet to disclose full timescales for shutdowns. The distribution of sulphuric acid was also hampered through much of 2021. Issues remained in getting barged acid on to trucks at the start of the year, because of the shortage of truck drivers in Europe. First quarter contract prices for sulphur-based acid were settled at an increase of €50-70/t on 4Q 2021 levels, bringing the range to €173-220/t c.fr. This is a €53/t premium to the NW Europe smelter grade contract price. More recently high energy prices have led some end users of acid plants to lower production in Europe and there is some concern on the supplier side around demand in the region.

The tightness in the copper concentrate market was expected to somewhat relax in 2022, buoyed by higher copper prices and increased Covid-19 vaccination rates, allowing healthier staffing at mines. This is expected to lead to an increase in smelter-acid production in China through the year. Strengthening domestic demand in March limited available acid for the export market but an uptick in supply through the is expected to lead to higher export volumes. The China export price was assessed by Argus at $125-135/t f.o.b. on 10 March, the same level as the Japan/South Korea price. This represents around a $100/t gap with the European export price because of differing fundamentals. This gap is expected to close once the European supply balance improves, but this is unlikely during 2022.

Base metals prices on the London Metal Exchange (LME) have been mixed amid recent volatility. Nickel prices were suspended after unprecedented increases in the benchmark prices, which surged above $100,000/t, led the exchange to put trading of the metal on hold. Copper prices on the LME also firmed to over $10,000/t with a large drawdown of copper inventories in the LME warehouse system supported prices. Stocks were already tight prior to the decline. Higher metals prices support sulphuric acid consumption at mining operations. There is some concern over acid consumption in Chile as the newly elected Chilean-government took a first step towards its promise of nationalising metals mines in a motion passed on 5 March. The environmental committee of Chile's constituent assembly, which is in charge of writing the country's new constitution, approved an early proposal targeting large scale copper, lithium and gold mines by 13 votes to 3. Chile consumed 8.7 million t of acid in 2021 and imported 2.9 million t. The Chilean price was assessed by Argus at $235-245/t c.fr. on 10 March with the market in flux. Buyers had been expected lower prices after the second quarter but higher freights and bunkers and a tighter supply stream from Asia may push prices higher.

Buyers in India adopted a wait and see approach in mid-March following the increase in prices to $165-175/t c.fr. on higher freight and tender awards. Fertilizer producer Iffco has a planned 3-week turnaround at its Paradip plant in March. Sulphuric acid demand was expected to be strong in 2022, supporting the outlook for strong imports from the country. The Indian government raised the budget allocated to fertilizer subsidies for the 2022-23 financial year, doubling funds for phosphates-based fertilizers. The drawdown of finished fertilizer stocks is a scenario that suppliers will be keen to avoid following the issues this caused last year. But the ammonia supply disruptions has raised questions for the phosphate industry and in turn sulphuric acid demand is likely to fluctuate. ■

Price Indications

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

Cash equivalent	**September**	**October**	**November**	**December**	**January**
Sulphur, bulk ($/t)					
Adnoc monthly contract	180	194	230	265	310
China c.fr spot	230	302	325	327	342
Liquid sulphur ($/t)					
Tampa f.o.b. contract	195	183	183	183	282
NW Europe c.fr	228	228	228	228	327
Sulphuric acid ($/t)					
US Gulf spot	230	230	228	238	238

Source: various

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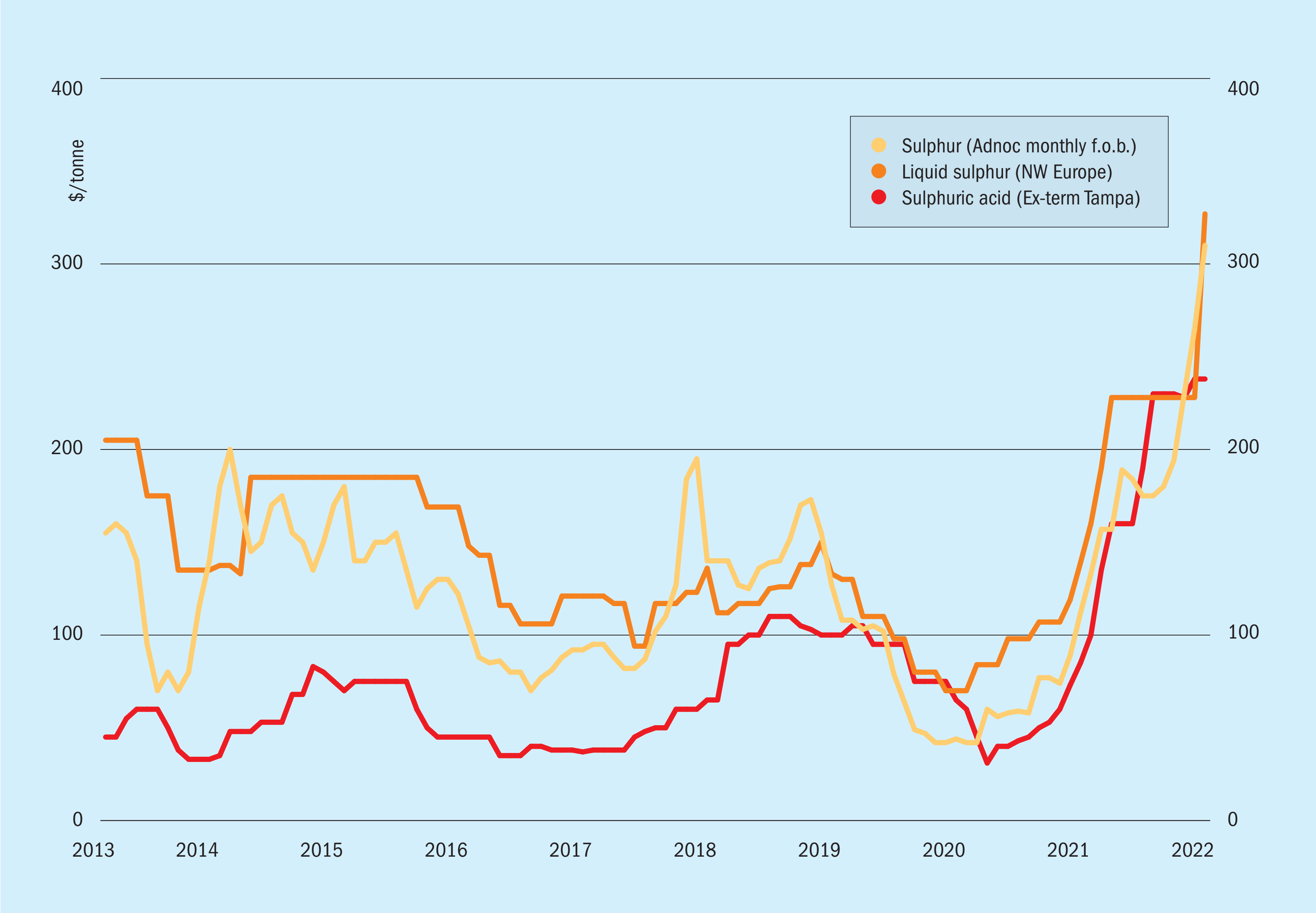
Market Outlook

Historical price trends $/tonne



Source: BCInsight

SULPHUR

- Developments in the Russia-Ukraine conflict is going to be a key influence for the sulphur market through the year. The potential loss of Russian sulphur to key import markets such as North Africa and Latin America is likely to lead to trade flows increasing to these regions from the Middle East and North America.
- The extent to which Kazakhstan exports will be limited will also be a critical factor for the outlook for pricing. There is potential for some supply to move to China but another likely outcome is for sulphur to be blocked temporarily, pending any policy or legal restrictions.
- Rising Chinese sulphur supply is likely to be a focus point for the market as this will provide a limit to how much sulphur is required to be imported. Any reductions in imports to the country could provide supply to other markets impacted by the shortfall from Russia and Central Asia.
- Outlook: Global sulphur prices are likely to see further increases in the short term through the month of April. Concern is mounting in the market that the swift upward spike in pricing may be followed by a downward correction of equal scale. The supply side capacity additions in the Middle East may help to ease the shortfall from Russia but uncertainties still remain around Kazakhstan supply which would also have a significant impact to trade flows and pricing.

SULPHURIC ACID

- Canadian Pacific (CP) railway workers were threatening to strike in March amid trucker protests on the Canada-US border. The strike had the potential to impact the CP railway from 16 March, potentially impacting the flow of acid.
- The spike in sulphur prices may lend support to sulphuric acid market merchant trade in the short term, but regional supply/demand balances will determine whether spot availability can cover demand.
- In China, new supply is expected from the Yantai Guorun Copper smelter in Shandong, expected to start up this year with 720,000 t/a acid capacity. The Xinjiang Zijin Mining smelter is also expected to ramp up to full capacity this year following a start-up back in 2020.
- Acid demand is in question because of the uncertainty in the fertilizer market. The disruption to ammonia supply and trade is likely to lead to potential cutbacks in processed phosphates production during the second quarter, impacting the outlook for sulphuric acid consumption.
- Outlook: Sulphuric acid prices are likely to remain stable to firm in the short term but as with all commodities, volatility is likely to be a part of the market in the months ahead. Availability from Europe may be hampered further by the high energy prices but reductions in operating rates by end users may partially balance supply side losses. ■


Science behind Technology

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Sulphur Industry News

WORLD

Widespread economic fallout from Ukraine conflict

Russia's invasion of Ukraine, the consequent sanctions imposed by European and North American countries, and fears over further sanctions and a widening of the conflict have had sent a systemic shock through the world trading system. Stock markets dropped sharply, and the Russian rouble lost 30% of its value. The most immediate short and medium term impact is likely to come from Russian banks being cut off from the SWIFT international payment system, making exports of commodities more difficult, although no direct restrictions or embargos have been imposed on Russian products as of time of writing.

Oil prices jumped, trading around $100/barrel for Brent Crude; Russia accounts for about 10% of global oil supply, and oil markets remain tight. 'OPEC+' – a coordinating body consisting of Organisation of Petroleum Exporting Countries members with Russia and her allies – were expected to confirm plans to raise output by 400,000 bbl/d from April, but have not been able to meet existing quotas, running at an estimate 970,000 bbl/d below existing quotas. The group is forecasting an oil market surplus down to 1.1 million bbl/d for 2022. European gas prices also jumped; Russia supplies 40% of Europe's gas, rising to 50% for Germany and almost 100% for Hungary. There were also indications of longer term dislocations. BP announced that it would be selling its 19.75% stake in state-owned Russian oil giant Rosneft. ■

BELGIUM

Sulphur concrete railway sleepers for Infrabel

Concrete manufacturer De Bonte says that it has been contracted to supply 200,000 railway sleepers for the Belgian state rail maintenance company Infrabel. The company says that the sleepers will be manufactured from sulphur concrete, which emits 40% less carbon dioxide than traditional concrete. The process replaces cement and water with sulphur as a binding agent, mixing it directly with the granules. This avoids the energy-intensive process of converting limestone into cement, and allows the process to be operated at 140°C – sufficient to melt the sulphur for casting – whereas traditional cement production requires temperatures up to 1,400°C, hence the higher CO_2 penalty. The sulphur concrete is projected to last up to 40-50 years, and is said to have a resistance to dynamic train loads at least as good as that of traditional cement-based concrete sleepers. Sulphur concrete is also less porous than conventional concrete, and hence less susceptible to water penetration. It is also recyclable – the material can be melted and hardened again and again.

De Bonte says that this is a "real revolution", and the first large scale use of the material in the rail sector. The sleepers will be produced at a site in Baudour near Saint-Ghislain, in Belgium's Wallonia region, in cooperation with De Bonte's Research and Development Centre in Laakdal, Antwerp. De Bonte bought the 100,000 m² Baudour site in 2017 and spent €14 million on refurbishing buildings and installing two production lines for sulphur concrete products: sleepers and sewer pipes. The company says that its ambition is to market sulphur concrete and its applications globally, and that it is in talks with France and the Netherlands for orders of the sulphur concrete sleepers. Other potential applications include platform edges.


PHOTO: INFRABEL

Laying sulphur concrete sleepers in a test application last year.

UNITED ARAB EMIRATES

Partnership for process equipment supply

The Gulf-based Petronash Group, an engineering solutions provider to the energy industry, has announced a strategic partnership with Canada's ALCO Gas and Oil Production Equipment to design, build, and deliver processing equipment for the oil and gas industry in the Middle East and North Africa region. Petronash established in 2000, provides design,

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manufacturing, installation and services of engineered packaged equipment, with manufacturing facilities in the UAE, Saudi Arabia and India.

ALCO supplies packaged natural gas facilities including, carbon capture, flare gas recovery, sulphur recovery, dewpoint control, amine sweetening, HC fractionation, molecular sieve, glycol dehydration and inlet separation.

INDIA

Gas treatment market to grow at 6% over next five years

Indian consultancy company IndustryARC forecasts that the gas treatment market is forecast to reach $3.8 billion by 2026, after growing at an average annual growth rate of 5.8% during 2021-2026, in spite of the impact of the covid-19 pandemic. Amines represent that largest share of the market for CO_2 and H_2S removal in petrochemical plants, natural gas processing plants, and refineries. The growing adoption of acid gas removal is due to the increasing use of natural gas as a cleaner source for electricity generation in countries such as China, India, Malaysia, and Indonesia. Regionally, Asia represents the largest market, with a share of 38%, due to the increasing oil and gas industry and government initiatives in Asian countries such as India, China, Japan, and others. The Indian government alone plans to invest about $102 billion on oil and gas infrastructure over the next five years, including increasing the country's LNG re-gasification capacity from 42.5 million t/a to 70 million t/a by 2030 and 100 million t/a by 2040. China's natural gas consumption rose to 10.8 trillion cubic feet in 2019 and gas' share of Chinese energy consumption is expected to rise to 14% by 2030. Elsewhere, Canadian oil and gas companies invested C$27.3 billion in 2021 and US natural gas production will rise to 384.9 billion cubic meters (bcm).

MALAYSIA

Carbon capture to form part of sour gas project

Malaysia's Petronas says that its first carbon capture and storage (CCS) project, Kaswali Phase 2, will be up and running in 2025, and its second in 2026. Kaswari 2 is being touted as the largest CCS project in the world, with 4 million t/a of CO_2 to be captured over the project's anticipated 20 year operating life. CO_2 extracted and compressed from the project will be piped 135 km to the M1 field, where it will be reinjected into a depleted reservoir. Petronas says that it will use its Cryomin cryogenic CO_2 recovery technology for the project, as well as PN2 hollow fibre membranes for the lines, and corrosion prediction software for supercritical CO_2.

Next up will be the Lang Lebah offshore field, which has reserves of 5 tcf of gas. Gas process from Lang Lebah will include H_2S removal at an onshore processing plant, OGP2, with the CO_2 then being piped back offshore for injection at the depleted Golok field. Lang Lebah will be one of the key projects for the Sarawak Integrated Sour Gas Evacuation System (SISGES), which Petronas said will be a catalyst for the monetisation of high contaminant fields in the state of Sarawak.

Malaysia says it has identified up to 46 tcf of carbon dioxide storage potential in 16 sites, offshore Sarawak and Peninsular Malaysia. It will offer some of them to third parties, hoping to establish Malaysia as a regional CCS hub. Petronas has already signed memoranda of understanding with companies such as Shell, ExxonMobil, Cosco and Japex to explore possibilities and opportunities to provide CO_2 storage solutions for Malaysia and the region.

RUSSIA

SRU for new refinery

In January Maire Tecnimont announced that it had signed an EPC contract via its subsidiaries Tecnimont and MT Russia with Rosneft for the implementation of a vacuum gasoil hydrocracking complex at the Ryazan Refining Company, 200 km southeast of Moscow. The overall contract was valued at approximately €1.1 billion. However, even at the time Tecnimont noted that the contract was subject to financial closure and other "certain conditions", and that project duration had not been formally set as yet. The likelihood of the project proceeding in the light of the recent raft of financial sanctions announced against Russia seems remote.

The scope of work was envisaged to entail the design, supply of equipment and materials, construction, start-up and commissioning, and project finance services for the 40,000 bbl/d hydrocracking complex, intended to bring it up to Euro-5 standards, and would include hydrocracking units, hydrogen production, sulphur recovery units, and offsite facilities. ■

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UNITED KINGDOM

Sulphuric acid slurry treatment launched in UK

German slurry handling specialist Vogelsang has just launched a new acidification technology which it claims will reduce ammonia emissions from agriculture, reducing up to 70% of ammonia to nutrient rich ammonium. Its new *SyreN* technology is an onboard sulphuric acid dosing system for tractors that treats slurry or digestate as it is applied to the land. It uses a front-linkage mounted unit to carry the acid, which also improves tractor weight distribution. The acid is dosed when the organic fertiliser is fed to the applicator, with a pH regulator automatically controlling and adjusting the flow. Nitrogen uptake of organic fertilizer is also increased by up to 1/3 as the ammonium is more easily metabolised by the soil. Results from a study in Germany showed that the acidifying slurry increased crop yield by up to 20%. The sulphur contained in the acid also becomes available to the plants as sulphate after spreading, eliminating the need for an additional pass over the field to administer a supplementary sulphur fertiliser, such as ammonium sulphate nitrate. At approximately 30 kg/ha, the amount of sulphur introduced into the crop with the *SyreN* system corresponds to the average amount of sulphur that is already applied to crops in the course of a growing season.

Commenting on the introduction of the technology to the UK and Ireland, Vogelsang's *SyreN* specialist, Sion Williams, said: "The UK and the EU have set out plans to reduce agricultural emissions by 2030. Treating slurry with acid delivers this and has the added benefits of increasing yield, reducing input costs and reducing the prevalence of odours that occur during application." ■

Electric vehicle demand leading to nickel shortage

Demand for electric vehicles is leading to a boom in demand for nickel, cobalt and lithium, with prices at multi-year highs. Reuters reports that more than 6.36 million electric vehicles were sold last year globally compared with 3.10 million in 2020, with China accounting for half of this total. Shortages of nickel have led to stocks in London Metal Exchange approved warehouses falling by 65% since April 2021. Stocks of bagged briquette, easily crushed into small particles and dissolved in sulphuric acid to make nickel sulphate for batteries, are down 67% since last April. Most of this has been shipped to China. Total nickel demand rose to 2.8 million t/a last year, with batteries now accounting for 11% of the market. This share is expected to rise to 13% this year. Nickel prices have reached $24,800/tonne, their highest level since 2011.

SWITZERLAND

EuroChem posts record 2021 earnings

EuroChem Group has reported earnings of $3.9 billion for the full year 2021, against sales of $10.2 billion. The profit figure is more than double that for 2020, which the company attributed to higher fertilizer prices, as well as a 6% increase in total sales volumes and higher operating efficiencies. Curtailments and countervailing duties impacted global trade flows, which made for a very competitive environment, but the company argued that this also rewarded more flexible and diversified operators. Overall, total sales volumes were up 6% to 27 million tonnes in 2021, with phosphates seeing a 17% rise. Sales of MAP/DAP climbed 10% to 2.6 million t/a, with third-party product sales accounting for roughly 40%. That together with the Group's own production of phosphates fertilizers at Lifosa helped to increase sales volumes in the US by 38% year on year. The company is also in the process of completing the acquisition of the Salitre do Serra phosphate project in Brazil from Yara International for $410 million. When it comes on stream in 2023 it will add 1 million t/a of phosphate capacity in MAP, SSP, TSP and nitrophosphates. Parallel to this, EuroChem has agreed to take a majority stake in Brazilian fertilizer distributor Fertilizantes Heringer.

"These encouraging results will allow EuroChem to build upon its position as a leading global fertilizer player," said CEO Vladimir Rashevskiy. "The supportive environment enables us to set even higher goals for ourselves and invest in ambitious new projects to stay on our growth trajectory."

UNITED STATES

Mosaic reports strong results

The Mosaic Company has reported net income of $1.6 billion for full year 2021, including fourth quarter net income of $665 million. Full year revenues were up 42% year on year to $12.4 billion, as stronger pricing more than offset lower volumes. Adjusted EBITDA in 2021 totalled $3.6 billion, a record figure, up 129% from 2020. Cash from operating activities was up 38% percent from the prior year. The company's phosphate division earned $1.2 billion in 2021 on total sales of $4.9 billion, compared to an operating loss of $147 million in 2020, with record sales figures for the company's *MicroEssentials* micronutrient enhanced fertilizer range. Phosphate sales volumes decreased from 8.5 million t/a in 2020 to 7.7 million t/a, reflecting the impact of Hurricane Ida in the second half of the year, but this was more than offset by the rise in average selling prices to $618 per tonne, up from $360/t in 2020. In its results presentation, the company said that it expects upward phosphate pricing momentum to continue. Global demand for grain and oilseeds remain high while stock-to-use ratios are at the lowest point in more than a decade. Food security concerns, rising biofuel consumption, and textiles are driving demand for corn, soybeans, wheat, rice, coffee, palm oil, cotton and other agricultural commodities. As a result, strong global fertilizer demand in 2022 is expected as growers seek to maximise yields. China's domestic phosphate industry is also undergoing significant change as production is diverted from export markets toward domestic industrial and agricultural demand, a secular trend that could outlast the current short-term export ban.

"Mosaic delivered record EBITDA in 2021, and we expect strong performance to continue in 2022," said Joc O'Rourke, President and CEO. "As a result of successful investments like our new Esterhazy K3 potash mine, Mosaic Fertilizantes in Brazil, and our cost-structure transformation, we are generating tremendous value in the current environment. This has provided us with the opportunity to return significant capital to shareholders, while still investing efficiently in the business and strengthening the balance sheet."

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Elessent announces acid catalyst price hike

Elessent Clean Technologies, the new owner of the former DuPont Clean Technologies division, has announced an additional global price increase of $0.30/litre for its MECS® sulphuric acid catalyst products, effective immediately. The company says that additional surcharges may apply for freight, near term delivery and specialty product grades.

BRAZIL

Itafos re-starts acid production at Arraias

Itafos says that it has resumed sulphuric acid production and sales at Arraias. The recommissioning of the previously idled sulphuric acid plant was completed on schedule, within budget and with no reportable environmental releases or recordable incidents.

"We are pleased to have safely and successfully completed the recommissioning of the sulphuric acid plant at Arraias. While we continue to evaluate strategic alternatives for Arraias, we are opportunistically restarting the sulphuric acid plant to supply market demand and deliver positive margins," said G. David Delaney, CEO of Itafos.

Arraias' sulphuric acid plant has a capacity of 220,000 t/a. The company says that it expects to operate the sulphuric acid plant at Arraias with a base load capacity of approximately 10,500 tonnes per month (126,000 t/a). Arraias has secured short-term sulphuric acid offtake agreements for this capacity with pricing linked to sulphur benchmarks. Based on market demand, Itafos expects to opportunistically produce additional volumes of sulphuric acid to be sold on the spot market. The remainder of the infrastructure associated with Arraias' vertically integrated phosphate fertilizer business, including its mine, beneficiation plant, acidulation plant and granulation plant remain idled. The Arraias site, at Tocantins, includes idled capacity of approximately 500,000 t/a of single superphosphate (SSP).

CANADA

Chemtrade reports loss for 2021

Chemtrade Logistics Income Fund says that it made a net loss of C$180.5 million for 4Q 2021, C$155 million higher than for 4Q 2020. This was primarily due to the sale of its potassium cholide and vaccine adjuvants businesses, on which the company took a non-cash impairment of C$130 million. Overall revenue for 4Q 2021 was C$353.8 million, up C34.4 million on the previous year due to higher prices, especially for merchant and regenerated sulphuric acid.

Revenue for the full year 2021 was C$1.4 billion, the same as for 2020, with EBITDA C$280.4 million, adjusted cash flows from operating activities of C$159.4 million and a net loss of C$235.2 million.

Scott Rook, Chemtrade's president and CEO said, "2021 ended on a much stronger note than it started. We were able to significantly strengthen our balance sheet during the year. The fundamentals for several key products in our portfolio are very strong as we enter 2022. We are pursuing exciting organic growth opportunities in ultra-pure sulphuric acid and by-product green hydrogen. Finally, further to our objective of being an industry leader in corporate environmental, social and governance (ESG) matters, we have now established ESG targets that we will strive to achieve in the short and the long term."

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PHOTO: TOYO ENGINEERING CORPORATION

Fertilizers and Chemicals Travancore site at Cochin.

INDONESIA

Ground broken on copper smelter expansion

Indonesia-based PT Smelting, a joint venture between Mitsubishi Materials and Freeport Indonesia, has started construction on a $231 million copper smelting facility expansion project. The expansion will boost copper cathode capacity at the Gresik smelter on East Java from the existing 300,000 t/a to 342,000 t/a. This project is also expected to boost the processing capacity of the smelter from the current 1.0 million t/a to 1.3 million t/a of copper concentrate. The expansion project includes a new sulphuric acid plant, to be designed and built by Metso Outotec, which is also designing and supplying key process equipment and process control systems for the main areas of the smelter complex, the copper electrolytic refinery, gas cleaning, the slag concentrator and the effluent treatment plant.

Shipments begin from PT Huayue

PT Huayue, a joint venture between Zhejiang Huayou Cobalt, Tsingshan Holding Group and China Molybdenum Co, says that it has shipped its first 9,500 tonne batch of mixed hydroxide precipitate (MHP) from its new HPAL-based nickel plant via the port of Morowali to Ningbo in China. The $1.28 billion joint venture began trial production at the end of November 2021, and at capacity will produce 60,000 t/a of nickel and 7,800 t/a of cobalt.

RUSSIA

Major equipment items arriving for Nornickel Sulphur Programme.

Major equipment items are now arriving at Norilsk for the construction of facilities as part of the the Nornickel Sulphur Programme, according to the company. The programme is aimed to address the site's persistent problem with sulphur dioxide emissions, and includes the intermediate production of sulphuric acid with a high degree of sulphur dioxide utilisation (99% or more of the gas from the units where it is installed). The acid will then be neutralised with calcium carbonate.

As of the start of December, more than 700 tonnes of various units have already been installed out of the total 7,000 tonnes. Ball mills are being assembled at the limestone milk production site, which will produce powder for preparing this neutralising solution. The Velesstroy contractor has installed the largest part of one of the ball mills – a drum that weighs 28 tonnes. In the near future, the largest equipment, the heat exchangers for sulphuric acid production site will arrive at the port of Dudinka. Each of these exchangers weighs over 200 tonnes.

Nornickel aims to close the heating circuit of the sections for the production of limestone milk and the production of sulphuric acid "soon". Within three months, it also intends to erect building frames and a heating circuit for three other crucial facilities. Construction of storage for gypsum is reportedly 80% completed. By summer 2022, individual tests and commissioning are planned to begin.

INDIA

Rama Phosphates acquires land for SSP project

Rama Phosphates Ltd has acquired 21 hectares (52 acres) of land in the Nardana Industrial Area from the Maharashtra Industrial Development Corporation (MIDC) for the construction of a new phosphate fertilizer plant. The company has also received consent from the Maharashtra Pollution Control Board to manufacture 216,000 t/a of single super phosphate (SSP), including lines fortified with zinc and boron. Approval has also been granted for the construction of a 90,000 t/a sulphuric acid plant as part of the complex. The company says that it is in the process of finalising supply of plant and machinery, and hopes to begin production at the end of the 2023-24 financial year.

Talks on fertilizer import deal with Russia

In early February an India engaged in its first intergovernmental negotiations with over for the long-term supply of fertilizer. India is reportedly seeking guaranteed supply of 1 million t/a each of diammonium phosphate (DAP) and potash; and about 800,000 t/a of NPK fertilizers, via deals with Rashtriya Chemicals and Fertilizers Ltd, National Fertilizers Ltd, Madras Fertilizers Ltd, Fertilizers And Chemicals Travancore and India Potash Ltd with Russian companies including Phosagro and Uralkali. Indian companies already have an import deal for 400,000 tonnes of DAP with Phosagro. However, the progress of negotiations following the Russian invasion of Ukraine and subsequent sanctions regime is not known.

Closure of smelter did not affect air quality

A recently published study on air quality in Thoothukudi has shown no change following the shutdown of the Sterlite Vedanta copper smelter. Sulphur dioxide levels were assessed at just 1 microgramme per cubic meter higher while the plant was operating, according to the study which was prepared by the Asian Institute of Technology, Bangkok and National Institute of Technology in Jamshedpur. The smelter was shut down in 2018 following local riots which left 13 dead when the plant was blamed for health problems in the area. The study says that SO_2 emissions from the operation of Sterlite Copper were less than 10% of total SO_2 emissions in Thoothukudi (formerly Tuticorin). Concentration levels of particulate matter (PM10, PM2.5), and nitrogen dioxide in Thoothukudi between 2015 and 2020 were comparable to those observed in Mumbai, Kolkata, and Chennai, which were coastal cities like Thoothukudi, as well as with those at Manali, Cuddalore, and Coimbatore. Lower levels of PM10 were found following the closure of the smelter, which was attributed to less movement of traffic, including heavy duty trucks in and around the plant.

The Sterlite copper smelter, with a capacity of 400,000 t/a, supplied more than one third of India's demand for refined copper and 1.2 million t/a of associated sulphuric acid production and 220,000 t/a of phosphoric acid production.

Expansion in phosphate capacity

State-owned FertiliZers and Chemicals Travancore Ltd (FACT) is expanding its NPK fertilizer capacity at Kochi. Indian project management Nuberg EPC has been selected for the construction of the brownfield 1,650 t/d NPK plant on an EPC lump sum turnkey basis, bringing total production capacity to 3,650 t/d of complex fertilizer on completion in mid-2023.

Nuberg EPC will execute the project based on a pre-neutraliser with pipe reactor technology licensed from INCRO SA. It is primarily designed to produce NPK 20:20:0:13 with a rated capacity of 75 t/h in a single stream using pre-neutraliser technology and diammonium phosphate using pre-neutraliser and pipe reactor technology, using ammonia, phosphoric acid, sulphuric acid, urea etc as required.

Additionally, Nuberg will be carrying out the design and detailed engineering of a plant for the future production of different grades of NPKs using ammonia, phosphoric acid, sulphuric acid, muriate of potash, urea etc.

A. K. Tyagi, managing director, Nuberg Engineering Ltd., commented: "We are thankful to the Government of India and Fertilizers and Chemicals Travancore Ltd entrusting another turnkey project to our engineering capabilities and EPC services and solutions."


PHOTO: DPM

Dundee Precious Metals' Tsumeb smelter, Namibia.

CANADA

Record results for DPM

Dundee Precious Metals (DPM) has announced record financial results for 4Q21 and full year 2021. Adjusted net earnings for 4Q 2021 were $51.4 million compared to $44.0 million in 4Q 2020, and for full year 2021 adjusted net earnings were $202.0 million, compared to $188.4 million in 2020 due primarily to higher realised gold and copper prices, partially offset by the planned maintenance shutdown at the Tsumeb smelter in

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Namibia in the first quarter of 2021, as well as unplanned maintenance downtime due to water leaks in the off-gas system during the second half of 2021. Complex concentrate smelted at Tsumeb during 4Q 2021 was 51,932 tonnes, comparable to the corresponding period in 2020. Complex concentrate smelted at Tsumeb in 2021 of 189,705 tonnes was 18% lower than 2020 due primarily to the planned first quarter Ausmelt furnace maintenance shutdown, as well as unplanned maintenance downtime due to water leaks in the off-gas system during the second half of 2021. The next smelter maintenance shutdown is expected in 2Q 2022, with complex concentrate smelted expected to be between 210-240,000 t/a in each of 2022 and 2023, and 220-250,000 t/a in 2024.

DEMOCRATIC REPUBLIC OF CONGO

Upgrade for Kamoa project

China's Zijin Mining says that the Kamoa-Kakula copper project in DRC will undergo a $50 million debottlenecking expansion to boost capacity and output. Kamoa-Kakula is a joint venture largely held by Zijin and Canada's Ivanhoe Mines, each of which have a 39.6% stake, with the DRC government holding most of the remainder. The debottlenecking will increase capacity of the concentrator plants, which process ore brought from the mine, to 9.2 million t/a of ore from the existing 7.6 million t/a. Copper output will increase from 400,000 t/a to 450,000 t/a. The timescale for the project is around 12 months, with a third, "significantly larger" concentrator also planned and expected to be commissioned in 4Q 2024. A $770 million copper smelter is also under development at the site, with commissioning expected in 2025, to reduce the project's reliance on third-party smelters for ore processing.

CHINA

Chinese copper smelter output down in January

Sumitomo Metal Mining (SMM) says that Chinese domestic copper cathode output was 818,100 tonnes in January 2021, down 6% on December, though 2.5% up on January 2020, due to shutdowns at Fangyuan and Lanxi Zili. Copper concentrate stocks in smelters were relatively abundant. The output of smelters affected by blister copper will gradually return to normal as global supply chain problems ease.

The Kamoa copper facility.

PHOTO: IVANHOE MINES

Domestic smelters are likely to continue to be profitable in spite of lower sulphuric acid prices compared with the second half of 2021. SMM expects that Chinese smelters will maintain high output in 2022. According SMM, China's output of nickel sulphate stood at 26,100 tonnes metal content in January 2022, or 118,600 tonnes product, down 6.25% from the previous month but up 62.9% year on year.

AUSTRALIA

Increase in scope for HPAL project

Ardea Resources, which is developing the Goongarrie nickel-cobalt project at Kalgoorlie, east of Perth in Western Australia, says that it has expanded the scope of the Goongarrie project to processing 3.5 million t/a of nickel bearing rock; a 50% increase. The company is in the process of preparing a definitive feasibility study in conjunction with Wood Engineers. Goongarrie is a huge nickel and cobalt laterite deposit, one of the largest in the world, and will be based on high pressure acid leaching (HPAL) to generate mixed hydroxide precipitate (MHP) for lithium ion batteries, now slated to process 3 million t/a of 1% nickel bearing rock in two HPAL trains. The new addition will be 0.5 million t/a atmospheric leach circuit to process serpentine deposits. Ardea says that this will make the process more efficient and lower the carbon intensity of nickel formation. It will also increase sulphuric acid consumption of the project and require a larger sulphur burning acid plant to feed the HPAL and atmospheric leach processes, with a consequent increase in steam generation which facilitates the project's off-grid, carbon free, site energy balance.

MOROCCO

OCP Group to partner with Koch

Morocco's OCP Group has signed an agreement with US-based Koch Ag & Energy Solutions to allow Koch to acquire a 50% stake from OCP Group in the Jorf Fertilizers Company III (JFC III). Once closed, the transaction will create a joint venture equally owned by OCP and Koch. JFC III comprises an integrated phosphate fertilizer production unit at OCP's huge Jorf Lasfar site, with an annual production capacity of over 1.1 million t/a of phosphate-based fertilizer.

Soufiyane El Kassi, chief growth officer at OCP Group: "JFC III production will be [jointly] marketed by OCP and Koch Fertilizer, LLC. In addition, the companies plan to collaborate to supply ammonia and sulphur to OCP Group, and will rely on their logistical capacities for the export of fertilizers from Morocco. Our collaboration with Koch will take a new step after more than ten years of commercial relations."

Executive vice president of Koch Fertilizer Scott McGinn said that the agreement testifies to a long-standing relation with OCP, noting that both companies share the same ambition of expanding phosphate offerings worldwide. "We are excited to grow Koch Fertilizer from being primarily a producer and marketer of nitrogen," McGinn added, emphasizing that Koch looks forward to partnering with OCP. ■

People

Haldor Topsoe has appointed **Elena Scaltritti** as the company's new chief commercial officer. She will take up her new position no later than July 1st, 2022. She has previously been executive vice president at Korea's SONGWON Industrial Group, where she was responsible for the group's commercial activities.

"I'm excited and very much looking forward to work with Elena. She has solid chemical industry experience and a strong commercial background. With Elena's hands on experience of driving growth, working with commercial excellence, key account management, and pricing, she can secure our leading position in existing markets and help us accelerate Topsoe's position in the green energy market," said Roeland Baan, CEO at Topsoe.

Dundee Precious Metals has announced that chairman **Jonathan Goodman**, who has held this position since 2013, will not be standing for re-election at the company's 2022 annual meeting. The board of directors has determined that Peter Gillin, currently serving as deputy chair, will assume the chair position, subject to his re-election as a director at the annual meeting of shareholders to be held on May 5th 2022. Goodman founded DPM in 2003, serving as president and CEO until 2013, executive chair from 2013 to 2017 and as chair since 2017. During his tenure, the Company has transformed the Chelopech mine into a world-class underground operation, successfully developed Ada Tepe, Bulgaria's first new mine in over 40 years, and has overseen the growth of DPM.

Jonathan Goodman.

In a statement, **Peter Gillin** said: "on behalf of the board and DPM management, I would like to acknowledge and thank Jonathan Goodman for the pivotal contributions he has made since 2003 in his capacity as founder, shareholder, CEO, and now as chair of DPM's board of directors. Starting with the acquisition of the Company's Bulgarian assets and their transformation into world class operations, Jonathan has been an integral part of DPM's growth into the leading environmentally and socially responsible mid-tier producer we are today. His strong leadership and guidance over the years established a strong foundation for the Company's values, which has been critical to our success and will continue to serve us well going forward."

"I am extremely proud of what we accomplished at DPM since the Company was founded in 2003," said Goodman. "I believe we have built an exceptional company with a promising future, consisting of world-class assets, strong partnerships with stakeholders and a very unique culture. I have full confidence that DPM's board and management will continue to build on these successes to deliver value for all stakeholders." ■

Calendar 2022

! The following events may be subject to postponement or cancellation due to the global coronavirus pandemic. Please check the status of individual events with organisers.

MAY

9-11

TSI Sulphur World Symposium,
TAMPA, Florida, USA
Contact: Sarah Amirie,
Director of Operations, TSI
1020 19th Street, NW, Suite 895,
Washington, DC 20036, USA
Tel: +1 202 296 2971
Email samirie@sulphurinsitute.org
Web www.sulphurinstitute.org

24-26

Middle East Sulphur Conference (MESCON),
ABU DHABI, UAE
Contact: Amanda Whicher,
Portfolio Director, CRU
Tel: +44 20 7903 2448
Email: amanda.whicher@crugroup.com
Angie Slavens, Managing Director,
UniverSUL Consulting
Tel: +1 913 526 0007
Email: angie@universulconsulting.com

JUNE

8-9

ESA Spring Meeting, LISBON, Portugal
Contact: Francesca Ortolan,
Sector Group Manager, Cefic
Tel: +32 499 21 12 14
Email: for@cefic.be

10-11

AIChE Clearwater Convention,
CLEARWATER, Florida, USA
Contact: Michelle Navar,
AIChE Central Florida Section
Email: vicechair@aiche-cf.org
Web: www.aiche-cf.org

20-22

4th European Sustainable Phosphorus
Conference, VIENNA, Austria
Contact: Chris Thornton, European Sustainable
Phosphorus Platform (ESPP) secretariat
Tel: +33 474 93 07 93
Email: info@phosphorusplatform.eu

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ASRL Chalk Talk, CALGARY, Alberta, Canada
Contact: Alberta Sulphur Research Ltd
Tel: +1 403 220 5346
Email: asrinfo@ucalgary.ca

SEPTEMBER

14-15

Oil Sands Conference & Trade Show,
CALGARY, Alberta, Canada
Contact: Bruce Carew, EventWorx
Tel: +1 403 971 3227
Email: marketing@eventworx.ca

OCTOBER

9-13

XIII Round Table for Sulfuric Acid Plants,
TEMUCO, Chile
Contact: Portus #1361, San Felipe,
Valparaíso 2171881, Chile
Tel: +56 34 251 5557

24-26

38th CRU Sulphur + Sulphuric Acid
Conference, THE HAGUE, Netherlands
Contact: CRU Events
Tel: +44 (0)20 7903 2444
Fax: +44 (0)20 7903 2172
Email: conferences@crugroup.com

24-26

The 8th SAIMM Sulphur and Sulphuric Acid
Conference, CAPE TOWN, South Africa
Contact: Gugu Charlie,
Conference Coordinator, Southern African
Institute of Mining and Metallurgy
Tel: +27 73 801 8353
Email: gugu@saimm.co.za

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The 2022 price shock

The extensive sweep of financial sanctions against Russia in the wake of the invasion of Ukraine, coupled with Russia's position as the leading exporter of numerous commodities means that the impact of the 2022 price shock may be worse than 2008.

On February 24th Russian forces crossed the Ukrainian border in several places as part of what Russia's president Putin described as a 'special military operation'. The pages of this magazine are not the place for a discussion of the rights and wrongs of the action, but regardless, the impact upon the commodity markets which are the source and destination for the world's sulphur is likely to be profound.

Sanctions

A suite of sanctions was rapidly imposed by the United States, European Union and other states to target Russian financial institution and individuals. The sanctions included removing Russian banks from the SWIFT messaging system for international payments; freezing the assets of Russian companies and oligarchs in western countries; and restricting the Russian central bank from using its $630 billion of foreign reserves which would have helped blunt the effect of sanctions. The sanctions were tighter and more far reaching than most had expected, and immediately led to a currency crisis in Russia, with Russian bonds falling to a C ('junk') rating and the rouble losing 30% of its value. The prospect of a sovereign default by Russia is now regarded as "extremely likely". Russia has imposed limits on cash withdrawals and movement of currency.

Equally far-reaching have been western companies announcing their disengagement from Russia; with names as diverse as BP, McDonald's and Apple announcing they would no longer be operating. This in turn has opened up concerns over expropriation of assets by the Russian government. In the longer term, Russia has for some years been running a current account surplus, and with prices of the commodities that it exports rising due to fears of supply interruption, it could in theory be better off, provided that it is able to continue selling them. But that of course will not necessarily be the case; removal from the SWIFT system makes international payments far more difficult.

Oil markets

One of the largest impacts will be upon oil markets – oil is Russia's biggest export by value. The cost of crude oil has already reached $115/bbl on fears of disruption to Russian exports, which total around 4 million bbl/d. Sanctions have complicated operations for large producers including BP, Shell, Exxon and Chevron. BP, Shell and Equinor have already indicated that they will sell up their assets in Russia and move out. Exxon says that it will pull out of the $4 billion Sakhalin Island project and make no new investments in Russia.

The question now is what will happen to Russia's existing exports. There are already indications that traders are unwilling to buy Russian oil because of the difficulties of securing payments and possible reputational risk in doing so. Though there is no official embargo, there could be a de facto 'creeping embargo' on Russian oil. Russian crude was already trading at a $28/bbl discount at time of writing. However, 4 million bbl/d is not easily replaced. There are fears that oil prices could rise towards $150 or even 200/bbl, levels not seen since the 2008-9 commodity price spike. Though OPEC+ could raise production, membership of Russia in the extended group does complicate matters. At its most recent meeting OPEC+ elected to leave quotas unchanged, and indeed, for reasons including covid restrictions and technical issues, OPEC+ has not even been able to meet its own existing quotas. There is believed to be some spare production capacity in Saudi Arabia, Kuwait and the UAE, but perhaps only a total of 2 million bbl/d.

In its absence, the US has been looking elsewhere to try and keep a lid on global oil prices. There have been attempts to more quickly resolve the Iran nuclear agreement which the Trump administration pulled out of, but a deal here requires Russia's sign-off, and so progress on releasing an estimated 800,000 bbl/d of production remains stalled for now. There have even been rumours that the Biden administration has been in discussions with Venezuela about loosening sanctions to release perhaps 500,000 bbl/d of production from there - US oil producers have suggested that president Biden talk to them instead if they want to boost oil output, although there is equally thought to be limited scale for immediate increases in production from the shale patch beyond a couple of hundred thousand barrels per day. Essentially, there is simply not enough oil production capacity around to replace Russian exports.

On the one hand, oil embargoes are hard to enforce and oil is a fungible commodity. China, India and others might well be prepared to continue buying Russian oil at knock-down rates. But the truth is that we may be seeing the start of an oil shock that persists for a couple of years, on a scale with 1973 or 1980-81.

Gas markets

After oil and refined products, natural gas is Russia's third major export. Russia exported 240 bcm of natural gas in 2020, almost all of it to Europe, and represented 40% of all EU gas imports – that figure is as high as 94% for e.g. Finland. Europe's dependency on Russian gas has long been regarded as its Achilles heel, and the EU has continually talked about reducing this, via renewables or diversification of gas supply. However, the bloc has equally hamstrung itself by phasing out coal and nuclear power, which has ironically increased its exposure to Russian gas. Since the outbreak of hostilities in Ukraine, Germany has finally cancelled the Nordstream 2 pipeline project, and the EU

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PHOTO: MAXIM KOROCHENKO/ALAMY

Sulphur storage at Gazprom Astrakhan, Russia.

has suggested it could reduce its dependence on Russian gas by 2/3 by the end of 2022, primarily by importing more LNG, but its ability and willingness to do this in the light of record gas prices in the continent – touching almost $100/MMBtu at one point – remains very much open to question.

Fertilizer

Russia and Ukraine are also major exporters of fertilizer, especially nitrates. Ammonia prices have been particularly badly hit, with the combination of reduction of 25% of traded supply and shutdowns in Europe caused by high gas prices leaving an already tight market very short. Another casualty of the crisis has been EuroChem's bid for Borealis' nitrogen business, mostly based in France and Austria. A euro 455 million deal had reportedly been agreed in early February 2022, but on 11th March, Borealis CEO Thomas Gangl said in a public statement: "we have closely assessed the most recent developments around the war in the Ukraine and sanctions that have been put in place. As a consequence, we have decided to decline EuroChem's offer."

On the phosphate side, Russia accounts for around 14% of the world's mono-ammonium phosphate (MAP) exports. MAP prices have already surged past $1,000/tonne. The Russian Ministry of Industry and Trade has announced that national fertilizer manufacturers would be 'temporarily' suspending exports, in light of the ongoing war in Ukraine.

Of greater worry perhaps for the world as a whole is that Russia and Ukraine collectively represent 30% of world wheat exports, and 20% of corn; their major customers are Egypt and Turkey. The loss of so much grain, at the same time that high fertilizer prices lead to lower application levels, could lead to major disruption to world food supply, with shortages in some developing countries.

Sulphur

There is also likely to be a major impact on the sulphur market, although the extent of that remains difficult to gauge at the moment. Russia typically exports around 3 million t/a of sulphur, though this figure was down to 1.8 million t/a in 2021 due to increased demand from Russia's phosphate sector. In addition to this, Kazakhstan exported 3.6 million t/a of sulphur via Russia in 2021. These together represent almost 20% of around 30 million t/a of globally traded sulphur. Although Kazakhstan has other options, such as export east into China, these are long rail routes, time consuming and expensive, and it is unlikely that all of its production could be redirected that way.

At present the willingness of markets to take Russian sulphur under the new financial sanctions regime is still unclear, but if buyers do stay away, sulphur markets could well see a sudden tightening of supply at the same time that phosphate production outside of Russia sees a boost in demand to make up for lost Russian phosphate output, though again it remains to be seen what record high ammonia prices and high sulphur prices will do to the willingness of DAP producers to keep producing. At the same time, the new nickel capacity coming on-stream in Indonesia is also leading to increased demand for sulphur; Argus estimates an additional 900,000 t/a of sulphur will be consumed there this year as compared to last.

Set against this, the availability of additional sulphur volumes from the Middle East could be a key factor in moderating price rises, which have already passed $330/t f.o.b., and which could well move higher. Though short of the $800/t values briefly seen in 2008, these are still historically very high prices for sulphur, and a remarkable turnaround from the low prices of just a couple of years ago.

The past decades have shown that imposing sanctions can be quick, but removing them can take time, and we may be about to see a remaking of the global economy and trade routes on a similar order to the fall of the Berlin Wall and the collapse of the Soviet Union. ■

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Can HPAL supply enough nickel?

A shortages of highly pure nickel is driving major new investment in high pressure acid leaching plants, especially in Indonesia, with a significant impact upon sulphuric acid and sulphur demand.

Indonesia's Morowali Industrial Park, showing HPAL units under construction.

PHOTO: IMIP

Sulphuric acid's greatest use by volume is for extraction of valuable elements from mineral ores. While the phosphate fertilizer industry represents the lion's share of this, processing of other ores has been a rapidly growing sector over the past few decades. This began with copper leaching via solvent extraction/electrowinning, use of which began in earnest in the 1970s, but which became far more widespread in the 1990s, especially in Chile and Peru. Acid leaching of uranium also increased rapidly at around the same time, especially in Kazakhstan. And nickel leaching of laterite ores – a process commercialised at Moa in Cuba in the 1960s – led to a leap in demand for acid and sulphur from the late 1990s and early 2000s to help feed China's industrial boom, via the high pressure acid leach (HPAL) process in Australia, Philippines, Madagascar and New Caledonia. Acid demand for HPAL processing rose within a few years to several million t/a.

The end of China's breakneck industrialisation, the commercialisation of cheaper methods of laterite processing, and technical issues with HPAL production have meant a pause in development over the 2010s, but now there is a new burst of enthusiasm based on demand for nickel sulphate for batteries. But is even the current slate of HPAL projects enough to supply rapidly increasing demand for so-called 'Class 1' nickel?

Demand

Nickel demand reached 2.45 million t/a. The primary demand driver is for stainless steel production. Figures from the International Nickel Study Group show that in 2020 just over 70% of nickel went to make stainless steel. Alloy steels and casting, non-ferrous nickel alloys, and nickel electroplating each occupied 7-8% of finished nickel demand. And nickel demand for battery production reached 6% that year and an estimated 8% in 2021. However, this balance is changing rapidly. Stainless steel demand peaked in 2019 and has actually run slightly lower for 2020 and 2021 because of the covid-19 pandemic as people drove less and bought fewer new cars. Battery demand, conversely, is rising rapidly as electric vehicle use gains traction. The quantity of nickel used in the battery sector is growing rapidly, as nickel is used in nickel-cadmium, nickel-metal-hydride, nickel-iron, nickel-zinc, nickel-hydrogen and, increasingly in lithium-ion batteries because of the high energy density of nickel-containing cathodes. This growth is expected to continue with the increasing adoption of high nickel intensity battery chemistries.

Nickel consumption in the batteries sector is forecast to expand to 10% in 2022, driven by the rapid penetration of electric vehicles. In the first 10 months of 2021, total new energy vehicle sales grew by 177% in China compared to the same period for 2020, according to the China Association of Automobile Manufacturers.

Table 1: **Mined nickel by country, 2021, tonnes metal**

Country	**t/a**
Indonesia	780,000
Philippines	290,000
Russia	230,000
New Caledonia	190,000
Australia	160,000
Canada	130,000
China	120,000
Brazil	100,000
Others	400,000

Source: INSG

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A rebound in stainless steel production is also forecast as covid worries fade in the developed world. Global stainless steel production is on track to rise 14% year on year in 2022, with Indonesian production forecast to nearly double, and all major regions seeing double-digit growth.

Sources of nickel

China is the major consumer of nickel, accounting for 59% of the nickel market in 2020, and the country has been the main driver of new nickel demand and production for three decades now. While China is the main consumer, its domestic reserves of nickel are relatively modest, and so it must import it from overseas. The countries with the largest reserves of nickel are Indonesia and Australia, each with about 20 million tonnes, followed by Brazil (11 million tonnes) and Russia (6 million tonnes). But these do not necessarily represent the largest current sources of nickel, which are shown in Table 1.

The reason for this discrepancy is in part due to different nickel ore distribution. Nickel ores broadly exist in two different forms; sulphides, and laterites, which are an oxidised form found mainly in tropical regions. Laterites are the more common form of nickel, representing about 60% of all known deposits, and sulphides only 40%. However, sulphides tend to have higher nickel concentrations and are easier to extract the metal from, so their mining was historically preferred. Processing of nickel laterite ores is more difficult and has come to rely upon two main routes; pyrochemical or acid leaching. Pyrochemical routes are generally cheaper, but the nickel that they produce is often compounded with iron. This is not a problem if the destination for the nickel is stainless steel use, but it means that the nickel cannot be used for demand uses that require high purity nickel. Much of the growth in nickel supply, especially in Indonesia, was used in China to produce so-called 'nickel pig iron' (NPI) for steel production. But batteries require so-called Class 1 nickel (>99.8% purity), which pyrochemical processes cannot achieve using nickel laterite ores.

Acid leaching

Acid leaching of nickel is much more difficult than it is for, e.g. copper, because the nickel is more tightly chemically bound to the ore. This means that standard SX/EW routes cannot be used to process nickel. Nickel acid leaching therefore takes one of two forms. The first, heap leaching, is a fairly simple process involving pouring acid over crushed rocks at atmospheric pressure. However, it is a very slow process requiring several passes and can consume very large volumes of acid – up to 60 tonnes per tonne of nickel produced. It also means dealing with large volumes of acidic waste water. For these reasons, commercial nickel heap leaching projects remain few and far between, with one in China and another under development in Brazil.

The process can be speeded up and contained by using higher temperatures and pressures. This is the basis of the high pressure acid leach (HPAL) process. However, as any acid producer knows, high pressure and temperature sulphuric acid is ferociously corrosive, and the process uses

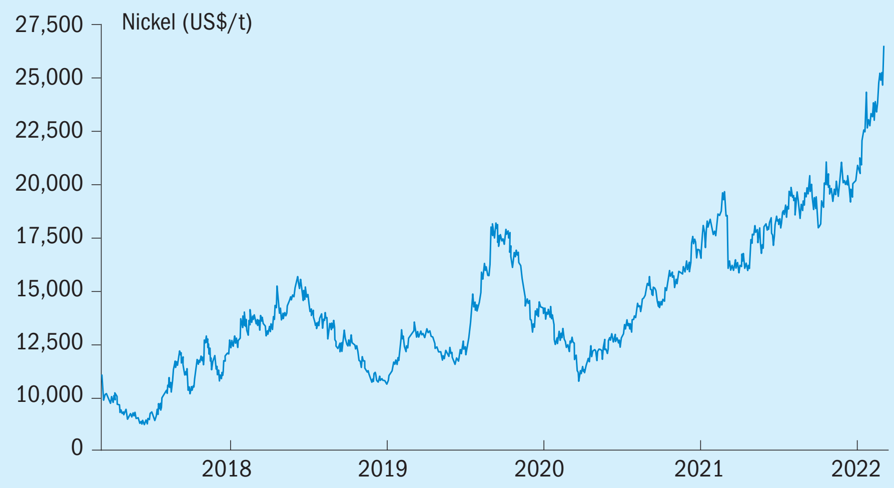
Table 2: **HPAL projects**

Operator	Capacity (t/a Ni)	Location	Start-up	Notes
First generation				
Sherritt	37,000	Moa Bay, Cuba	1959	Expansion planned
Second generation				
Centaur	9,000	Cawse, Australia	1998	Shut down 2008
Glencore (was Anaconda)	45,000	Murrin Murrin, Australia	1999	
Preston Resources	10,000	Bulong, Australia	1999	Shut down 2003
Sumitomo	24,000	Coral Bay, Philippines	2005	
First Quantum (was BHP)	36,000	Ravensthorpe, Australia	2007	Restart 2020
Trafigura (was Vale)	60,000	Goro, New Caledonia	2010	Shut down 2020
Sumitomo	60,000	Ambatovy, Madagascar	2012	
MCC	33,000	Ramu, Papua New Guinea	2012	
Sumitomo	36,000	Taganito, Philippines	2013	
Third generation				
Ningbo Lygend	37,000	Obi Island, Indonesia	2021	
	18,000			Second phase 2023
PT Huayue	30,000 x 2	Morowali, Indonesia	2022	Second phase 2023
Under development				
PT QMB	50,000	Morowali, Indonesia	2022	
Clean TeQ	21,000	New South Wales, Australia	2025	
BASF/Eramet	42,000	Weda Bay, Indonesia	2026	
SMM/Vale	40,000	Pomalaa, Indonesia	2026	

Source: BCInsight

expensive titanium-clad autoclaves as reaction vessels. The extremely strenuous reaction conditions make HPAL an infamously temperamental process. It can also be very expensive Of the nine HPAL sites that made up the second wave of adoption (see Table 2), over the period 1998-2013, some (e.g. Bulong) were forced to close due to technical issues, and others (Ravensthorpe, Ambatovy) by production costs. Part of the problem was the growth in NPI production, which undercut HPAL for stainless steel use. It is the battery market which has driven the current wave of HPAL projects.

Fig. 1: **Nickel price, 2017-present**



Source: Trading Economics

Shortage of Class 1 nickel

The key issue for the nickel market at the moment is the shortage of Class 1 nickel production because of the huge rise in uptake of electric vehicles. Global sales of electric passenger vehicles are projected to surpass 10.5 million units this year, 4 million more than in 2021. By 2030, electric vehicles are expected to occupy 40-50% of global sales for new cars. This will mean that 1.8 million t/a of Class 1 nickel is required for battery production by that time.

This time last year, Elon Musk identified lack of supply of Class 1 nickel as one of the key constraints in expanding the production and use of electric vehicles. Last year, Chinese Tsingshan announced plans to convert NPI into nickel matte which can be further processed into sulphate, but the Bank of America says that it expects tightness in refined Class 1 nickel for 2022, with a deficit of 41,000 tonnes compared with a growing surplus for Class 2 nickel, as NPI. Rystad Energy forecasts that global nickel demand will climb to 3.4 million t/a in 2024 from 2.5 million t/a this year, and suggests that current mines and projects cannot be brought on stream quickly enough to avoid a gap between supply and demand of 200,000 t/a in 2024 and 560,000 t/a in 2026.

Nickel prices

Nickel prices dipped around March-April 2021, but since then have been rising steadily (see Figure 1). Expectations of strong supply growth were not borne out as nickel pig iron operations, particularly in China and Indonesia, did not match supply expectations due to covid-related travel restrictions and power issues. Norilsk also reported lower production, and Vale lowered its production guidance following disruptions and license issues at Onca Puma. Rising power prices also caused some ferronickel producers to halt production. Delays to HPAL projects also contributed to supply being lower than expected, although it still rose by 5.6% year on year according to the INSG. The forecast for 2022 is that delayed projects will finally come onstream, especially among Indonesia NPI producers, and supply will grow by 15%.

In spite of this, the 14% growth in stainless production forecast for this year and 40% increase in electric vehicle demand means that while the deficit in the overall nickel market may be corrected in 2022, the structural tightness in the battery nickel market will continue to support higher prices for Class 1 nickel.

Russia

One of the factors adding fresh pressure to the nickel market right now are the sanctions that have been imposed on Russia in the wake of the invasion of Ukraine. Russia produces 17% of the world's 'Class 1' nickel, required for electric vehicle batteries, from Norilsk Nickel's huge mines in northern Siberia. With customers in Europe and North America unlikely or unable to buy Russian nickel, the competition for alternative sources is likely to be intense. This has been a major factor in driving nickel prices past $26,000/tonne on the London Metal Exchange, an 11-year high. So far, Norilsk Nickel's shipments have not been significantly disrupted, according to Bloomberg, though some shippers have declined to transport its nickel and there is reportedly a shortage of containers, but it was early days at time of writing.

From January to November 2021, the majority of Russia's class 1 nickel products went to China and the Netherlands, which each received 37% of the exports, according to the International Nickel Study Group. Germany received about 16% of Russia's class 1 nickel exports during the same period.

HPAL projects

The rush for HPAL projects, particularly by Chinese battery makers, has been an attempt to secure supplies of Class 1 nickel to avoid this looming shortage. The initial focus has been on Indonesia, which has a history of tie-ups between Chinese consumers and local nickel producers, especially for nickel pig iron production. When Indonesia banned the export of nickel ore a lot of Chinese NPI production effectively offshored to Indonesia.

HPAL project announcements have come thick and fast. Among the first to start up, in March last year, was Chinese mining firm Ningbo Lygend, which produces mixed (cobalt/nickel) hydroxide precipitates (MHP), including 100,000 t/a of nickel sulphate (35,000 t/a nickel) in the first phase and 160,000 t/a of nickel sulphate in the second phase, as well as 20,000 t/a of cobalt sulphate.

Zhejiang Huayou Cobalt's Indonesian joint venture shipped its first batch of MHP in February. The joint venture, PT Huayue, set up with Tsingshan Holding Group and China Molybdenum Co, started trial

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production in end-November, has the capacity to produce 30,000 t/a of nickel and 3,900 t/a of cobalt in the first phase. A second identical phase is due to start up in 2023.

PT QMB New Energy Materials being developed by majority owner Jingmen GEM and Guangdong Brunp, also at the Indonesia Morowali Industrial Park (IMIP). Start-up is due for later this year.

Sumitomo Metal Mining (SMM) said in November last year that construction should begin in 2022 on the Pomalaa nickel project in Indonesia. This would be a partnership with PT Vale Indonesia to build a 40,000 t/a mixed nickel sulphide HPAL plant, with mechanical completion in 2026.

Meanwhile, in Australia, Clean TeQ is aiming to produce an average of 21,300 t/a of nickel and 4,400 t/a of cobalt (as sulphates), as well as scandium oxide and an estimated 50,000 t/a of ammonium sulphate. The $1.4 billion project will include a sulphur burning acid plant to feed the HPAL autoclaves, and will use renewable solar power. Clean TeQ says that the ore body has a low acid consumption compared to other HPAL projects, and at capacity should require 660,000 t/a of sulphuric acid.

BASF and Eramet have initiated a feasibility study on building an HPAL plant at Weda Bay, Indonesia with a base metal refinery at a location to be determined. The HPAL plant would process locally secured mining ore from the Weda Bay deposit to produce a nickel and cobalt intermediate. Projected capacity is 42,000 t/a of nickel and 5,000 t/a of cobalt, with a potential start-up in 2026.

In addition to these, there are a number of other more speculative projects in both Indonesia and Australia which are at the feasibility study stage.

Acid impact

Sulphuric acid consumption in HPAL is around 260-400 kg/tonne of ore processed, depending on the rock grade and reaction conditions, which translates to around 30-40 tonnes of acid per tonne of nickel produced. As Table 2 shows, plants recently finished or currently under construction will add 165,000 t/a of HPAL nickel over the next few years, with another 100,000 t/a of potential additional capacity from 2025-26. In theory, this represents several million t/a of additional sulphuric acid demand, and with most HPAL units likely to work off captive sulphur burning acid plants, perhaps 2-3 million t/a of sulphur demand.

The caveat is of course the difficulty and reliability of the HPAL process. Historically it has required an average of four years to achieve 80% of nameplate capacity for existing HPAL producers, and although some have been considerably faster, Murrin Murrin in Australia took seven years to achieve more than 50% capacity. Even so, this could represent an additional 5 million t/a of acid demand. CRU is forecasting that total acid demand from the battery metals sector could reach 11 million t/a by 2025, double what it was in 2020.

With potential shortfalls looming, nickel prices are forecast to remain high for the next few years, especially for the purest grades, and this should continue to allow HPAL projects to be financed and built, and, indeed, may encourage more new project developments. With electric vehicle uptake to represent around 40% of all new vehicles by 2020, it looks as if this sector of the acid market may be about to take off. ■

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Offshore rigs in the Hasbah gas field, Saudi Arabia.

PHOTO: SAUDI ARAMCO

Decarbonising gas processing

As all industries come under pressure to decarbonise, are there ways to reduce the carbon footprint of sulphur recovery operations?

The 2015 Paris Agreement set the goal of keeping global average temperature increases less than 2°C above pre-industrial levels by 2050, and produced a roadmap for countries and industries looking to combat climate change via reducing emissions of greenhouse gases, particularly carbon dioxide but also methane into the atmosphere. So far, more than 800 companies have committed to science-based targets to align strategies with the Agreement. All industries are likely to face increasing pressure over the coming years to reduce the carbon footprint of their operations, and the oil and gas industries are likely to be under some of the most intense pressure. Some companies, including BP, Norway's Equinor and Spain's Repsol, have already pledged to reduce some or eliminate all of their emissions in absolute terms by 2050. Shell has pledged to cut absolute emissions from its operations by 50% by 2030. Others, including Total, are focusing on reducing the carbon intensity of their operations and products. In any case, reducing the carbon dioxide equivalent emission of oil and gas operations will become a growing issue for the sector over the coming years. Historically there has been some confusion over what is being measured and relative to what baseline which has muddied the waters of carbon emissions reduction, although next year a new reporting standard, developed by the independent Global Reporting Initiative (GRI), comes into force which aims to make the various pledges and reporting standards more transparent and allow greater comparison between companies.

The United Nations Framework Convention on Climate Change (UNFCCC), whose most recent Conference of Parties (COP-26) was held in Glasgow last October and November, defines three classifications of emissions in the greenhouse gas protocol:

- Scope 1: direct emissions related to on-site fuel combustion or fleet vehicles;
- Scope 2: indirect emissions related to emission generation of purchased energy, such as heat and electricity;
- Scope 3: other indirect emissions related to both emissions from upstream and downstream business activities.

For the oil and gas industry, Scope 3 emissions effectively refer to the use of their products by consumers, and while the continuing move to electric vehicles and other lower carbon alternatives will gradually reduce demand for hydrocarbon products in the future, companies processing oil and gas are likely to have to focus initially on their Scope 1 and 2 emissions. Shell's pledge above covers Scope 1 and 2 emissions only, likewise Exxon and Equinor (and only for Norway in Equinor's case). BP, Total and Eni have agreed to consider Scope 3 emissions in their own targets.

Reducing methane waste

Oil and gas companies are likely to focus on upstream activities for ‘quick wins’, as reducing leakage and flaring of methane will enable major savings – methane’s global warming potential is around 30 times that of carbon dioxide. The International Energy Agency (IEA) 2020 Methane Tracker estimates that oil and gas industry methane emissions were equivalent to more than 81 million tonnes of CO_2 in 2019: 4% from incomplete flaring, 28% from fugitive releases, and 68% from venting. US shale gas production has seen emissions rise as lack of gathering infrastructure and pipeline capacity in some shale areas make it cheaper to vent or flare cheap natural gas than to transport it to buyers. There are also major campaigns under way to reduce flaring; the IEA estimates that some 75% of emissions from flaring could be avoided, and that 40% overall could be prevented at no net cost if captured gas was utilised for commercial purposes. It is reckoned by some analysts that roughly half of all GHG reductions over the next 2-3 decades within the oil and gas industry could be accounted for by reduction of methane waste.

Electrification of operations

In a gas processing plant, steam turbines typically generate energy from a process gas stream, as the fuel is readily available. However, not only does this burn valuable product, it also increases CO_2 output. Electrification of some pumps, compressors etc can mitigate against this, depending on the source of the electricity. For example, China’s CNOOC is planning to bring power from an onshore grid to two fixed, high-voltage AC power platforms in the country’s first platform electrification. In the UAE, ADNOC’s offshore production facilities will connect to Abu Dhabi Power Corporation’s onshore electricity grid via the region’s first high-voltage direct current subsea transmission system.

This can further reduce emissions when integrated with renewable power sources; solar photovoltaic (PV), wave energy, and wind power. Falling costs of renewable generation and potential access to carbon credits can make renewable power a cheaper option, depending on the setting. Norway’s Equinor reckons that the electrification of its Johan Sverdrup field has led to the oil produced from it being achieved at CO_2 emissions of just 0.67 kg per barrel, compared with an average of 9 kg elsewhere.

Energy efficiency measures

Sulphur recovery units (SRU) are one of the higher energy parts of a gas processing plant, using burners to convert part of the H_2S in an acid gas stream to SO_2 which then reacts with the remaining H_2S to form sulphur and water (the Claus reaction). Using existing process energy more efficiently offers potential for savings in CO_2 footprint, via waste heat boilers and steam export. However, there can be a tension between higher levels of sulphur recovery and emissions of CO_2. In particular, moving from 99.9% recovery to the very highest levels of sulphur recovery (>99.98%) involves progressively more stringent conditions – especially as regards tail gas treatment – and can increase CO_2 emissions by up to 50%[1].

Alternative tail gas treatment technologies can improve the energy balance. Where there is sufficient demand, conversion of the sulphur component of a Claus plant stream to sulphuric acid, such as via the Topsoe WSA process, can add an exothermic section which allows more heat to be recovered for power/steam export. Bechtel is working on a pressure swing adsorption Claus process; a single-step sulphur removal and recovery technology that can reduce plant capital cost and improve operating efficiency by eliminating amine treatment as well as providing a high purity carbon dioxide stream for use in CCS/EOR.

Digitisation

The use of digital technologies can also help drive process efficiencies. Analysing plant data can boost the efficiency of production through, e.g. better control of process conditions and improved management of energy balance, as well as data driven maintenance; more accurately predicting problems, and enabling more timely interventions.

CCS

Carbon capture and storage (CCS) is becoming an increasingly attractive option for large scale operators looking to reduce CO_2 emissions. Gas processing plants are generally sited near oil/gas wells and have existing pipeline connections, meaning that diversion of CO_2 to exhausted wells or to existing oil wells for enhanced oil recovery (EOR)can be a practical and relatively less expensive option. In the case of EOR it can even pay for itself. Gas processing plants, especially those dealing with large scale sulphur recovery, also can already offer an existing large source of amine for carbon dioxide absorption via tail gas treating units.

In the UAE, the Abu Dhabi National Oil Company (ADNOC) is planning to capture 4.2 million t/a of CO_2 from its operations at the Habshan-Bab gas processing facilities and the Shah sour gas plant and use it for enhanced oil recovery at the Rumaitha and Bab oilfields as part of plans to reduce national carbon footprint by 70% by 2050.

Separating CO_2 from nitrogen can be a less efficient process, meaning that operating an SRU at 100% oxygen enrichment can not only improve throughput and raise operating temperatures to increase the destruction of contaminant species, but also assist with downstream CO_2 recovery[2].

Alternatively, cryogenic CO_2 recovery systems are under development which cool CO_2-laden gases to the point that the CO_2 desublimates, separate the desublimated solids from the light gases, pressurises the CO_2 stream, and warms both the CO_2 and the gas streams back to their initial temperature via heat recovery, delivering liquid CO_2.

Supportive policies

While the COP-26 meeting focused on developing market mechanisms to try and encourage decarbonisation, including more widespread and better regulated markets for carbon credits to avoid some of the issues with existing schemes, market mechanisms in themselves will not be enough to secure the changes in the way we use energy that will be needed to meet decarbonisation targets. A supportive public energy policy environment will be needed to create the impetus for scaling the uptake of low-carbon fuels, along with recognition that large scale use of CCS will be essential to meet climate targets. It may also need to recognise that, as with sulphur recovery and carbon efficiency, there are trade-offs in process sectors such as gas processing that need to be acknowledged. ■

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SulGas Virtual 2022 Conference

The fourth SulGas Conference organised by Three Ten Initiative Technologies took place 1-4 February as a virtual event. Selected highlights from some of the presentations from SulGas 2022 are given below.

This year's SulGas Conference, now in its fourth year, was held for the second time as a virtual event due to the ongoing Covid-19 pandemic challenges and restrictions. Organised by Three Ten Initiative Technologies, the Sulgas Virtual 2022 Conference was bigger than ever attracting 436 participants from 80+ countries including 40+ operating companies. The event was held over four days from 1-4 February and combined a mixture of technical presentations and Q&A sessions as well as an exhibition and networking opportunities. All being well, the plan is to return to an in-person event in 2023.

The aim of the SulGas conference is to bring together all stakeholders from across the refining, gas processing, chemicals, technology, and engineering companies in the area of sulphur and gas treating. SulGas focuses on issues unique to India in the areas of equipment and process design, process optimisation, operations, near misses, analytical methods, and troubleshooting.

The keynote speaker for SulGas 2022 was **S. Bharathan**, Executive Director – R&D of Hindustan Petroleum Corporation Limited, who provided an overview of the oil and gas industry in India focusing on three main themes: desulphurisation, decarbonisation, and digitisation.

Starting with desulphurisation, current research and development in hydroprocessing was highlighted, including improved reactor internals and new hydrotreating catalysts designed for low pressure (<25 bar), lower hydrogen consumption, enhanced lifetime, and low metal loading. There have also been advances in solvents, sorbents, and membranes. Future research will be carried out into selective catalytic reduction. A large number of biogas plants will be built in India in the next 2-3 years, all of them requiring gas cleaning as the first step.

The focus of the presentation then moved on to decarbonisation and how refineries will look in the future as they transition from traditional refinery processes to a future with low-carbon refineries. India's contribution to CO_2 emissions in 2019 was 2.6 trillion tonnes. Use of natural gas instead of naphtha and intermediate fuel oil (IFO) in hydrogen generation units (HGUs) and process heaters/furnaces could reduce CO_2 emissions by >30%.

The presentation finished with a discussion on the benefits that digital transformation has already brought to the oil and gas industry and what can be expected in the future.

Deep desulphurisation requirements

In recent years Indian refiners have faced the dual challenge to switch over simultaneously to BS VI fuels and also change over to low sulphur fuel oil (LSFO) due to IMO regulations in 2020. In a bid to curb vehicular pollution, the Indian Government decided in January 2018 to implement stricter emission norms of Bharat Stage (BS) VI from April 1, 2020, by skipping BS-V altogether. The main challenge in moving from BS IV to BS VI was an 80% reduction in sulphur from 50 to 10 ppm for both MS and HSD coupled with a revision of a few other major parameters specific to MS and HSD. **Nagendra Hindupur** of Hindustan Petroleum Corporation Ltd discussed the challenges faced by refiners, the strategies that were used to roll out BS VI fuels successfully by April 2020 and alternatives to manage refinery residue in the changed fuel oil quality post IMO 2020 implementation.

Debottlenecking for capacity increase

Subramanya Prabhu of Mangalore Refinery and Petrochemicals Ltd described MRPL's low-cost modification scheme to enhance the AAG processing capacity of its existing conventional Claus process. MRPL operates

PHOTO: TOMASSEREDA/ISTOCKPHOTO.COM

six sulphur recovery trains. The capacity of SRU 2/3 has been increased by approximately 14% compared to the previous maximum throughput by using an in-house oxygen enrichment scheme. The SRU units were debottlenecked with minor investment by making use of an available oxygen-rich waste stream from the polypropylene nitrogen plant.

Process instrumentation and control

One of the key topics of the conference was the importance and challenges of sulphur plant process instrumentation and control. **Jochen Geiger** and **Anantha Kukkuvada** of Ametek Process Instruments reviewed today's process analysers and best practices to maximise the full benefits of analysers. The air demand/tail gas analyser can contribute up to 10% of the total efficiency of the sulphur plant. A closed control loop, including a H_2S in feed gas analyser can add another 3%. Analysers have an average lifetime of approx. 15 years and maintenance continues to be the largest cost component of the lifecycle cost for analysers. The importance of involving specialist analyser vendors during the front-end engineering and detailed engineering stages of a new project and having a complete analyser maintenance team and philosophy in place at start-up was emphasized. Bringing together the process, analyser, control, and piping engineering disciplines of the team so all benefits are realised is key as is the regular training of operators and maintenance staff to keep up with the latest technical advancements.

Angshuman Paul of Adage Automation focused on the design of process analyser sample probes and sample transport lines to ensure representative and rapid sampling and to avoid the possibility of contamination or dead volume. Adage provides complete, integrated analyser systems and all related services from initial engineering through manufacturing, testing and field start-up. Having an integrated analyser system comprising the sample recovery systems, stream selection facilities, temperature-controlled analyser houses etc., has the benefit of providing a single channel for communicating and interfacing, and helping to achieve consistent design, assembly, and component selection.

Prakhar Rohila of Bharat Oman Refineries Ltd (BORL) presented a new interlock scheme developed in-house for BORL's SRU reheaters. The original interlock scheme was unreliable and was experiencing faulty signals leading to tripping of the units during electrical faults such as power dips, bus changeover and voltage dips. Tripping of the units had a number of negative consequences such as flaring of acid gas to the environment, financial losses due to loss of sulphur production (7 t/h), reduced reliability, and less margin for restart-up as the burners are turned off when the heater trips, leading to delays in the start-up time. Since implementing the new interlock scheme there has been no tripping of the system.

Pandemic challenges

Prolonged idling of SRUs

Umang Shrivastava of Mangalore Refinery and Petrochemicals Ltd (MRPL) shared MRPL's experiences and the challenges faced in preservation of its sulphur recovery units after prolonged idling during the pandemic. MRPL operates a 15 million t/a integrated refining and petrochemical complex, which has six trains of SRUs. During the pandemic, as demand for auto fuels reduced worldwide, the process units were either operated at lower load or idled and the SRUs were forced to shut down to avoid operating below turndown limits. The main challenges of the prolonged idling were how to keep the units free of corrosive substances and moisture and how to sustain them under an inert atmosphere. Several challenges were faced in bringing the plants back on online. Critical equipment such as incinerators and condensers caused bottlenecks due to leakages, and back pressure etc. Lessons learned and best practices to ensure reliable operation post prolonged idling were discussed.

Start-up and shutdown with constrained manpower

Harpreet Singh of Indian Oil Corporation Ltd (IOCL) described IOCL's journey towards commissioning of the BS-VI ARU/SWS/SRU/TGTU plant at IOCL Panipat Refinery. A number of challenges were faced during the Covid crisis in 2020. Covid-19 affected the commissioning activities, limiting the

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manpower and mobilisation of personnel. After the first Covid wave, plant commissioning activities resumed with limited manpower.

Remote start-up of sulphur recovery units

Jan Willem Hennipman of Comprimo recounted how Comprimo was able to provide remote support for the start-up of sulphur recovery units during the Covid-19 pandemic when international travel came to a virtual standstill. As the usual practice of providing on-site support for operator training, plant inspection, commissioning and start-up could no longer be done "in person", other means had to be explored to be able to support the operating companies during the initial start-up of their facility.

Jan discussed several start-ups that were completed during the pandemic with remote and partial remote support from the Comprimo subject matter experts. Some of the pitfalls of providing support remotely for start-ups as well as lessons learned from their experiences was shared. In addition, by using newly developed tools, Comprimo was able to provide better support to the operating companies without requiring on-site presence. The new tools enable operating companies to better train their operators for normal and upset conditions of their sulphur recovery units and provide an on-line continuous support system in which plant operation can be optimised in real time for better on-line reliability and lower emissions.

Amine systems

Chemical cleaning in gas treating systems

Ritesh Gulabani of Dow provided guidance on chemical cleaning in gas treating systems. The most widely used processes to sweeten natural gas, refinery gases, syngas, LPG and biogas use amines such as MEA, DEA and MDEA to absorb H_2S and CO_2 from sour gas streams. The removal of undesired deposits from the system during turnarounds is of paramount importance to ensure reliable and efficient operation until the next scheduled shutdown. Consequently, chemical cleaning at the start-up should be considered as an integral part of the best practices for any gas treating system.

Importance of lean amine quality

Muhammad R. Tariq of Saudi Aramco presented their experiences of H_2S breakthrough into the sweet gas from the acid gas removal unit of a gas plant, resulting in a gas that could not meet the treated gas H_2S spec of 4 ppmv. Amine quality is a major factor to achieve treated gas spec. The gas plant team found that the issue started when the plant started to process different feed gas. The problem was correctly identified in a short, systematic and effective investigation that combined field measurements and simulations with good analysis. It was discovered that the H_2S concentration in feed gas was higher compared than the unit design, the lean amine circulation and concentration were lower than the required and the amine solution was contaminated with degradation products like DEA, MEA and TEG which impacted CO_2 slippage and increased reboiler and overhead condenser duties. The issue was subsequently successfully fixed by increasing the amine circulation rate to control the H_2S content in the treated gas, controlling the rich amine loading, controlling the amine concentration per design 50 wt-% to improve the acid pickup rate, adjusting he steam rate to the stripper column to achieve the required lean loading, and using the bleed and feed method to minimise the amine degradation contaminants to <2 wt-%.

Best practices

Use of refinery fuel gas in SRUs

Sulfur Recovery Engineering (SRE) has extensive experience and knowledge in the analysis of process streams including refinery fuel gas (RFG). **Dharmeshkumar Patel** and **Ahmad Nyeazi** of Sulfur Recovery Engineering Inc. examined the pros and cons of using refinery fuel gas in the SRU process. RFG is an important utility for refinery facilities. Its composition depends on various factors (crude type, unit operations etc.) but is typically made up of C1-C4 hydrocarbons, hydrogen sulphide, hydrogen, and other light components. Most facilities attempt to recover the hydrogen from this stream using various technologies. The majority of the hydrogen sulphide is also removed. When used in sulphur recovery units, RFG has its benefits and some drawbacks. RFG composition tends to fluctuate which can have costly consequences, e.g. soot in SRU converters. Knowing the composition is crucial to ensure problems are not amplified in the SRUs.

Recommended responses to TGU upsets

Breakthrough of SO_2 or elemental sulphur from a sulphur plant tail gas unit (TGU) reactor into the downstream quench tower and amine system can be catastrophic. It can result in plugging, corrosion, emissions violations, and unplanned shutdowns, with high costs associated with equipment repair and production downtime. Although the chemistry behind how SO_2 or sulphur breakthrough occurs is relatively well known, the operational indicators associated with a breakthrough event and the proper responses are less well known and are often ignored or misunderstood. **Jan Kiebert** and **Gerald Bohme** of Sulphur Experts detailed the causes of SO_2 and sulphur breakthrough events, all of the operational indicators associated with a breakthrough event, and the recommended responses in order to quickly correct the operation and to minimize the impact on the tail gas unit equipment and operation.

Incinerator design

Acid gas incinerator replacement

Noor Azalea of Petronas shared the lessons learned when new requirements for CO emissions were introduced which led to a thorough analysis of the existing acid gas incinerator (AGI) and its fitness for service. The diagnosis led to the discovery of major defects which may have arisen from incomplete combustion, flame impingement, high convection section temperature and carbon, monoxide and unburned hydrocarbon from the stack.

Despite multiple test runs and modifications, the AGI failed to meet even its intended original design and the decision was made to replace it. The root causes of the AGI underperformance from many aspects of design, operations, control and maintenance have been incorporated into the new design of the AGI.

Ceramic solutions for the SRU reaction furnace and incinerator

Uday N. Parekh of Blasch Precision Ceramics showcased innovative ceramic solutions for improving the operational performance and the structural reliability of the SRU reaction furnace and the incinerator. Conventional checkerwall or choke rings in the reaction furnace often do not provide the desired structural integrity, resulting in compromised performance and shorter run lengths. Also, achieving the desired CO destruction in the incinerator often poses a challenge. Operational data was shared to demonstrate how superior materials and design can be used to address these problems. ■

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Simplified sulphur recovery technology

A new cost-effective alternative sulphur technology, providing a simple and robust process to achieve an overall sulphur recovery efficiency of 99.9+% is being developed by Saudi Aramco. **J. P. O'Connell** and **I.A. Alami** of Saudi Aramco discuss the new technology, its benefits and current stage of development.

The emission regulations for sulphur dioxide (SO_2) continue to become more stringent with time, which is placing more pressure on the refineries and gas plants to increase the recovery efficiencies of their existing sulphur recovery units (SRUs). In many countries around the world, this equates to either upgrading an existing facility or designing a grassroots SRU to be able to achieve an overall recovery efficiency of 99.9+% on a daily basis. This typically results in adding a tail gas treatment (TGT) unit behind the Claus plant, which increases the cumulative recovery efficiency from between 95 to 98% to the required 99.9+%. The addition of the TGT requires major capital investment and significantly increases the operating costs of the SRU. It is for these reasons that a cost-effective alternative for achieving a sulphur recovery efficiency of 99.9+% will always be a welcome addition to the existing choices of sulphur technologies.

SSRT

The basis of the new Saudi Aramco Simplified Sulphur Recovery Technology (SSRT) is the deletion of the traditional Claus and TGT catalytic stages. Each catalytic stage includes a reheater, a catalytic converter/reactor and a condenser/cooler. The new SSRT technology, therefore, represents a reduction in equipment of three heat exchangers (i.e., two Claus condensers and one TGT cooler), three catalytic beds (i.e., two Claus converters and one TGT hydrogenation reactor) and three reheaters (i.e., two Claus reheaters and one TGT reheater). These deletions result in savings in both capex and opex.

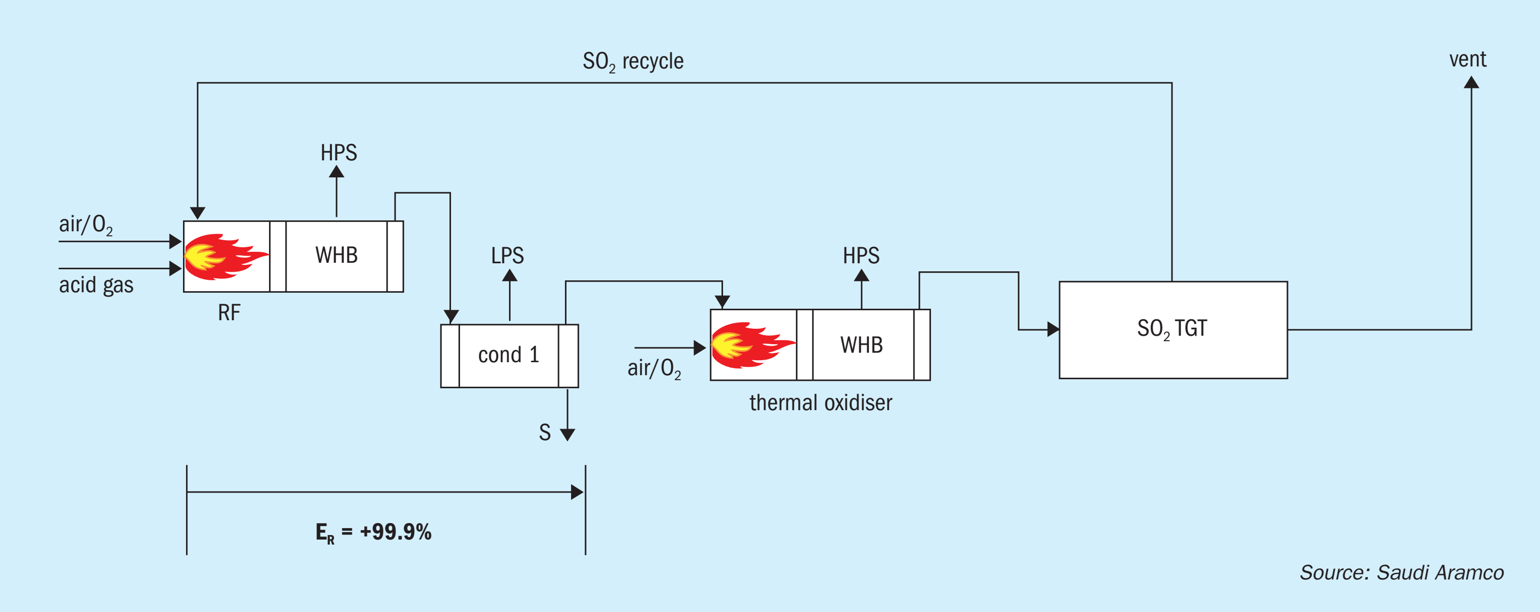
The front end of the SSRT configuration includes a thermal stage consisting of a reaction furnace connected to a waste heat boiler (WHB), followed by a single condenser for removing the sulphur product. The process gas from the condenser is further processed in a thermal oxidiser (TOX), which converts all sulphur compounds, i.e., H_2S, COS, CS_2, sulphur vapour, and entrained liquid sulphur, to SO_2. There is a second WHB downstream of the thermal oxidiser that generates additional HP steam.

The cooled flue gas from the TOX/WHB is then processed in a regenerable SO_2 TGT unit, which allows for absorption and recycle of the SO_2 back to the reaction furnace. Currently, two commercialised regenerable SO_2 absorption technologies are available. These units include a direct contact condenser, absorber, and regenerator.

Oxygen enrichment can be utilised in both the reaction furnace and the thermal oxidiser.

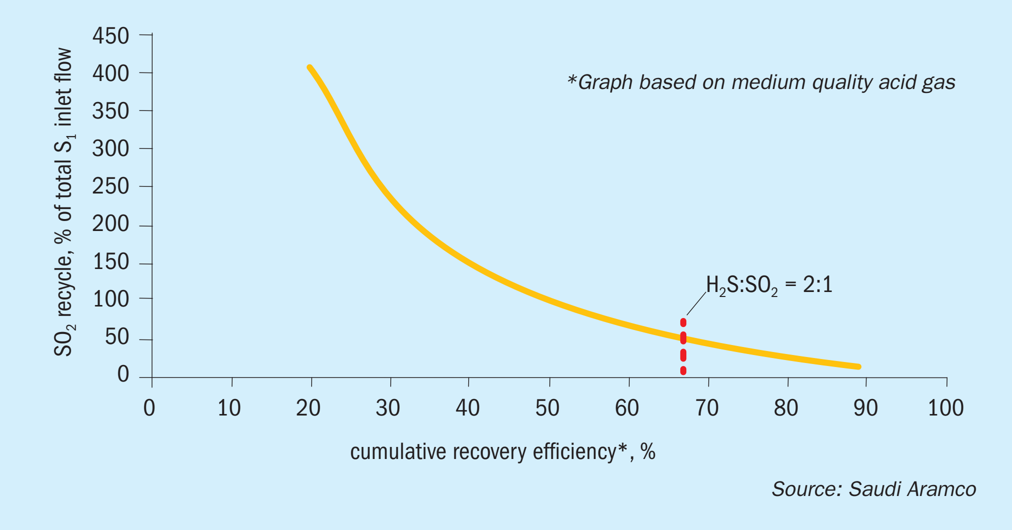
The patented SSRT process (Fig. 1) takes advantage of the fact that typical conversion of H_2S to elemental sulphur in the Claus plant reaction furnace ranges from 50 to 75%. The remaining sulphur compounds that would normally be converted to

Fig. 1: **Simplified Sulphur Recovery Technology (SSRT)**



Source: Saudi Aramco

Fig. 2: **Relationship of SO_2 recycle with reaction furnace recovery efficiency**



**Graph based on medium quality acid gas*

Source: Saudi Aramco

elemental sulphur in the downstream traditional Claus catalytic converters and H_2S in the TGT hydrogenation reactor are, instead, sent directly to the TOX for combustion to SO_2. Due to the quantity of combustible sulphur compounds remaining in the condenser tail gas stream, no fuel gas is needed in the TOX to maintain normal operating temperatures.

It is not immediately apparent how overall recovery efficiencies of 99.9+% can be achieved when there is only a thermal stage for the Claus reaction to occur. The explanation is in the differentiation between unit conversion efficiency of the thermal stage and cumulative conversion efficiency based on the amount of equivalent inlet sulphur in the feed gas streams. For example, if the feed stream contains 100 mol/h of H_2S and the SO_2 recycle is 50 mol/h, and the condenser produces 99.9 moles of S_1 equivalent, the unit conversion efficiency is 99.9/(100+50) = 66.6%, while the cumulative conversion efficiency is 99.9/100 = 99.9%.

It should be noted that the sulphur degassing unit liquid feed stream may have an H_2S content as high as 700-1000 ppmw, which is higher than the traditional value of approximately 300 350 ppmw, due to the liquid sulphur being in contact with a high H_2S concentration process stream in the condenser and should therefore be designed accordingly.

Thermal stage Claus reaction

The SO_2 that is recycled to the reaction furnace takes part in the Claus reaction to produce elemental sulphur. What is not well known, regarding the reaction furnace, is that the reaction of H_2S and SO_2 at typical reaction furnace temperatures, i.e., between 1,000°C and 1,350°C, is slightly endothermic[2]. The SSRT process therefore requires co-firing of fuel gas to sustain the required temperatures for the Claus reaction to proceed, while ensuring that all acid gas contaminants are adequately destroyed. The industry rule of thumb for achieving acceptable BTEX and NH_3 destruction is 1,050°C and 1,250°C, respectively, along with an adequate reaction furnace residence time, high intensity main burner and combustion chamber checker/HexWall.

Process stoichiometry

In order to optimise the Claus reaction in the SSRT reaction furnace, the traditional $H_2S:SO_2$ ratio of 2:1 must be maintained. Process simulations of the SSRT with high SO_2 recycle quickly revealed that this can only be maintained if the reaction furnace conversion efficiency is greater than 66.7%. If the reaction furnace does not obtain a minimum conversion of 66.7%, the $H_2S:SO_2$ is forced below 2:1 and a downward "spiralling" effect in conversion efficiency is observed involving higher SO_2 recycle rates and a corresponding requirement of higher fuel gas flow to maintain reaction furnace temperatures. This has an exponentially negative effect on both capex and opex.

This phenomenon therefore limits the use of the first patented SSRT configuration to SRUs that process a high quality acid gas stream, i.e., refineries. Due to the kinetic limitations of the reaction furnace, coupled with the requirement of fuel gas co-firing, reaction furnace unit conversions of >66.6% cannot be expected to occur with low to medium quality acid gas feed streams (i.e., acid gas feed streams with < 50 mol-% H_2S).

Fig. 2 illustrates how the SO_2 recycle rate increases as the reaction furnace conversion efficiency goes down for a medium quality acid gas. The curve extends past the 66.6 % reaction furnace efficiency to illustrate the effect of the "Extended Thermal Stage" technology in the second SSRT patent (see next section).

Extended Thermal Stage SSRT

To alleviate the limitation of acid gas quality for the application of the SSRT process, and the continued desire to eliminate all traditional Claus catalytic stages (i.e., reheater, catalytic converter, and condenser), an additional new technology has been incorporated and patented. The new SSRT technology takes advantage of the Gamson-Elkins relationship that reveals the Claus reaction equilibrium is favoured by cooling from reaction furnace conditions to WHB outlet conditions[2]. This relationship is implemented in the "SSRT with Extended Thermal Stage" patent via a small non-traditional catalytic section at the outlet of the WHB that allows for an increased conversion efficiency via the removal of only heat (see Figs 3 and 4). This can be accomplished by extending the outlet section of the WHB to allow for the addition of a small catalytic "zone" having a gas hourly space velocity (GHSV) of 3,000 to 9,000 h^{-1}.

The small catalytic zone could be designed as a plug flow reactor since pressure drop is not a major concern due to the limited equipment in the SSRT configuration. Therefore, the catalytic zone could take the shape of an extension of the WHB from three to six metres in length that includes a "caged" zone of typical alumina/titania catalyst, with multiple rows of thermocouples. Titania is recommended due to higher COS and CS_2 hydrolysis rates and longer lifecycle.

[*Note:* Alberta Sulphur Research Limited (ASRL) pilot tests proved that equilibrium, with respect to the Claus reaction, could be achieved under these conditions[3]. Should a catalyst change-out be required, Saudi Aramco employs an N+1 design philosophy for their SRUs to avoid acid gas flaring (i.e., an entire spare SRU).]

By adding a catalytic zone in the outlet section of the WHB, low thermal stage conversion efficiencies of between 20 and 50% (i.e., from poor quality acid gas streams) can be "pushed" to between to 70 and 90%. This allows for the ratio of $H_2S:SO_2$ to be maintained at 2:1 and

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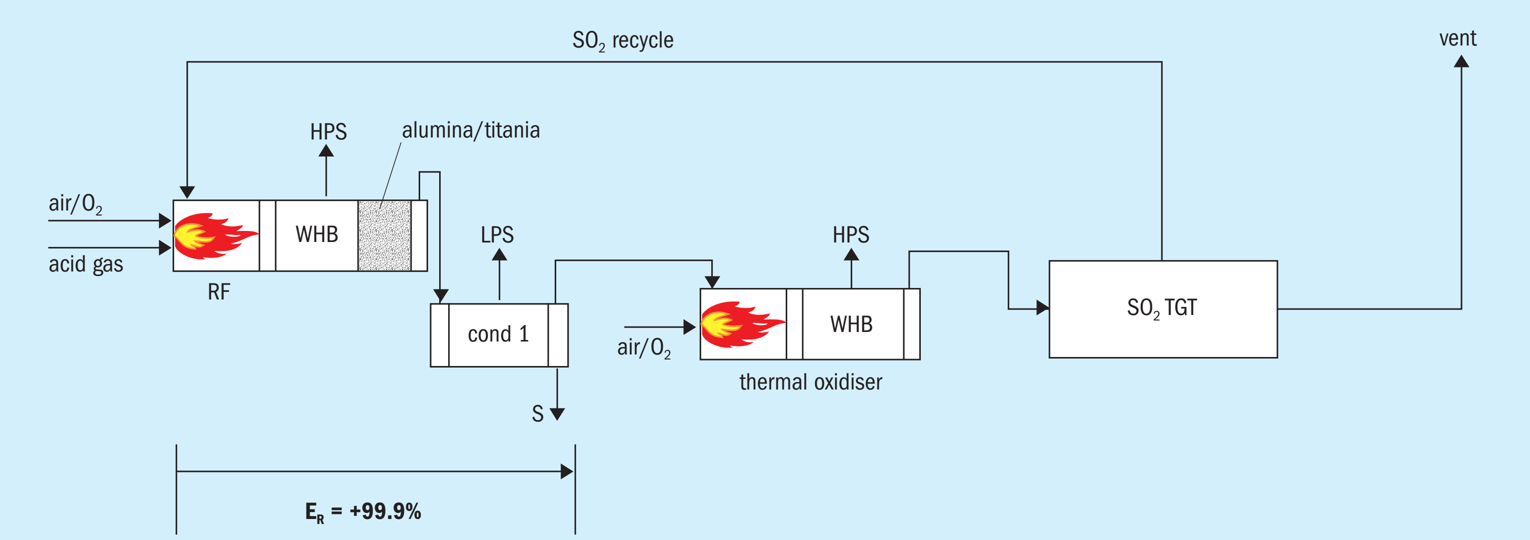
Fig. 3: **SSRT with extended thermal stage**



Source: Saudi Aramco

minimises the SO_2 recycle, which in turn minimises the amount of fuel gas co-firing required (i.e., conversion efficiencies above 66.6% allow for some of the H_2S in the acid gas to be combusted to SO_2). The "SSRT with Extended Thermal Stage" therefore allows any type of acid gas quality to take advantage of its minimised process configuration.

Pilot study

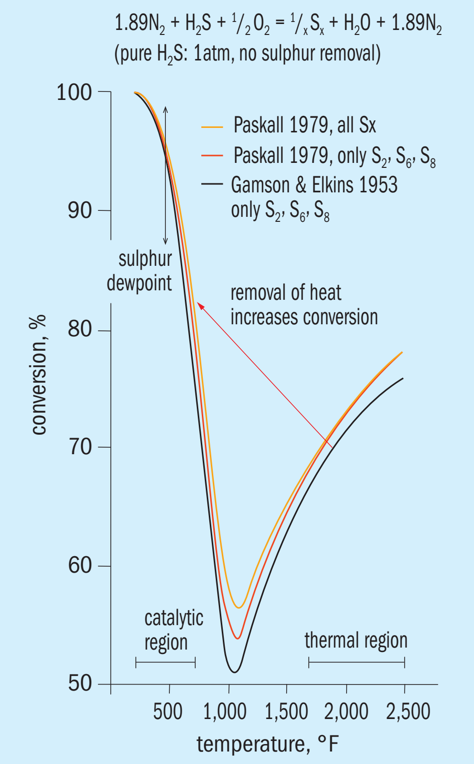
A pilot study of the SSRT thermal and catalytic stages was conducted by ASRL to prove the front-end kinetics for both the reaction furnace and the catalytic section[3].

The tests proved the viability of the high SO_2 recycle for an ultra-lean acid gas (i.e. 20% H_2S) and a typical refinery amine and sour water stripper (SWS) acid gas feed composition (i.e. 80% H_2S and 8% NH_3). The following critical parameters were used during the bench-scale tests:

- reaction furnace temperatures of 1,050°C for ultra-lean acid gas tests;
- reaction furnace temperatures of 1,250°C for refinery acid gas tests;
- reaction furnace residence times of 0.75, 1.0 and 1.5 seconds;
- BTEX concentration of 1,000 ppmv in acid gas feed streams;
- 40% O_2 enrichment employed;
- gas hourly space velocities of 3,000, 6,000 and 9,000 h^{-1} for catalytic section;
- titania catalyst in catalytic section;
- maximum bed temperature of 315°C for catalytic section.

The pilot test results are summarised in Tables 1 and 2.

Fig. 4: **Gamson-Elkins relationship for Claus reaction[2]**



Source: Saudi Aramco

A full-scale demonstration plant is planned to prove scale-up and operational simplicity of the SSRT process. A successful demonstration will allow for deployment of the technology in new greenfield SRUs for Saudi Aramco as well as licensing the technology internationally.

Advantages of SSRT

There are many advantages of the SSRT process compared to the conventional 2-stage Claus with reduction absorption TGT:

- Significant reduction in capex and opex.
- Elimination of all traditional catalytic stages and the operational and equipment issues associated with this equipment.
- Simplicity of control and operation. Thermal stage conversion is not overly sensitive to fluctuating air demand (i.e., air demand versus conversion curve is "flatter" than at higher conversions).
- Fast response to process upsets due to placement of the tail gas analyser at the outlet of the condenser (i.e., feedback dead time of seconds rather than minutes). Less panel operator intervention is required during upsets.
- All COS and CS_2 produced in the reaction furnace, and not hydrolysed in the extended WHB catalytic section, is combusted to SO_2, which is recycled and recovered. In the reduction absorption TGT, COS residuals cannot be avoided.
- SO_2 and sulphur breakthrough from the hydrogenation reactor in the reduction absorption TGT can cause severe operational issues and damage to the quench tower internals and piping as well as the downstream amine absorber. These issues are eliminated by using regenerable SO_2 TGT technology.
- All sulphur-containing vapor from pits, drums, degassing systems and liquid sulphur storage tank vents can be processed in the TOX, which is much simpler than recycling these streams to the reaction furnace.
- Untreated sour fuel gas and flash gas can be processed in TOX since all sulphur compounds will be combusted to SO_2 and recycled to the reaction

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Table 1: **Experimental results for 20% H_2S case**

GHSV (h^{-1})	Reaction furnace residence time (s)	Reaction furnace unit conversion (%)	Catalytic Section cumulative conversion (%)	Benzene destruction (%)	Toluene destruction (%)	Xylene destruction (%)	COS hydrolysis (%)	CS_2 hydrolysis (%)
3,000	0.75	47.0	72.6	78.6	100.0	100.0	78.9	91.0
6,000	0.75	46.7	71.4	78.6	100.0	100.0	49.2	64.9
9,000	0.75	48.2	70.8	78.6	100.0	100.0	39.6	49.2
3,000	1	51.1	74.3	96.4	100.0	100.0	77.0	87.8
6,000	1	52.6	73.5	96.4	100.0	100.0	34.1	50.5
9,000	1	52.5	70.5	96.4	100.0	100.0	55.3	41.7
3,000	1.5	49.3	71.2	100.0	100.0	100.0	80.6	83.8
6,000	1.5	48.7	71.7	100.0	100.0	100.0	55.6	50.9
6,000*	1.5	48.7	69.1	100.0	100.0	100.0	67.7	68.9
9,000	1.5	47.3	70.9	100.0	100.0	100.0	49.6	43.7
9,000*	1.5	47.3	68.7	100.0	100.0	100.0	59.6	57.6

**Catalytic section maximum bed temperature was raised to 350°C*

Table 2: **Experimental results for refinery acid gas case* (80% H_2S, 8% NH_3)**

GHSV (h^{-1})	Reaction furnace residence time (s)	Reaction furnace unit conversion (%)	Catalytic section cumulative conversion (%)	NH_3 destruction (%)	COS hydrolysis (%)	CS_2 hydrolysis** (%)
–	0.75	72.6	–	98.6	–	–
6,000	1	75.2	91.8	100	59.7	–
–	1.5	74.0	–	100	–	–

**Oxygen enrichment level of 40 percent. **CS_2 not detected at the outlet of the reaction furnace.*

furnace for recovery. This is not the case for an SRU with a reduction absorption TGT unit where any sulphur compounds being processed in the TOX will result in SO_2 emissions.

- Due to the reduction in equipment, compared to the traditional Claus/TGT plant, the required acid gas feed pressure at the SRU battery limit for SSRT can be significantly reduced. This will allow for upstream gas treating regenerators to operate with lower back pressures, which will result in lower reboiler duty, i.e., energy optimisation.
- The footprint of SSRT is significantly smaller than the traditional 2-stage Claus with reduction absorption TGT.
- 100% O_2 enrichment technology can be used in SSRT with high acid gas quality feed streams without the need for additional reaction furnace temperature control technology, which must be used for traditional Claus plants.
- Start-ups and shutdowns are greatly simplified and can be accomplished in 24 hours.
- The vent stream from the SSRT TGT is CO_2, with a small amount of O_2 and is ready for sequestration without the need of an additional low pressure amine system.

Conclusion

Saudi Aramco's Simplified Sulphur Recovery Technology (SSRT) technology offers the industry a new cost-effective process that is both simple and robust, and capable of maintaining an overall sulphur recovery efficiency of 99.9+%.

Along with innumerable process advantages that have been listed come various other tangible/intangible benefits such as reduced tube-to-tubesheet failures in the condensers, elimination of extended fuel gas sweep procedures for shutdowns, drastically reduced turnaround length (i.e., testing and inspection), elimination of "channelling" in Claus converters during high turndown scenarios, and elimination of all process reheaters. ■

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Sulphuric acid plant integration in a chemical complex

A sulphuric acid plant forms critical material and energy interfaces with other plants in several different types of chemical and metallurgical complexes. **Shailesh Sampat** of SNC-Lavalin discusses how the acid plant design is customised to match the product mix and the energy requirements of the complex to provide the optimum solution for energy and material requirements.

Although the principal function of the sulphuric acid plant is to produce sulphur-based compounds using sulphur or sulphur dioxide (SO_2) as raw material, it also serves as a critical source of energy for the complex. Heat generated due to the combustion of sulphur, conversion of SO_2 to sulphur trioxide (SO_3) and formation of sulphuric acid are all significant offering value in terms of energy which is comparable to the value of production of sulphuric acid and other chemicals for the associated site processes. Sulphuric acid plants operate with a zero or negative carbon footprint, as all the power required to run the complex can be generated within the complex with the possibility to export power. This essentially reduces the carbon footprint of the entire complex.

It is not surprising therefore that the sulphuric acid plant is a critical part of several different types of chemical and metallurgical complexes. In fact, many chemical/metallurgical complexes are designed and built around a sulphuric acid plant. This article provides an insight into the configurations of several types of chemical complexes that are integrated around the sulphuric acid plant. These include:

- phosphatic fertilizer complex (diammonium phosphate, single super phosphate, phosphoric acid);
- pyrometallurgical complex (copper smelter, zinc roaster);
- hydrometallurgical complex (copper, nickel, cobalt leach);
- detergent/dyestuffs (linear alkyl benzene, lauryl alcohol, alpha olefins).

SNC-Lavalin has experience in building numerous types of complexes around sulphuric acid plants. This has led to a deep understanding of licensor's technology as well as requirements of different types of industrial complexes. Developing a good match between the two is the main role of an engineering contractor.

While designing such complexes, one needs to understand the interfaces between the sulphuric acid plant and the remainder of the complex.

There are two types of interfaces between a sulphuric acid plant and the rest of the complex:

- Material interfaces: These are interfaces consisting of raw materials and final products from the plant. In the case of metallurgical gas plants, SO_2-bearing gas streams from a smelter or roaster forms an important interface.
- Energy interfaces: These are energy streams which can be in form of low-pressure/high-pressure steam, electric power, hot air or hot water.

Some of the interfaces have intermediate buffers in terms of storage tanks and vents or drains that allow short term delinking of each area or each plant from one another, to allow independent operation. In many cases there is no buffer capacity in between plants in the complex and changes at one end immediately impact the operation at the other end. So, taking stock of the upstream and downstream plant capacity requirements for receiving the sulphur-based gas, and producing sulphur products for leaching etc., accounting for each end of the sulphuric acid plant, becomes the first design requirement in any sulphuric acid plant process design. Defining the operating factor, availability and utilisation of each plant is an essential first step in the process design.

SNC-Lavalin has extensive experience in customising sulphuric acid plants for phosphatic fertilizer complex, hydro-metallurgical plants producing copper/nickel/cobalt, and pyro-metallurgical plants such as copper smelters and zinc roasters.

Sulphuric acid plants produce a number of important sulphur compounds:

- 93-98.5% sulphuric acid: Used for producing phosphatic fertilizers such as phosphoric acid and single superphosphate from rock phosphate in a fertilizer complex. Also used for leaching copper/nickel/cobalt from the ore in a hydro-metallurgical plant.
- Oleum with 25%-65% free SO_3: Used as a sulphonation agent in complexes producing detergent, dyestuffs, and pharmaceutical intermediates.
- SO_3 pure liquefied: Used as a gas phase sulphonation agent within the complex or transported for use in other locations.
- SO_2 gas stream of various concentrations: Used as a reactant in hydro-metallurgical copper plants, caprolactam

plants, cyanide destruction in mining operations and for bleaching in paper production.

Due to the exothermic nature of the reactions, a sulphuric acid plant is a major source of energy and often provides a large fraction of the energy requirements in the complex. This energy can be in different forms as described below:

- High-pressure (HP) steam 40-60 barg 400-500°C: Produced in economisers, boilers and superheaters using heat of combustion of sulphur and heat of conversion of SO_2 to SO_3. Generally used for generating electrical power in a turbogenerator. Alternatively, it can also be used to drive large equipment such as main air compressors, boiler feed water pumps, etc.
- Intermediate-pressure (IP)/low-pressure (LP) steam at 6-11 barg pressure: Generated in the Heat Recovery System (HRS) of the absorbing acid circuit using heat of absorption of SO_3 and formation of sulphuric acid. Alternatively, LP steam is extracted from the turbogenerator set that runs on HP steam feed. Used in sulphur section, phosphoric acid evaporators, desalination plants.
- Electrical power: HP steam is taken to a turbogenerator to generate electrical power for the entire complex. It often runs all of the major electrical drives in the complex and also exports power to the main grid.
- Hot air: Used in rotary dryers for granular fertilizers and spray dryers for detergents.
- Hot water: Saline water feed to desalination plant can be preheated to save energy. Warm water can be produced for cleaning gypsum cake from the phosphoric acid plant.

Phosphatic fertilizer complexes

A typical phosphatic fertilizer complex utilises 93-98.5% sulphuric acid to extract phosphate content from rock phosphate to produce phosphoric acid or lower-end fertilizers such as single superphosphate (SSP).

Energy recovery

Since the product mix does not include oleum, a plant designer can maximise energy recovery as HP steam from the gas circuit, generate IP/LP steam from the HRS in the acid circuit and in some cases, hot air for granulation plants. Generally, HP and IP steam produced in the sulphuric acid plant is taken to the turbogenerator set to generate electrical power. LP steam is extracted for use as required in the complex.

Energy requirements

Energy demands of a complex vary depending on the type of fertilizer being produced, the production capacity as well as the technology used. Typical phosphoric acid/diammonium phosphate complexes use LP steam in phosphoric acid concentrators. The amount of LP steam requirement varies depending on concentration of the weak phosphoric acid produced in the complex which, in turn, depends on technology used for producing it (dihydrate, hemihydrate, hemi-dihydrate, etc.). Use of dihydrate technology produces phosphoric acid with a lower initial concentration and requires more steam in evaporators to concentrate it.

In some cases part of the high-level heat recovery comes in the form of hot air, which is used for granulation plants.

Saline water feed to the desalination plant is also preheated in some cases using energy available from the sulphuric acid plant.

Electrical power required to operate various plants

Typically, the capacity of the sulphuric acid plant is greater than 2,500 t/d for a phosphoric acid complex. For such large plants, the turbogenerator set for power generation and intermediate extraction of LP steam is economical. Steam generation at 60 barg gives a better return by higher power generation. At the same time, a significant amount of steam needs to be extracted from the turbine at ~7 and 3 barg for in-plant use in the sulphur section of the sulphuric acid plant and phosphoric acid plant evaporators. This limits the power generation in the turbogenerator set under normal operating scenarios.

Sulphuric acid plant capacities for a single superphosphate complex are smaller (100-200 t/d). In these plants, steam is utilised to drive major equipment such as the turbo-blower, boiler feed water and cooling water pumps.

The material and energy block diagrams in Figs 1-3 show how the requirements of a phosphoric acid complex are matched with the energy recovery from a sulphuric acid plant in three different cases.

In the case of a sulphuric acid plant with no HRS in a small SSP fertilizer complex (Fig. 3) the steam generated in the sulphuric acid plant is used to drive large equipment such as turbo-blowers, BFW pumps, cooling water pumps etc. Due to the smaller size of plants, use of steam to drive large equipment is more economical compared to installing a condensing turbogenerator set.

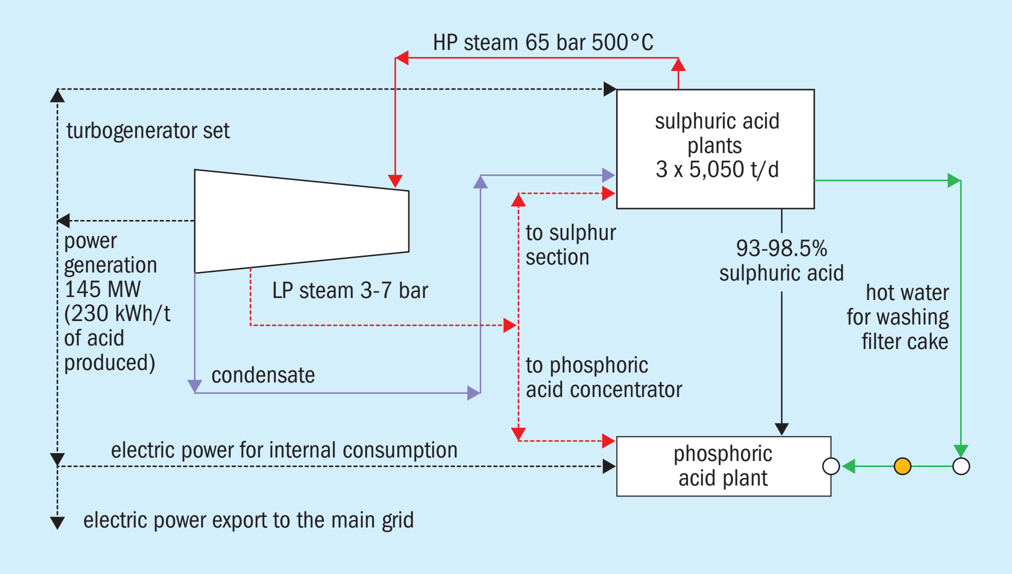
Pyrometallurgical complexes

Pyrometallurgical complexes consist of roasters/smelters that decompose sulphur-containing metal ores to produce metals such as copper and zinc. Sulphur present in the ore is converted to SO_2. SO_2-bearing gas streams from multiple sources (smelter/converter) are fed to the sulphuric acid plant to produce 93-98.5% sulphuric acid. These gas streams form important interfaces with the acid plant


IMAGE: SNC-LAVALIN

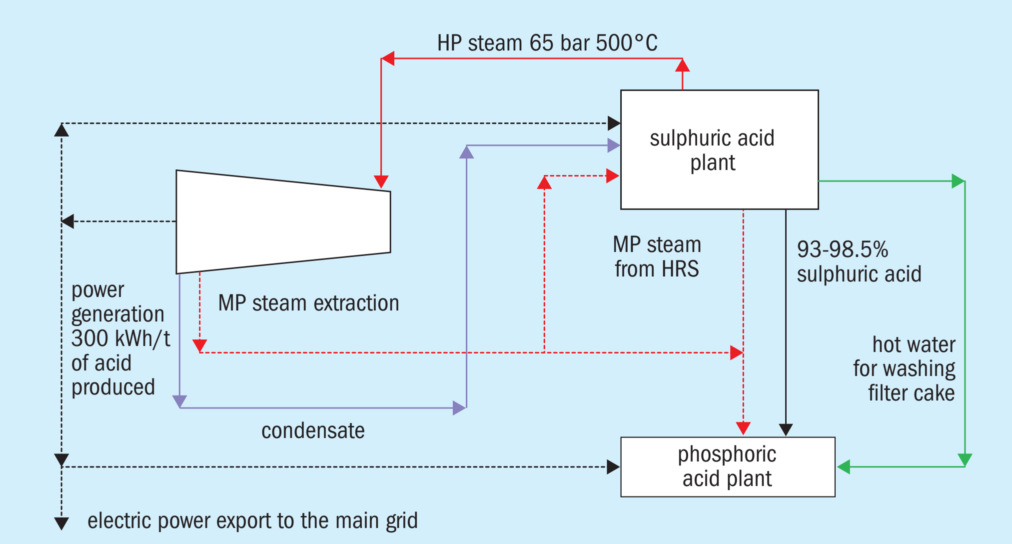
3D model of a large acid plant (no HRS) in a fertilizer complex.

Fig. 1: **Sulphuric acid plant (no HRS) in a phosphatic fertilizer complex**



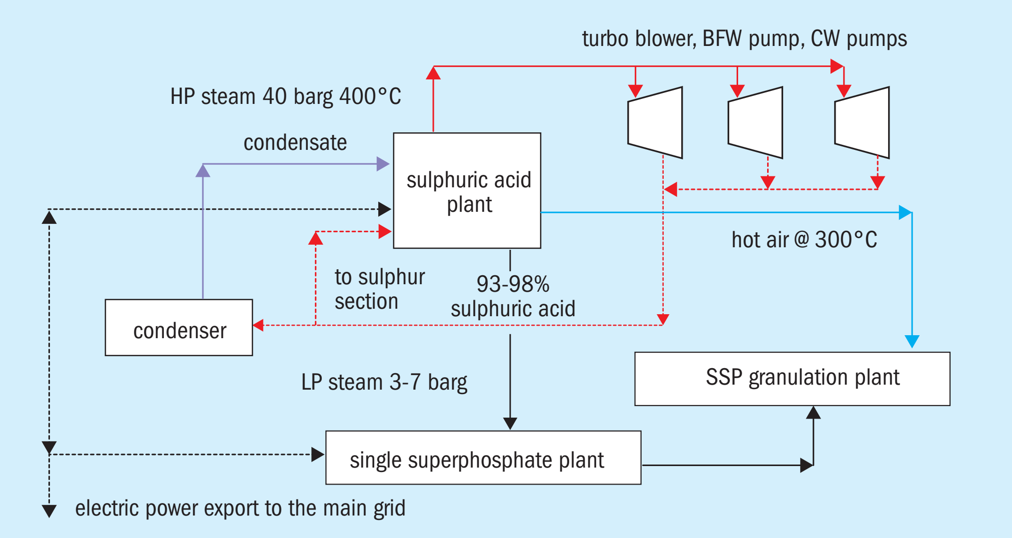
Source: SNC-Lavalin

Fig. 2: **Sulphuric acid plant (with HRS) in a phosphatic fertilizer complex**



Source: SNC-Lavalin

Fig. 3: **Sulphuric acid plant (no HRS) in a small SSP fertilizer complex**



Source: SNC-Lavalin

as it is necessary to maintain adequate suction at all the sources of SO_2 as Pierce-Smith converters go through different operations (slag blow, copper blow etc.). Gas flows and suction pressures at sources should stabilise quickly after every such change to avoid SO_2 gas leaking out into the working area.

Recent developments in metallurgical processes have resulted in gas streams containing higher SO_2 concentrations. This not only allows autothermal operation of the sulphuric acid plant in DCDA mode but also allows heat recovery as MP/HP steam or hot air.

Sulphuric acid is essentially a by-product in these complexes. Sometimes a phosphatic fertilizer complex is built to utilise this acid. However, this is not always economical due to non-availability of rock phosphate at remote locations. Often sulphuric acid is sold off to consumers at throw away prices with no value addition for the plant operator. SNC-Lavalin also has access to technology to convert SO_2-bearing gas streams directly to sulphur.

Raw materials and products

In the case of a pyrometallurgical complex, the sulphuric acid plant has a material interface with the metallurgical plant in the form of the incoming SO_2 gas stream. In addition to this, there will be other interfaces depending on how the sulphuric acid is utilised (refer to the earlier section on phosphatic fertilizer complexes).

Energy recovery

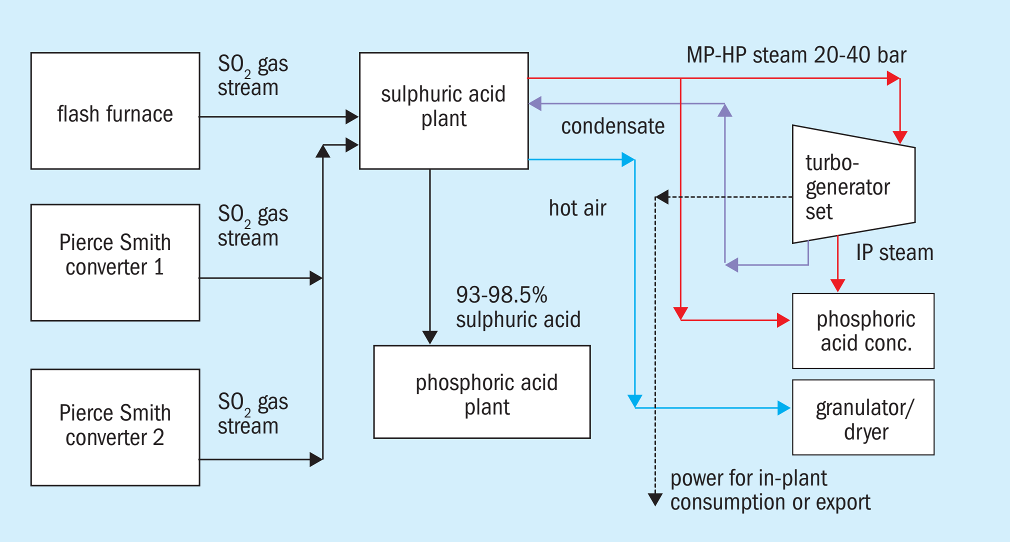
Excess heat in the system can be recovered as hot air in SO_3 coolers or as steam in boilers. Boiler systems generally produce MP steam (≤20 barg), however production of HP superheated steam at 40 barg is possible if high SO_2 concentration is available on a consistent basis. Heat recovery from the acid circuit using HRS is also possible in such cases.

Energy requirements

Hot air or MP steam can be used in concentrate dryers at inlet of the smelter/roaster. Hot air or MP steam can also be used in other locations in the complex such as phosphoric acid evaporators, granulator/dryers depending on how the sulphuric acid is utilised. If HP steam is generated, it can be utilised to drive equipment or generate electricity.

The material and energy block diagram in Fig. 4 shows how the requirements of the pyrometallurgical complex are matched

Fig. 4: **Sulphuric acid plant in a pyrometallurgical complex**



Source: SNC-Lavalin

with the energy recovery from the sulphuric acid plant.

Hydrometallurgical complexes

Hydrometallurgical complexes use 93-98.5% sulphuric acid to leach the target metal ions such as copper, nickel or cobalt from the ore. At times, a gas stream containing 12% or more SO_2 is also required to creating a reducing environment in the leached liquor.

Energy recovery

Since the product mix does not include oleum, the plant designer can maximise energy recovery as HP steam from the gas circuit and LP steam from the HRS in the acid circuit. Generally, the HP and IP steam produced in the sulphuric acid plant are taken to a turbogenerator set to generate electrical power. LP steam is extracted as required in the complex.

Energy requirements

All the steam is sent to a turbogenerator after meeting the internal requirement of the acid plant, as steam is not required as a heating media elsewhere.

The material and energy flow diagram in Fig. 5 shows how the requirements of the hydrometallurgical complex are matched with the energy recovery from the sulphuric acid plant.

Detergent/dyes/sulphonation complexes

The main products from such complexes are formulations containing sulphonate of organic compounds such as linear alkyl benzene, lauryl alcohol, and alpha olefins. The sulphuric acid plant is the source of the sulphonating agents; oleum for liquid phase sulphonation and SO_3-containing gas stream for gas phase sulphonation. Plants are generally smaller in size compared to those in fertilizer complexes. In high humidity locations, the moisture balance in the plant may cause issues if production of high-strength oleum and SO_3 gas need to be maximised. In such cases, part of the moisture from the air is removed by other drying methods like pre-cooling or silica gel dryers.

Energy recovery

Due to the presence of the oleum circuit, sulphuric acid plants in these complexes do not have an HRS based IP steam recovery from the acid circuit. The HP steam circuit is similar to the standard. Hot air generation is possible.

Energy requirements

Spray dryers in detergent plants and dyestuff plants require heat in the form of hot air.

Steam generated in the sulphuric acid plant is used to drive large equipment such as turbo-blowers, BFW pumps, cooling water pumps, and others. Due to the smaller size of the plants, the use of steam to drive major equipment is more economical compared to installing a condensing turbogenerator set, unless shortage of water forces the issue.

The material and energy block diagram in Fig. 6 shows how the requirements of the detergent complex are matched with the energy recovery from the sulphuric acid plant.

Engineering of interfaces for the complex

Each interface needs to be engineered carefully to ensure smooth and seamless operation of the entire complex under all possible operating scenarios. The following criteria need to be considered carefully while engineering the interfaces.

A sulphuric acid plant in a pyrometallurgical complex.

A sulphuric acid plant with HRS in a hydrometallurgical complex.

PHOTOS: SNC-LAVALIN

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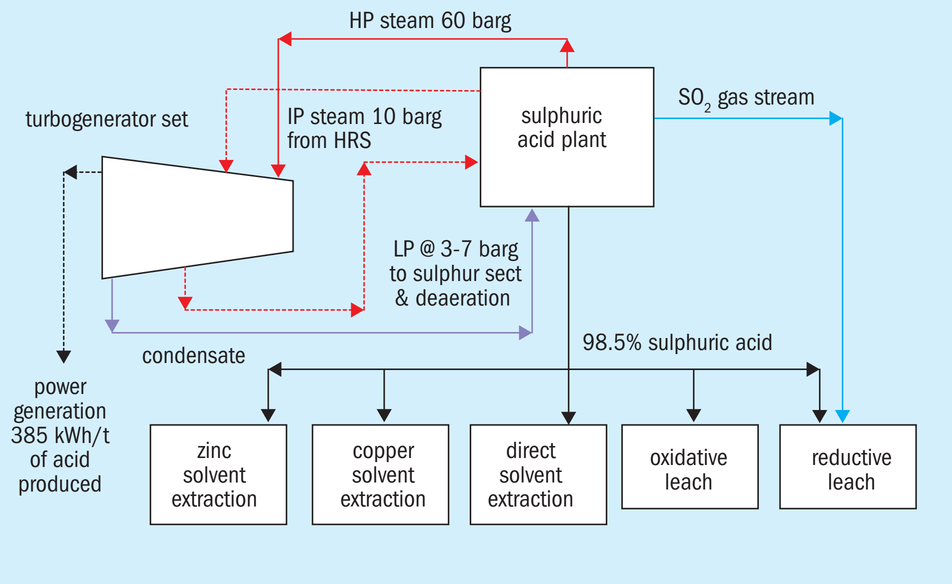
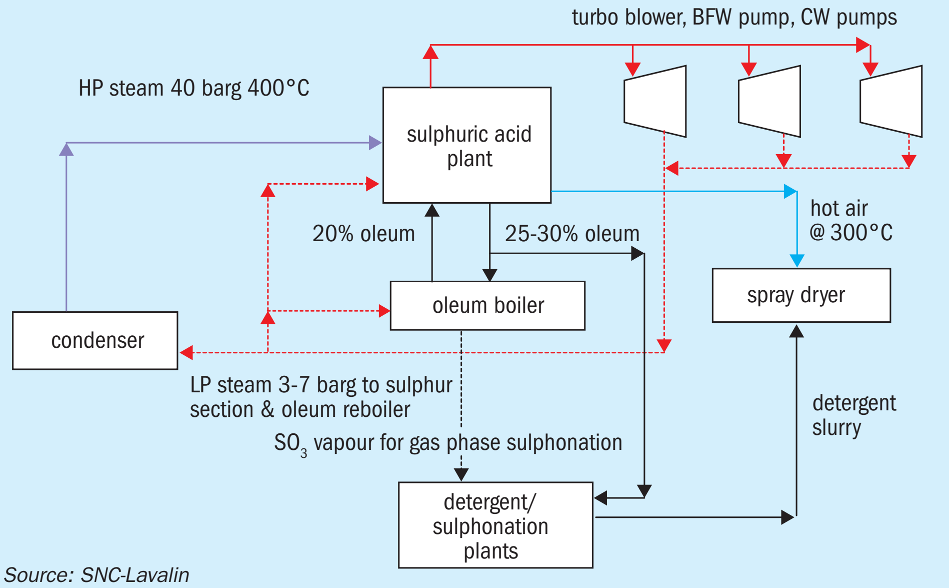
Fig. 5: **Sulphuric acid plant in a hydrometallurgical copper complex**



Source: SNC-Lavalin

Fig. 6: **Sulphuric acid plant in a detergent complex**



Source: SNC-Lavalin

Likely operating scenarios: The complex will rarely run with all the plants running at 100% capacity. Each plant will run at a turndown condition from time to time due to maintenance problems, lack of raw material etc. For example, in a phosphoric acid plant complex it is quite normal for the phosphoric acid plant to be run at lower capacity for extended periods due to problems associated with material handling equipment and varying nature of phosphate rock. Good understanding of all these operating scenarios is necessary to understand the most likely operating case(s) – and to customise plant design accordingly.

Process conditions: Pressure, temperature, composition and flow rates at the exit of one interface should match the requirements of the receiving interface in all the operating scenarios. Pressure and heat losses between the export point and receiving points need to be considered carefully. In case of a mismatch in the flow at export point and receiving point during any operating scenario, suitable buffer between the two points needs to be built up. This could be in terms of intermediate storage, vent or drain lines in case the production exceeds requirement. On other hand, alternative source needs to be built up in case production falls short of requirements. The start-up boiler is an example of this case. Size of buffer (storage tank, start-up boiler, vent or drain line) needs to be determined by careful analysis of various scenarios and expected time duration for such mismatch scenario to exist.

Piping designs: Pipe specifications in terms of materials, pressure and temperature ratings need to be consistent across interfaces. Stress at connecting interfaces need to take into account support designs on both sides of the interface. Suitable provision for the thermal expansion of pipes should be included after considering pipe designs on both sides of the connecting points.

Process control: The process control strategy should be carefully reviewed to ensure that control loops on both sides of interface are harmonious with each other. A conflicting control strategy on both sides of the interface can cause serious problems during operation.

Safety: After completion of the interface design, an interface HAZOP is recommended to identify operating hazards that arise due to interface engineering.

Brownfield plants: Any revamp or installation of a new plant within an existing complex offers several additional challenges in terms of matching interfaces and layout. With a good understanding of technology and requirements of the complex, an engineering company can deliver optimum solutions with minimum interference in operation of existing plants.

Role of engineering company: The engineering company usually forms an interface between the technology supplier and the owner of the complex. The engineering company needs to have deep understanding of the technology and requirements of the complex. It needs to analyse both ends and play a proactive role in finalising the basic engineering package prepared by the technology licensor to ensure a perfect match between the two ends. This is an important role and selection of a good engineering company to build a complex is as important as selection of proper technology. An engineering company without proper understanding of the complex can result in building a complex that is far from optimum even with use of the best technology. On the other hand, selection of an engineering company with good understanding of the entire complex ensures a perfect match between acid plant and the complex.

SNC-Lavalin, with a strong base in all fields of engineering, project management, procurement, and construction management, can deliver many different types of chemical complexes with single point responsibility. ■

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Pathway to an emission-free fertilizer complex

With climate change looming there is an increased focus on reducing the environmental footprint of the production of fertilizers. The use of renewable energy/green hydrogen is one way to make the fertilizer industry more environmentally sustainable. In this article, **Rene Dijkstra** of Chemetics introduces the Green Fertilizer Complex. This practical solution integrates an oxygen-based sulphuric acid plant using the Chemetics' patented CORE-SO2™ process with a green hydrogen and ammonia facility to deliver low cost, low emission, and carbon-free phosphate (MAP/DAP) and/or sulphate (AMS) based ammonia fertilizers.

Large scale production of fertilizers containing phosphate and nitrogen is imperative to be able to produce sufficient food for the world's population. As a result, the fertilizer industry has become a significant contributor to worldwide CO_2 emissions especially if the process involves the use of ammonia in the production chain. As ammonia is not only used in fertilizer but is also increasingly seen as a potential energy carrier, it is to be expected that worldwide production of ammonia will continue to increase. As a result, there will be increasing pressure to replace the steam methane reforming process to produce ammonia due to its large CO_2 emissions.

The Chemetics CORE-SO2™ process offers a cost-effective method to produce sulphuric acid from sulphur with extremely low emissions while taking full advantage of by-products from other process units in the fertilizer complex and is particularly well suited for integration with a green ammonia facility.

The CORE-SO2™ process

The CORE-SO2™ process produces sulphuric acid from molten sulphur and pure oxygen utilising the proprietary Chemetics CORE™ reactor. The use of pure oxygen reduces the size, complexity, and the cost of sulphuric acid production as the CORE reactor can operate at SO_2 concentrations up to ~60 vol-%. As a result, the gas flow through the CORE-SO2 plant is reduced by more than 70% compared to the gas flow in a conventional sulphur burning acid plant using DCDA technology operating at 11.5 vol-% SO_2 to the converter. Advantages in capex are obvious, but the reduction in equipment size and count also allows much larger sulphuric acid plants to be designed, especially for plants supplied in modules which have inherent lower site erection time and cost.

The CORE-SO2 process consists of four main sections:

- SO_2 generation;
- SO_2 conversion system;
- absorption system;
- purge gas system.

SO_2 generation system

The first generation of the CORE-SO2 plant introduced at the 2018 Sulphur Conference utilised a submerged combustion system to ensure low temperatures in the SO_2 generator. Even though submerged combustion systems for sulphur have been in operation since 1989 to generate concentrated SO_2 gas, Chemetics discovered that it was not required to achieve its goals. Therefore, the CORE-SO2 process was further optimised, resulting in a reduction in the equipment count and a simplification of the overall design.

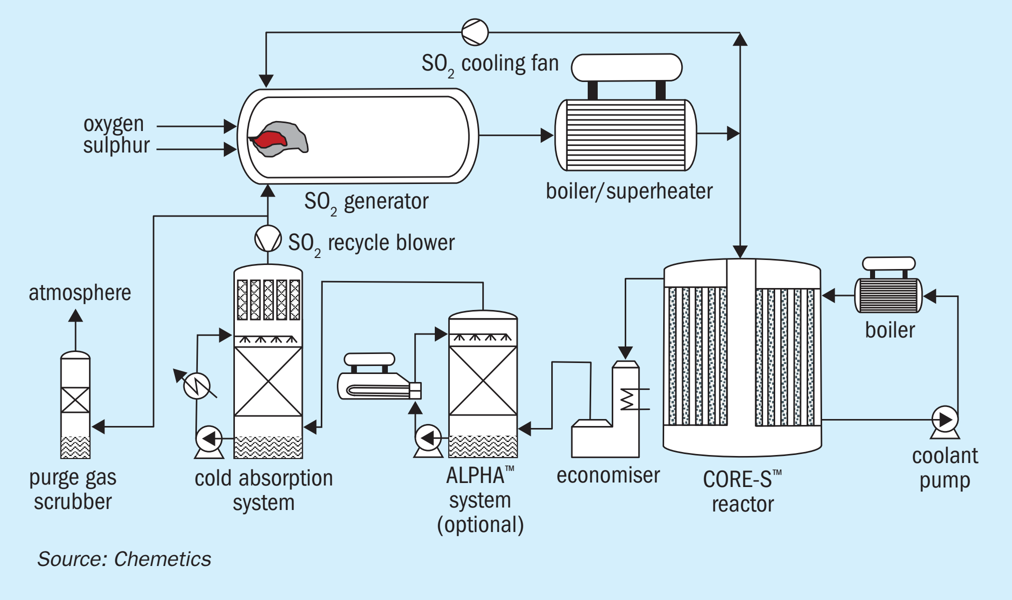
The new SO_2 generation system was developed to provide a familiar, yet highly efficient, combustion of sulphur and oxygen. The process is carried out using a standard combustion chamber with an integrated gas recycle. The easy to operate recycle system allows control of the combustion chamber temperature independently from the SO_2 concentration. Controlling this temperature is important to prevent refractory brick damage and the formation of nitrogen oxides which can form at high temperature from trace nitrogen contained in the oxygen feed. The gas from the SO_2 generator is cooled in a boiler/superheater combination before it enters the conversion system (see Fig. 1).

The SO_2 generator design is highly flexible, easy to control and allows a gas stream with any SO_2 concentration to be generated. Depending on the oxygen source, the SO_2 concentration leaving the SO_2 generation system will be controlled between 40 to 60 vol-%.

SO_2 conversion system

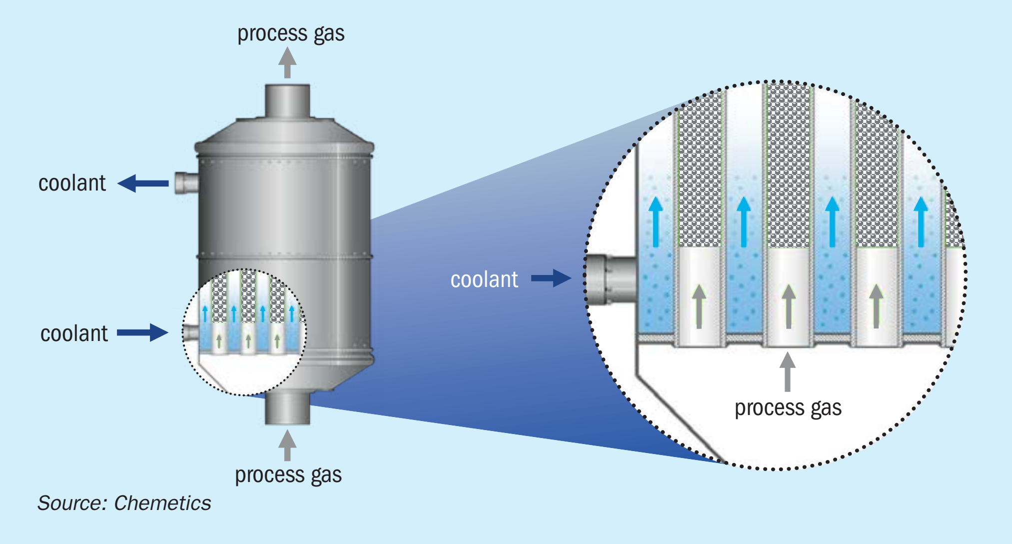
In the conversion system the SO_2 is further oxidised to SO_3 using a CORE-S™ reactor. The CORE-S reactor is a tubular reactor where the catalyst is located inside the tubes and a liquid coolant outside the tube (see Fig. 2). With this arrangement the gas is cooled as the heat of reaction for the SO_2

Fig. 1: **CORE-SO2™ process**



Source: Chemetics

Fig. 2: **CORE-S™ reactor**



Source: Chemetics

oxidation is released, allowing the reactor to operate with very high SO_2 concentrations compared to the traditional adiabatic converters used in the DCDA process. The CORE-S reactor is designed to process gas with up to 60 vol-% SO_2. This process gas enters the CORE-S system where most of the SO_2 is converted to SO_3. The coolant maintains the process gas temperature below 630°C to prevent catalyst damage. A specially developed catalyst mixture with high heat transfer capability is used to prevent hot spots in the centre of the catalyst. In the reactor more than 90% of the reaction energy is transferred to the coolant.

The cooling system maintains the optimum temperature to keep the catalyst active. It therefore operates at moderate temperatures, close to the catalyst activation temperature, and hence no special materials of construction are required in the CORE-S reactor system. The coolant temperature is controlled using a boiler producing saturated high-pressure steam. This configuration provides precise control of the temperature in the CORE-S reactor independently from other parts of the process. During start-up and periods when the plant is not operating the coolant temperature is maintained with a small electric heater and a hydrocarbon fired preheat system is not required.

After leaving the CORE-S reactor the process gas is cooled using an economiser. The cooled gas from the economiser flows to the absorption system where the SO_3 is converted to sulphuric acid.

Because of the compact design with small gas volumes more energy can be recovered. As a result, up to 10% more steam can be produced, depending on the selected steam pressure and temperature. Typical high-pressure steam export conditions are 60 bar(g) and 500°C, but these can be fully adjusted to meet client requirements. In most cases the HP steam is optimised for power generation in a turbine-generator.

Absorption system

The SO_3 formed in the CORE-S reactor is absorbed in the absorption system. This can be a conventional low temperature (cold) absorption system or a more energy efficient CES-ALPHA™ System to utilise the hot concentrated acid to produce medium pressure steam. Due to the much higher inlet SO_3 concentration in the CORE-SO2 process a higher percentage (>99%) of the SO_3 can be absorbed in the ALPHA tower resulting in more steam production than is possible for a conventional DCDA plant. Because the incoming oxygen contains no moisture (in contrast to ambient air) this MP steam production level can be maintained regardless of the plant location and the MP steam production is not reduced during times of increased humidity as experienced in a conventional acid plant using ambient air in many locations.

As a lower cost alternative to the MP steam generation, hot water can be provided which can be used to produce desalinated water or as heating medium in the complex. Producing a combination of steam and hot water is possible, allowing use of this valuable (green) energy to be tailored to the requirements of the fertilizer complex.

Most of the process gas leaving the absorption system is recycled to the SO_2 generation system using a small blower. This provides full utilisation and conversion of the SO_2 and O_2.

The acid from the absorption system is passed through a product stripper to remove dissolved SO_2 from the acid. The product stripper utilises a small flow of oxygen as the stripping medium. When the oxygen is received from an electrolysis unit, this product stripper is used to dry all the incoming oxygen before it is used preventing corrosion in the plant.

Plant emissions

The CORE-SO2 process results in very low emissions as only inert gases contained in the oxygen source need to be removed from the gas circulation. The significant impact this has on the stack volume and emissions is illustrated in Table 1. As can be seen, a CORE-SO2 plant operating with cryogenic oxygen can achieve an impressive 99% reduction in total annual stack emissions.

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Table 1: **Comparative data for a 2,500 t/d H_2SO_4 production with 130 ppmv SO_2/ 35 mg/Nm³ acid mist discharge limit**

Process	**DCDA**	**CORE-SO2™**	**CORE-SO2™**	**CORE-SO2™**
Oxygen source	Ambient air	VPSA	Cryogenic ASU	Electrolysis
O_2 concentration, vol-%	21	93	99.5	100
Gas to converter, Nm³/h	207,200	85,000	57,000	57,000
Gas to stack, Nm³/h	171,500	5,000	1,100	0
Stack SO_2 emissions, kg/t t/a	0.612 558	0.018 16	0.004 3.6	0 0
Stack H_2SO_4 emissions, t/a	52.5	1.5	0.3	0

Source: Chemetics

It is further important to note that a CORE-SO2 plant using only oxygen from an electrolysis system produces no effluents during normal operation and a stack with associated environmental permits may not be required.

Plants using oxygen from other sources require a purge stream from the recycle blower to remove inert gases (mainly nitrogen and argon) from the system which prevents accumulation. This purge flow is treated in the purge gas scrubber. Typically, depending on the plant size and location, a simple scrubber is sufficient. This fully integrated scrubber offers low operating cost and is designed to generate no effluent.

Sulphuric acid mist emissions are directly related to stack gas volume and as shown in Table 1, due to the low stack gas flow in the CORE-SO2 process become almost insignificantly small.

Oxygen supply

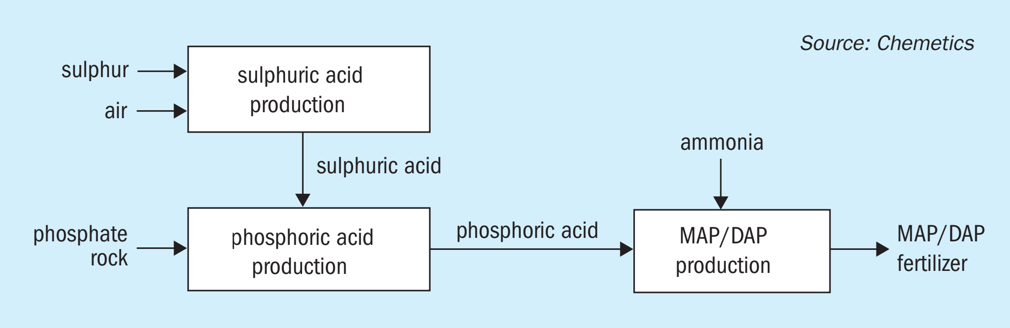
The CORE-SO2 will require a supply of high purity oxygen in an amount equal to almost 50% of the acid plant capacity. Thus, a 2,500 t/d sulphuric acid plant requires a 1,230 t/d oxygen supply source. Site locations with no existing oxygen supply will require a new dedicated or shared oxygen plant. There are two common options to supply the oxygen:

For smaller capacities a vacuum/pressure swing absorption (VPSA) system is the most cost effective. VPSA plants utilise adsorbent beds to separate the oxygen from the ambient air and produce an oxygen stream with a concentration up to ~93 vol-%. Capacities of individual units are limited to approximately 250 t/d oxygen, but the use of multiple units is not unusual to deliver higher capacities.

For oxygen capacities larger than approximately 500 t/d, cryogenic air separation units (ASU) are more cost effective and single train cryogenic units with more than 2,500 t/d oxygen capacity are currently operating. In the cryogenic ASU the oxygen is separated from the nitrogen using distillation at very low temperature where they are in the liquid state. The oxygen purity from the ASU is much higher than can be achieved in a VPSA systems with standard purity oxygen production defined as 99.5 vol-% or better. As previously shown in Table 1, this higher oxygen purity further reduces the stack emissions from the CORE-SO2 Process compared with VPSA oxygen.

An additional benefit of the cryogenic air separation is that it allows high purity nitrogen to be co-produced at virtually no additional cost. This is very useful in a fertilizer complex where ammonia is also produced as the ASU can produce both the nitrogen for the ammonia plant and the oxygen for the sulphuric acid plant. The ratio of nitrogen to oxygen produced can be selected at the design stage to match the ammonia and sulphuric acid production capacities required.

Fig. 3: **Simplified MAP/DAP fertilizer complex**



Source: Chemetics

The integrated fertilizer complex

A simplified fertilizer complex for production of MAP/DAP fertilizer is shown in Fig. 3. Sulphur and ambient air are used to produce sulphuric acid, which in turn is reacted with phosphate rock to produce phosphoric acid. The phosphoric acid then reacts with ammonia to produce the MAP/DAP (or NPK/TSP) products. Energy released in the production of sulphuric acid is recovered as HP steam and used to produce power. This power is used to operate the other units in the complex and in most cases excess power is available which can be sold. To avoid CO_2 emissions in the MAP/DAP granulation plant it will be necessary to install indirect drying of the product (e.g., steam drying) rather than the direct fired dryers that are currently more commonly used.

When ammonia production is added to the complex then further integration is possible. Ammonia is produced using the Haber-Bosch process from a mixture of nitrogen and hydrogen. The hydrogen is typically produced from natural gas using a steam methane reformer (SMR). Depending on the SMR design, nitrogen is either supplied by adding air into the reformer or by supplying it from an air separation unit. The latter process has the advantage that the amount of process gas leaving the SMR, which must be purified before the ammonia loop, is significantly reduced, and further allows other hydrogen sources to be easily incorporated.

The process using an ASU is depicted in Fig. 4. It is obvious that this line-up has additional benefits as the by-product oxygen from the ASU can now be used in a CORE-SO2 sulphuric acid plant.

Sufficient power can be produced from the energy released in the sulphuric acid and ammonia production units for the entire complex and no electrical power import is required. It is however obvious that the conventional ammonia process is a significant producer of CO_2 due to the hydrocarbon feedstock.

Green fertilizer complex

To make the fertilizer complex carbon free it is necessary to eliminate the CO_2 emissions from the production of ammonia and hence

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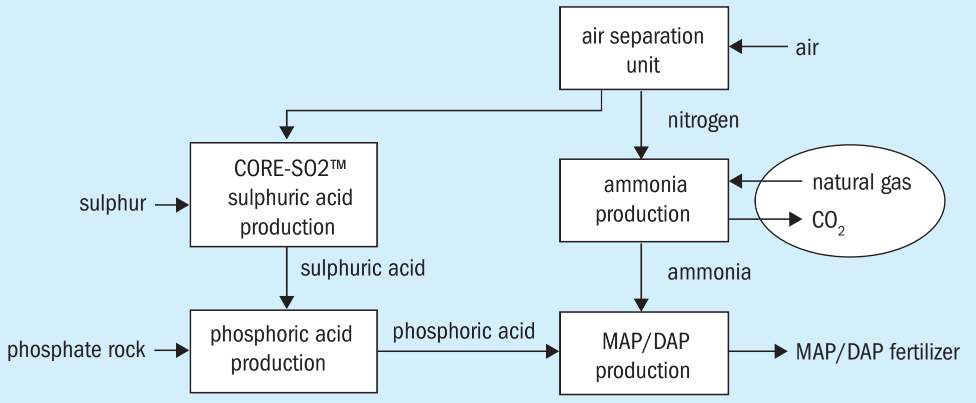
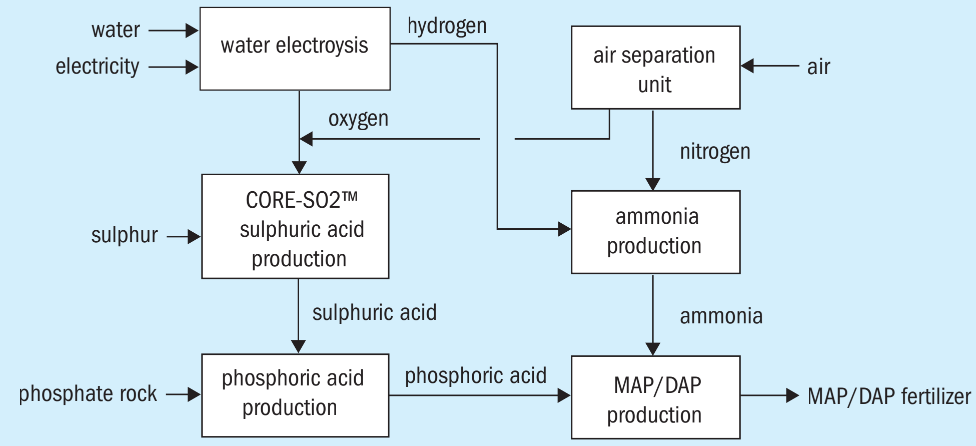
Fig. 4: **MAP/DAP fertilizer complex with ammonia production**



Source: Chemetics

Fig. 5: **Carbon-free integrated MAP/DAP fertilizer complex**



Source: Chemetics

a different source of hydrogen is required. This carbon-free hydrogen is often referred to as green hydrogen when the hydrogen is produced by electrolysis of water using renewable energy. Several options exist to produce green hydrogen. Both PEM and alkaline water electrolysis are already in use at industrial scale, and solid oxide electrolysis operating at higher temperature also holds promise for the future. In all cases, water is split into hydrogen and oxygen. The hydrogen is used for the ammonia production, but just as with the ASU unit, the by-product oxygen can now also be used to produce sulphuric acid. This additional oxygen source can either be used to produce more sulphuric acid or it can be used to reduce the size of the ASU. This process is shown in Fig. 5.

At the heart of this fully integrated complex is the CORE-SO2 Process to produce sulphuric acid from sulphur and pure oxygen. It not only takes full advantage of the 'free' by-product oxygen, but it also provides the power to run all unit operations except the electrolysis.

For locations with limited fresh water supply, excess energy from the CORE-SO2 plant can also be used to produce high quality desalinated sea water or brackish water for use in the electrolysis unit and steam boilers. The fully integrated process, now only using air, water, sulphur, and phosphate rock as raw materials produces fertilizer without any CO_2 or SO_2 emissions.

Noteworthy is that the integrated fertilizer complex as shown in Fig. 4 could be incrementally switched over to green hydrogen without any changes required for the other process units. This allows on-site green hydrogen capacity to gradually replace carbon-based hydrogen production as additional renewable energy sources become available. As a further benefit, when green hydrogen production is increased, the sulphur emissions from the sulphuric acid plant are reduced as less inert gases enter the process with the oxygen from the ASU.

Energy integration

The integration of the complex is not complete without optimising the energy integration. Both the sulphuric acid and ammonia processes produce excess energy. Most of this energy can be captured from high-temperature sources and is used to produce superheated high-pressure steam. For a complex producing only DAP this combined steam production at 60 bar(g) and 500°C works out to approximately 1.40 to 1.45 kg steam/kg sulphuric acid.

Low-pressure steam (at 5-7 bar(g)) is required for the deaerators, sulphur melting, phosphoric acid evaporators and the MAP/DAP granulation plants. This steam is generally provided using a combination of extraction from the turbine-generator and the steam generated in the ALPHA™ system in the sulphuric acid plant.

An important factor in the amount of LP steam required is the process selection for the phosphoric acid plant. The di-hydrate (DH), hemi-hydrate (HH), hemi-dihydrate (HDH) and others produce phosphoric acid from the main reactor at different concentrations ranging from 28% to 44%. Higher phosphoric acid concentrations require far less steam to reach the final merchant grade acid concentration in the subsequent phosphoric acid evaporators. With less LP steam required in the phosphoric acid evaporators, less or no steam will need to be extracted from the steam turbine and more electrical power can be generated. This will allow the complex to provide some stabilising baseload power to the water electrolysis.

Further opportunities for energy integration can be found by recovering and using low grade heat in the various units (e.g. using a hot water network). These are outside the scope of this article but should be reviewed early in any new project.

Conclusion

The Chemetics CORE-SO2 process sets new benchmarks for sulphur emissions, allowing a step change in reducing sulphur dioxide and sulphuric acid mist emissions compared to the traditional DCDA process. At the same time, it provides compelling economics with lower capex and opex. When integrated into a fertilizer complex these economics are further improved when taking advantage of 'free' by-product oxygen available from other units. Fully integrated with a green ammonia plant, the CORE-SO2™ process enables the production of low cost, CO_2, and sulphur emission-free fertilizer. ■

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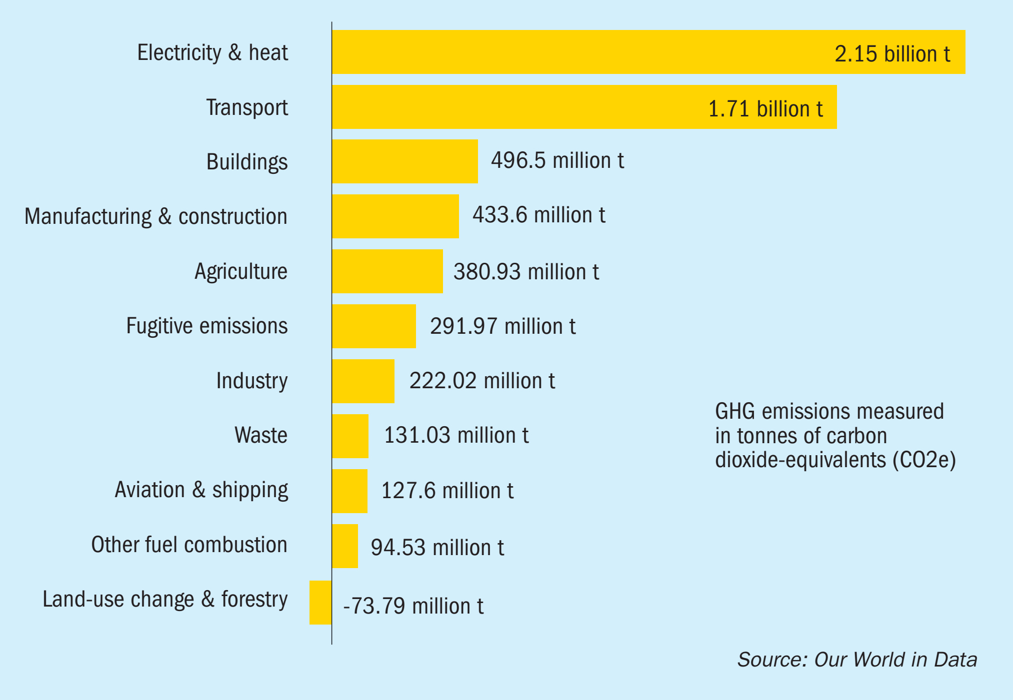
Decreasing CO_2 footprint with clean energy from sulphuric acid production

Ricardo L. Sepulveda of PegasusTSI reviews options to decrease the CO_2 footprint of a fertilizer industrial complex and illustrates the technical and economic feasibility of utilising clean energy from a sulphuric acid plant in a fertilizer complex to produce green hydrogen, which in turn can be used to produce green methanol or green ammonia.

Emissions of carbon dioxide (CO_2) and other greenhouse gases are one of the main drivers of climate change, and their reduction presents one of the most urgent challenges today. To slow down the global temperature increase, it is necessary to stabilise the CO_2 concentration and other greenhouse gases present in the atmosphere. But currently, far from stabilising their concentrations, greenhouse gases continue to accumulate.

To stabilise, or even reduce CO_2 concentrations in the atmosphere, the world needs to achieve net zero emissions. This requires large and rapid emission reductions (Fig. 1).

Fig. 1: **Greenhouse gas emissions by sector (US 2016)**



Source: Our World in Data

What is a green technology?

Green technology is a technology that is considered friendly to the environment based on its production process or its supply chain. One example is the hydrogen produced from renewable/clean electricity by water electrolysis.

The production of methanol using green hydrogen and the capture of CO_2 allows the decrease in carbon emissions in an industrial complex while generating green methanol.

$$CO_2 + 3H_2 \rightarrow CH_3OH + H_2O$$

Ammonia production using green hydrogen (H_2) and nitrogen (N_2), allows a decrease in carbon footprint in an industrial complex while generating green ammonia.

$$N_2 + 3H_2 \rightarrow 2NH_3$$

Methanol Production

Methanol is a valuable chemical with various uses, either as a hydrogen storage compound, a fuel, or as raw material to synthesise other chemical substances.

Conventionally, methanol is produced on an industrial scale from synthesis gas, a combination of varying amounts of H_2, CO, and CO_2 frequently derived from gasified coal or steam reforming of natural gas, which have an emission factor between 0.4 to 3.0 t CO_2/t methanol

In recent years, interest in methanol production from CO_2 has been growing, based on the concept of power-to-fuel. Specifically, power-to-methanol technology is based on the electrochemical separation of water into H_2 and O_2 with the subsequent catalytic hydrogenation of CO_2 to liquid methanol.

CO_2 hydrogenation to methanol is environmentally friendly for decreasing CO_2 emissions. The industrial implementation has been limited mainly due to the higher costs associated with capturing CO_2 and producing H_2 from clean/renewable energy compared to production from synthesis gas. However, in recent times, it has become necessary to consider new processes that incorporate environmentally beneficial features.

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Ammonia production

Ammonia is critical in the manufacturing of fertilizers and is one of the largest-volume synthetic chemicals produced in the world. Conventionally, ammonia is produced by converting hydrocarbons, (NG, LPG, naphtha), into hydrogen (via steam reforming), and combining it with nitrogen, which will have an emission factor of ~2.1 t CO_2/t NH_3. Fig. 2 shows the US ammonia supply/disposition balance.

Fertilizer industrial complex

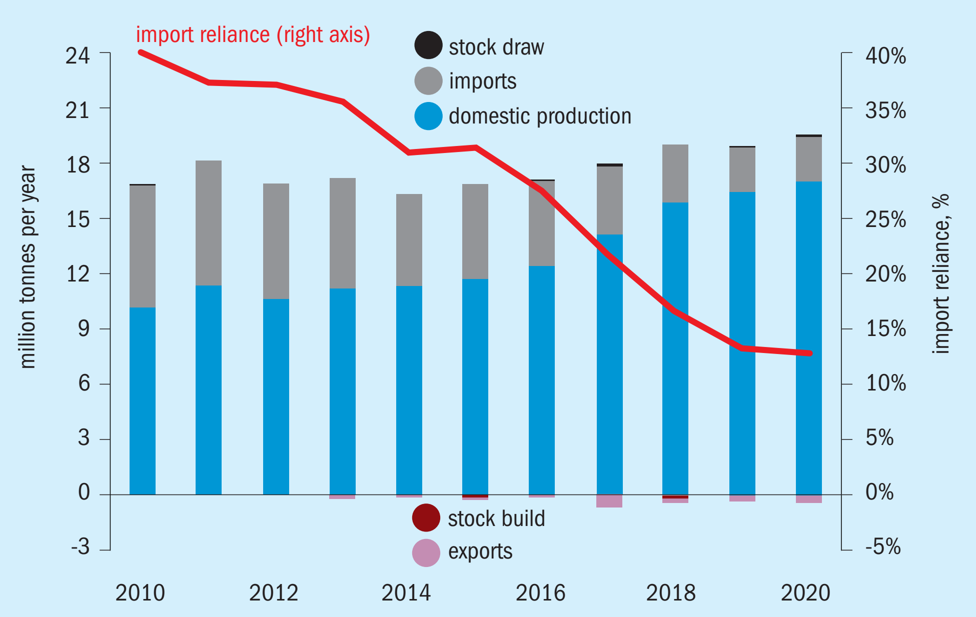
In the following sections options to decrease the CO_2 footprint in a fertilizer industrial complex are reviewed with reference to the following processes:

- sulphuric acid energy recovery;
- phosphoric acid production process/ CO_2 capture;
- ammonia consumption.

Sulphuric acid energy recovery

In a fertilizer industrial complex, sulphuric acid is used in the production of phosphoric acid. A by-product of sulphuric acid production is high-pressure steam which can be used for electric power generation and to provide a heat source for fertilizer production. New developments in optimising sulphuric acid plants, like the addition of heat recovery systems (HRS) to existing double contact double absorption plants, provides additional medium-pressure steam generation to allow the production of clean electricity in a condensing steam turbine.

Fig. 2: **US ammonia supply / disposition balance**



Source: US Geological Survey

Clean electricity can be used in an electrolyser for the electrolysis of water that separates hydrogen (H_2) and oxygen (O_2) from water (H_2O) to produce green hydrogen, which can be used as a raw material to produce green chemicals.

Fig. 3 shows the MECS® HRS™ technology, which captures and re-uses waste heat from the process and converts it to medium-pressure steam.

For example, a 3,400 t/d sulphuric acid plant can generate 150,000 lb/hr (68 m³/h) of medium-pressure steam, considering two HRS with a total capacity of 300,000 lb/hr (136 m³/h), the potential electric production in a condensation steam turbine generator will be 24 MW of net electric clean power.

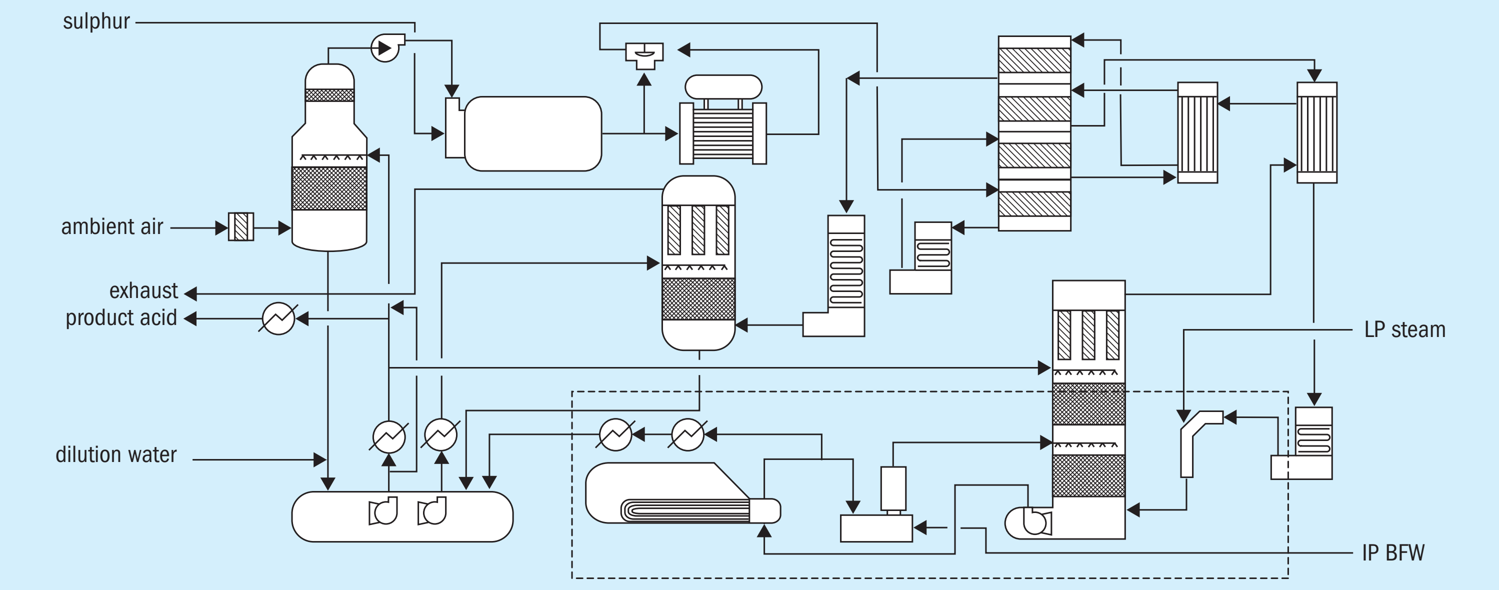
This clean energy will be the source for the production of green hydrogen in the fertilizer industrial complex.

Phosphoric acid production process/ CO_2 capture

Carbon dioxide is emitted when the limestone component ($CaCO_3$) of phosphate rock reacts with sulphuric acid (H_2SO_4).

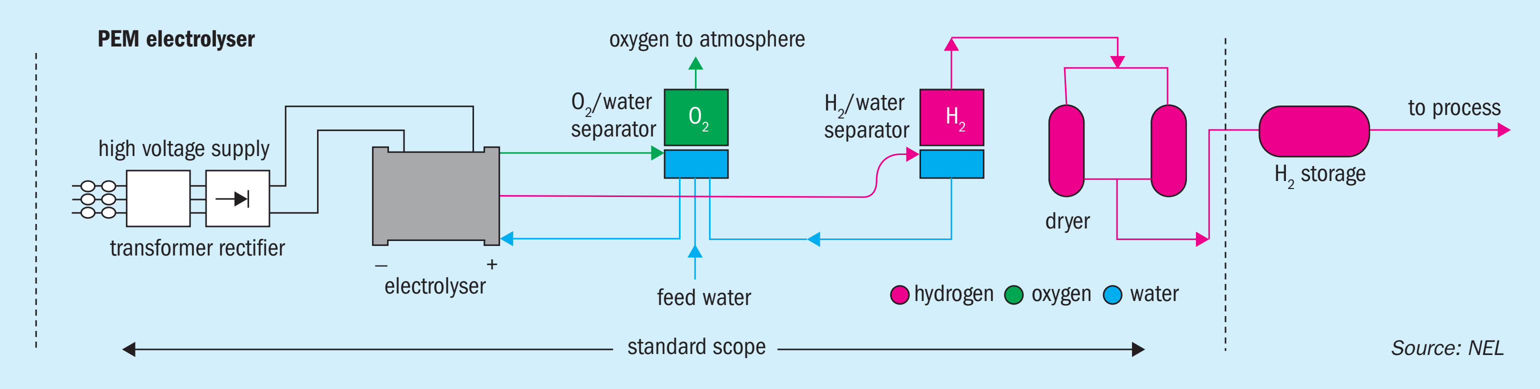
$$CaCO_3 + H_2SO_4 + H_2O \rightarrow CaSO_4 \bullet 2H_2O + CO_2$$

Fig. 3: **Sulphuric acid plant MECS® HRS energy recovery**



Source: Elessent Clean Technologies (formerly DuPont Clean Technologies)

Fig. 4: **Hydrogen production technology**



Source: NEL

Process emissions from phosphoric acid production in the US totalled 1.17 million tonnes CO_2 per year. According to the US EPA (Technical Support Document for the Phosphoric Acid Production Sector: Proposed Rule for Mandatory Reporting of Greenhouse Gases, 2009) phosphoric acid plants have an average emission factor of 0.15 t CO_2/t phosphoric acid.

A typical facility with a capacity of 1 million t/a of phosphoric acid will therefore have an estimated total CO_2 emission of 150,000 t/a.

For the production of green methanol, it is necessary to have a source of CO_2. The CO_2 from the flue gas of the phosphoric acid reactor could be captured, filtered, and concentrated to be used for the production of green methanol.

The production of methanol using green hydrogen and the capture of CO_2, decreases the carbon emission in a fertilizer complex while generating green methanol.

Ammonia consumption

The use of ammonia in fertilizer production e.g., the production of granular mono ammonium phosphate (GMAP) increases the CO_2 footprint of the fertilizer complex further due to the ammonia CO_2 footprint (2 t CO_2/t ammonia, based on steam reforming of natural gas).

A typical facility with a capacity of 1 million t/a of GMAP will need 130,000 t/a of ammonia which will create a total CO_2 footprint of 260,000 t/a. A partial replacement of the ammonia with green ammonia will decrease the CO_2 footprint.

Green hydrogen production

To obtain H_2 from the electrolysis of water, at an industrial level, there are two technologies available: alkaline electrolysis (AEL), with a temperature and pressure below 80°C and 30 bar, and proton exchange membrane electrolysis (PEM), with temperature and pressure lower than 100°C and 200 bar (Fig. 4).

AEL technology typically has a lower capital investment (generally uses nickel catalysts) but is less efficient. On the other hand, a comparable PEM technology unit will have a higher capital investment but is more efficient and can operate at higher current densities. Lower hydrogen production costs can be achieved at higher hydrogen production capacities.

In both cases, the dissociation of the water molecule occurs by an electric current applied to two electrodes separated by the electrolyte or a membrane that only allows the passage of positive ions, producing hydrogen at the cathode and oxygen at the anode.

A theoretical 100% efficient electrolyser would consume 39.4 kWh/kg H_2 (142 MJ/kg, 12.75 MJ/m^3). This electrical consumption value increases due to system inefficiencies and so for commercial applications it is around 55 kWh/kg H_2.

Generally, the hydrogen produced from electrolysis is for immediate use applications such as oxygen flares or when high purity hydrogen or oxygen is desired.

High pressure electrolysis (HPE) of water produces hydrogen at around 120-200 bar at 70°C. Pressurising the hydrogen in the electrolyser eliminates the need for an external hydrogen compressor; the average energy consumption for internal compression is around 3%.

CO_2 recovery

A large portion of carbon emitted to the earth's atmosphere every year is in the form of gaseous CO_2, and approximately 30% of this CO_2 comes from fossil fuel power plants.

In addition to rising levels of atmospheric CO_2, the earth's temperature is increasing. Since CO_2 can act as a trap for heat, the reduction of CO_2 emissions is an essential area of research.

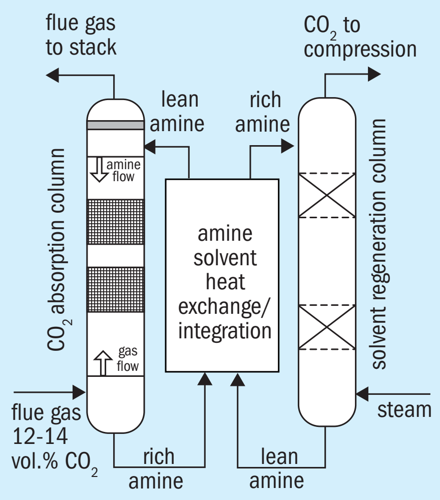
Separation and recovery of CO_2 are near-term goals for emissions reduction. Methods to obtain CO_2 from flue gas streams include absorption using solvents or solid sorbents, pressure- and temperature-swing adsorption using various solid sorbents, cryogenic distillation, membranes, among others.

The most promising current method for CO_2 separation is liquid absorption using monoethanolamine (MEA). While this method is currently the most widely adopted, the development of ceramic and metallic membranes for membrane diffusion should produce membranes which are significantly more efficient at separation than MEA absorption.

Liquid absorption

The gas stream enters an absorber reactor and flows countercurrently to a CO_2-lean solvent into which CO_2 is absorbed and reacts with the MEA to form water-soluble compounds. The treated gas is discharged to the atmosphere and the CO_2-rich solution is pumped to a stripper reactor for regeneration (Fig. 5). In the stripper, the CO_2-rich solution is heated in order to break down the salt and regenerate the MEA solvent. A reboiler provides the heat for regeneration of the MEA solvent in the stripper. Consequently, CO_2 is released, producing a concentrated stream which exits the stripper and is then cooled and dehumidified in preparation for compression, transport, and storage. From the stripper, the CO_2-lean solution is cooled and returned to the absorber for reuse. Usable MEA solution concentrations are typically limited by viscosity and corrosion. Therefore, current systems use only between 20% and 30% MEA, with the remaining being water. Although the water present in the solution helps control the solvent temperature during absorption, which is an exothermic reaction, the water also requires significant amounts of sensible heating and stripping energy upon CO_2 regeneration.

Fig. 5: **CO_2 recovery technology**



Source: PegasusTSI

Industrial case for a fertilizer complex

As previously described, an industrial fertilizer complex offers good potential for the production of clean energy coming from the sulphuric acid production energy recovery, which will generate medium pressure steam that can be used to produce clean electricity.

Considering the installation of HRS recovery systems in two sulphuric acid plants of 3,400 t/d, it is possible to generate an additional 300,000 lb/hr (136 m³/h) of medium-pressure steam, which can be used in condensation steam turbine generator to generate 24 MW of net electric clean power.

The potential production of hydrogen from a PEM electrolyser with 24 MW is 8.3 t/d of H_2 (3,000 t/a).

Carbon dioxide can be recovered from the phosphoric acid reactor flue gas in the phosphoric acid plant to decrease the CO_2 footprint of the fertilizer production and for the production of green methanol. In this case 21,700 t/a of CO_2 could be recovered, which could react with the 3,000 t/a of hydrogen to produce 16,500 t/a of green methanol (Fig. 6).

The green hydrogen can also be used in the production of green ammonia , which can be used in the production of GMAP fertilizer. The use of green ammonia in the production of GMAP fertilizer will have the impact of decreasing the CO_2 footprint, due to replacement of the ammonia produced via the natural gas steam reforming route, which has a CO_2 footprint of 2t CO_2/t ammonia.

In this case the 3,000 t/a of green hydrogen can be used for the production of 16,800 t/a of green ammonia (Fig. 8).

CO_2 emissions and footprint

The CO_2 emissions and footprint benefits of producing green methanol versus green ammonia in a fertilizer industrial complex has been studied.

Table 1 compares the impact on CO_2 footprint between methanol and ammonia production.

If the 24 MW of clean energy from the sulphuric acid plant were used for the production of green methanol the reduction in CO_2 footprint would be 28,300 t/a. Alternatively, if the clean energy were used for the production of green ammonia the reduction in CO_2 footprint would be 35,784 t/a.

The production of green ammonia therefore has a bigger impact in decreasing the CO_2 footprint in the fertilizer complex when using the same amount of green hydrogen.

Economics

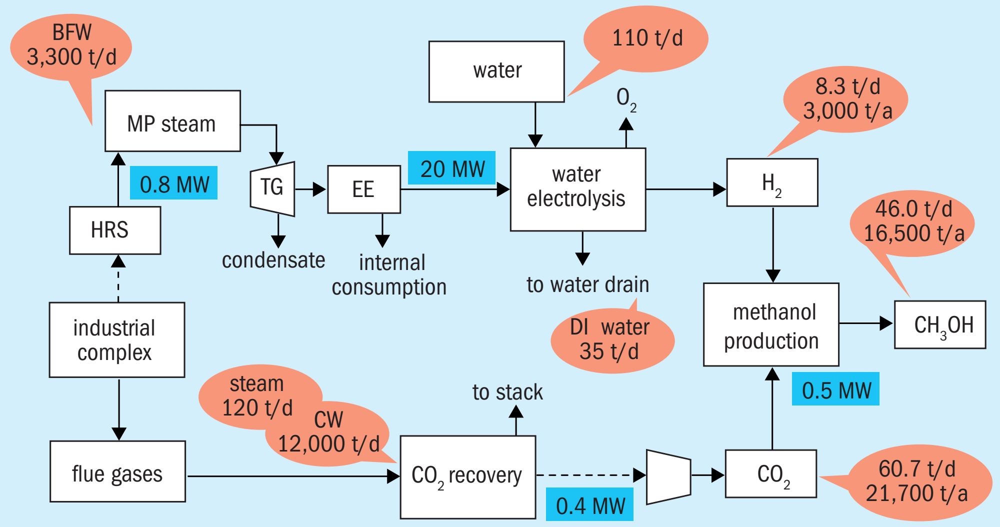
Green methanol

The total investment to produce 16,500 t/a of green methanol is estimated to be $228 million, which includes the two sulphuric acid plant heat recovery systems, steam turbine system, electrolyser, CO_2 recovery system and the methanol plant (Fig. 7).

The economic feasibility of green methanol on this scale is based on the following parameters:

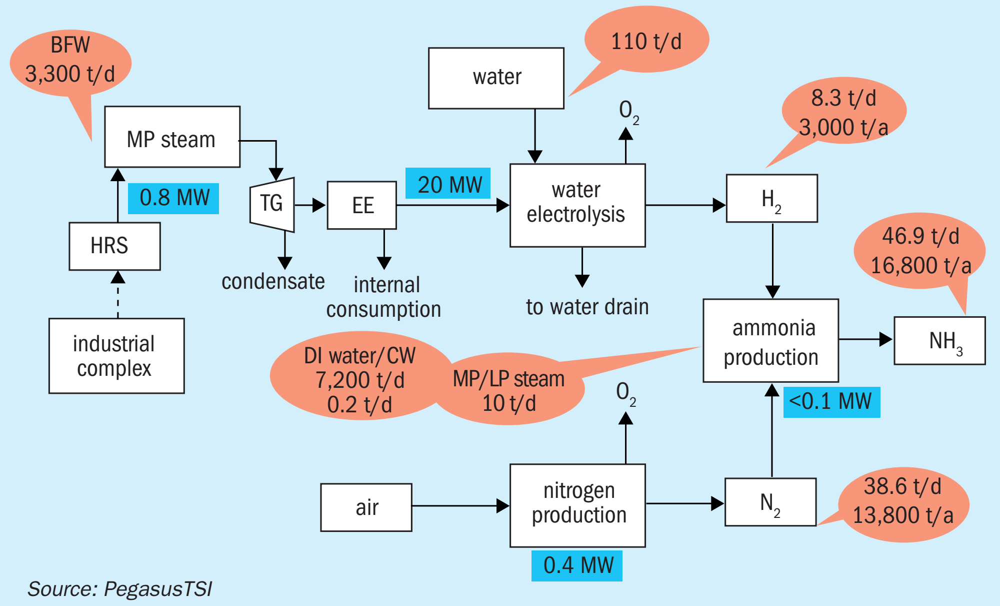
- Investment: $228 million
- Green methanol production: 16,500 t/a
- CO_2 Capture: 21,700 t/a
- CO_2 carbon credit: 50 $/t
- ROI: 8%

Fig. 6: **Methanol production data**



Source: PegasusTSI

Fig. 7: **Ammonia production data**



Source: PegasusTSI

Table 1: **Components modelled in simulation**

	Methanol	**Ammonia**
Energy production, MW	24	24
CO_2 capture, t/a	21,700	-
Production, t/a	16,500	16,800
Production/CO_2 footprint	0.4 kg CO_2/kg methanol	2.13 kg CO_2/kg ammonia
CO_2 footprint decrease, t/a	6,600	35,784
Total CO_2 footprint decrease, t/a	28,300	35,784
Carbon capture only, CO_2/MWh	108	-
Carbon capture + production plant, CO_2/MWh	140	178

Source: PegasusTSI

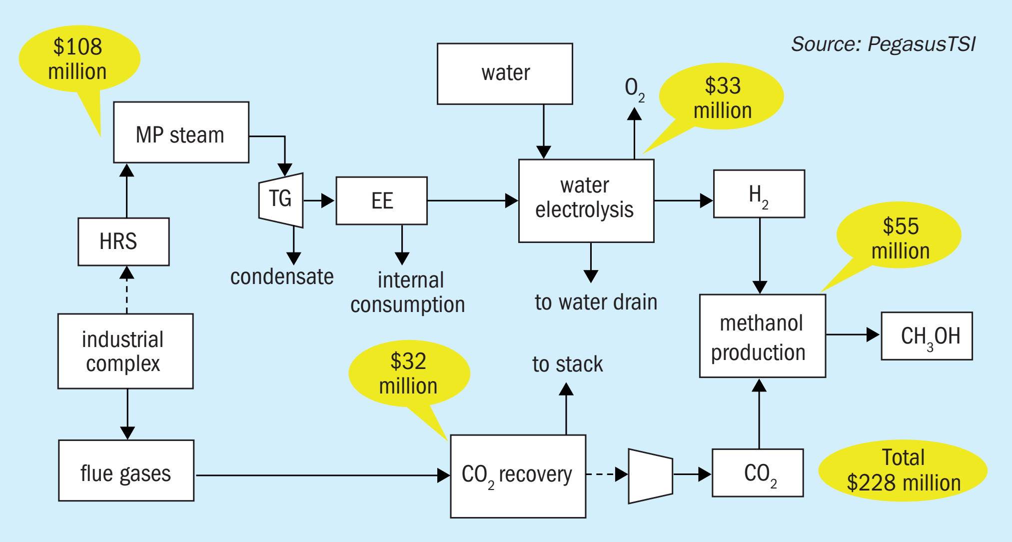
Under current market conditions (1Q 2022), the green methanol price is around 1,290 $/t, which exceeds the market price for methanol, which would be in the order of 500 $/t.

Despite the fact that the green methanol has a higher market price, there could be a demand for product that can decrease the CO_2 footprint of other companies that use methanol as a raw material.

Green ammonia

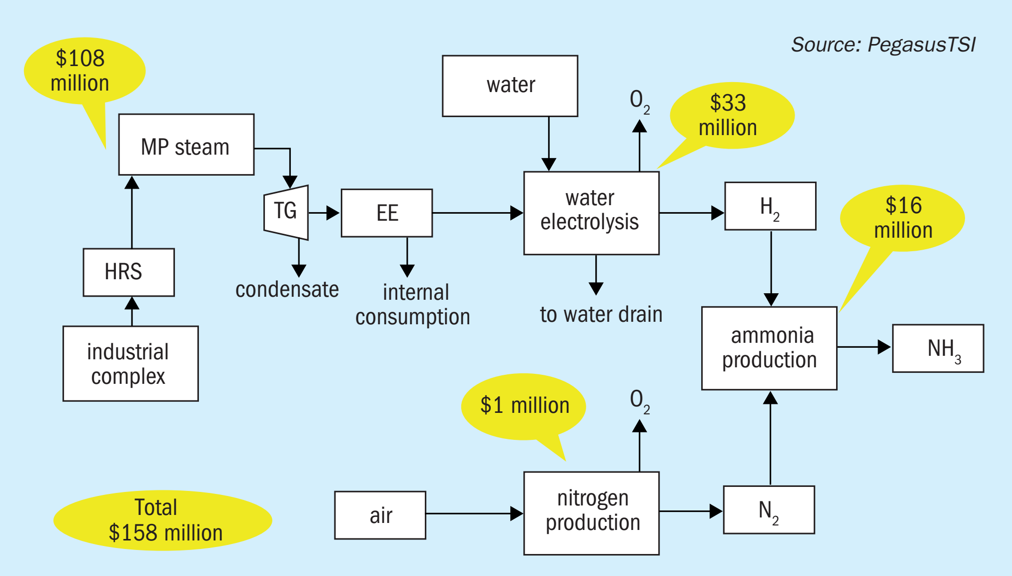
The total investment to produce 16,800 t/a of green ammonia is estimated to be $158 million, which includes the two sulphuric acid plant heat recovery systems, steam turbine systems, electrolyser, CO_2 recovery system and the ammonia plant (Fig. 9).

Fig. 8: **Methanol production capex**



Source: PegasusTSI

Fig. 9: **Ammonia production capex**



Source: PegasusTSI

The economic feasibility of green ammonia on this scale is based on the following parameters:

- Investment: $158 million
- Green ammonia production: 16,800 t/a
- CO_2 footprint decrease: 35,784 t/a
- ROI: 8%

Based on current market conditions, the green ammonia price is 900 $/t, which exceeds the current market price for ammonia, which is in the order of $500 $/t.

Despite the fact that the production cost of green ammonia is higher than market prices, there could be demand for fertilizer products that have a lower CO_2 footprint.

An additional consideration to improve the feasibility of green ammonia production is the potential for modification of an existing ammonia facility to use green hydrogen to decrease the capital investment and improve the feasibility of the project.

Conclusions

Technologies to decrease CO_2 footprint are commercially available and the economic feasibility will depend on the ability of the market to pay a premium for green methanol or green ammonia.

A preliminary analysis comparing green methanol and green ammonia production shows that in an industrial fertilizer complex green ammonia production may be attractive when a high CO_2 reduction is required with reduced capital investment.

A further factor that may be considered in a CO_2 reduction strategy is the use of other sources of renewable energy, like wind or solar together with the clean energy coming from the heat recovery system in the sulphuric acid plant to increase the capacity and decrease the production cost. ■

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